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The Spanish airport system: A critical assessment of the impact of AENA's managerial decisions on airports' technical efficiencies

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Business Department

Faculty of Economics and Business

iDEM International Doctorate in Entrepreneurship and Management

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Doctoral Thesis

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Abstract

This Thesis addresses the application to the airport industry of alternative methodological approaches to the conventional models commonly classified as non-parametric and parametric methods. The aim is to estimate and to confirm the consistency of the Spanish airports' efficiency across time. Therefore, several approaches are used in order to overcome specific limitations that the methodologies present compared to the other.

Within the non-parametric techniques Data Envelopment Analysis (DEA) is used and as parametric models, Stochastic Frontier Analysis (SFA). DEA has been extensively used worldwide in the airport industry and some studies refer to the Spanish case. Nevertheless, the conventional DEA models present some limitations; for example, they tend not to incorporate time related effects. The literature shows a lack of usage of SFA in empirical studies. Therefore, relevant insights are to be learned from the application to the Spanish airport system.

One important matter regarding few studies considering the Spanish airports is the lack of individual relevant financial information published by AENA. AENA is a government-owned company and manager of all the Spanish airports. The degree of centralisation of management is to the extent that airports managers cannot decide commercial policies (e.g. price and quality of the services provided). Additionally, the studies neither critically question nor assess the reliability of the data regarding representing a fair and true view of how the airports are performing from an operational perspective.

This Thesis is a compilation of chapters (four research papers) and one paper in progress. All the papers are empirical base with specific objectives in order to analyse the airports from different perspectives including the geographical location and the tourism attractiveness. Firstly, one major problem addressed in this Thesis is the reliability of the data provided by AENA, particularly with respect to investment (cost of capital). Secondly, to estimate the individual efficiencies of the airports and to evaluate the consistency of the most efficient airports not only across time, but supported by the application of the two stated methodological approaches. Managerial and policymakers' recommendations are drawn to improve the overall efficiency of the Spanish airport system. All the papers have been presented in international conferences relevant in the airport and aviation industry and also in methodological conferences. With the exception of the fifth paper (ongoing work), all the papers have been sent to refereed journals (peer review) cited at the Journal Citation Reports (JCR) and they are currently under review. Some extractions have been published as case studies and dissemination articles (*The Public Sphere Journal of Public Policy*, February 2017; *Inside O.R.*, March 2018)

The first paper uses Data Envelopment Analysis (DEA) combined with Multidimensional Scaling (MDS). The analysis is a cross-sectional study in 2013. One of the main issues of DEA is the inputs and outputs to be chosen. It is essential to critically assess the relevance of the variables to estimate the efficiency scores that could be potentially biased. The consideration of this combined methodology is that the efficiency scores are a consequence of the inputs and outputs chosen. This methodology helps disregard irrelevant combination of inputs and outputs. Additionally, it draws insights into the structural characteristic of the decision making units not captured by the conventional DEA potentially affecting the efficiency.

The second paper is based on the same previous methodology, but for panel data within a five-year period of time (2009-2013). The aim is to confirm the previous findings (first research paper) and the robustness of the efficiency frontier and internal structural characteristics of the airports. This paper also analyses the relevance of the different years of the study according to the several dimensions identified.

The third paper is based on centralised DEA in order to address the strong degree of centralised management applied by AENA. The conventional DEA models assume that changes in inputs and outputs to become more efficient are feasible. Nevertheless, the Spanish airports' managers do not have decision power, but AENA. Considering that all the airports are managed as a whole, this model addresses a potential reallocation of resources from one airport to another one with the aim of increasing the overall traffic for the system. Centralised DEA has been applied in the finance and banking sectors, but not in the airport industry with one paper in human resources reallocation. In this study, a non-oriented and non-radial approach is used (Slack-Based Inefficiency) to identify the individual pathway for each airport and for each input and output, rather than an overall radial reduction of inputs or an overall increment of outputs.

The fourth paper applies Stochastic Frontier Analysis (SFA) with the inclusion of fixed effects in the production function for a five-year period (panel data, 2009-2013). To control the special features of the decision-making units is essential to avoid model misspecifications. In a second step regression, the geographical location of the airports is intrinsically considered by analysing areas identified as touristic versus non-touristic and several touristic variables as potential drivers of airports' efficiency.

Finally, the fifth paper also applies SFA with the consideration of environmental variables in the inefficiency term (panel data, 2009-2013). A post-analysis of the number of airports within an amenity distance (catchment areas) is performed and closure recommendations are drawn regarding the most inefficient airports with a minimum impact on connectivity.

Keywords: *Data Envelopment Analysis (DEA); Stochastic Frontier Analysis (SFA); Centralised DEA; Multidimensional Scaling (MDS); Visualisation; Slack-Based Inefficiency (SBI); Technical Efficiency; Benchmarking; Dynamism; Centralised management; Environmental Variables; Fixed Effects; Catchment Areas; Spanish airport system; AENA*

JEL Codes: H54 Infrastructures; C33 Panel data models; C38 Classification methods; C61 Optimization Techniques Dynamic Analysis

Table of Contents

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Acronyms

ABS The Association of the Business Schools

ACETA *Asociación de Compañías Españolas de Transporte Aéreo*

ACI Airports Council International

AECFA *Asociación Española para la Coordinación y Facilitación de Franjas Horarias*

AENA *Aeropuertos Españoles y Navegación Aérea*

AESA *Agencia Estatal de Seguridad Aérea*

ALP Aircraft Landing Problem

ANOR Annals of Operations Research

ATC Air Traffic Control

ATM Air Traffic Movements

ATRS Air Transport Research Society

BAA British Airports Authority

BOE *Boletín Oficial del Estado*

CAA Civil Aviation Authority

CNMC *Comisión Nacional de los Mercados y la Competencia*

CPI Consumer Price Index

CREA *Comisión de Regulación Económica Aeroportuaria*

CRS Constant returns to scale

DEA Data Envelopment Analysis

DMU Decision Making Unit

DORA *Documento de Regulación Aeroporturaria*

EAC European Aviation Conference

EBITDA Earnings Before Interest Taxes Depreciation and Amortisation

EC European Commission

GA General Aviation

GDP Gross Domestic Product

IATA The International Air Transport Association

ICAO The International Civil Aviation Organization

IMAAJ *Ingreso Máximo por pasajero Ajustado*

JCR Journal Citation Reports

LCC Low Cost Carriers

MDS Multidimensional Scaling

MLE Maximum Likelihood Estimator

NAS Non-Audit Services

NDEA Network Data Envelopment Analysis

OR The Operational Research Society

O&IM Operations and Information Management Department

PAX Passengers

PSO Public Service Obligation Route

RTS Returns to Scale

SCR Slot Clearance Request

SFA Stochastic Frontier Analysis

SJR SCImago Journal Rank

SMA Schedule Movement Advice

TM Tourism Management

TP Transport Policy

TS Transportation Science

VRS Variable returns to scale

Chapter one

Introduction

1. Introduction

The aim of this Thesis is to estimate the technical efficiency of the Spanish airports and to search for explanatory reasons underlying these inefficiencies. The singularities of the Spanish regulatory framework imply the difficulties to compare the Spanish airports with other European and worldwide airports. The Spanish airports are government-owned and managed through a public company named AENA[1]. Airports do not compete and airports managers do not decide commercial policies for example, regarding the price of the quality of the services provided. All the decisions including accounting policies (i.e. depreciation methods) are decided centrally by AENA. The overall objective of this research is to estimate the consistent individual efficiencies of the Spanish airports and to determine if the type of management (fully centralised in AENA) is influencing negatively the airports' efficiencies. Alternatively, the existence of certain external factors (beyond AENA's control) influencing at least partially the efficiencies. The Spanish government has invested significantly in airports' infrastructure, but the traffic has not increased accordingly. In fact, Spain is one of the examples that the auditors from the European Commission have confirmed as public infrastructure investments at waste (European Court of Auditors, December 2014). There is a requirement of addressing the relation between airports' resources and traffic generated. Consequently, to determine a more appropriate method evidencing the regional area factual needs where airports are located.

The research questions to be addressed are: to confirm if the Spanish airports suffer from over-capacity understood as technical inefficiency based on the relation between inputs used and output produced. And secondly, to determine conclusive explanatory reasons causing these inefficiencies. Additionally, the conclusions of the analysis should provide insights into managerial and policymakers' recommendations.

The overall objective is to be met according to the following specific objectives,

- To estimate the individual technical efficiency levels of the Spanish airports based on specific inputs and outputs
- To determine reliable explanations of the efficiencies differing between controllable and uncontrollable factors by the airports' management (AENA)
- To conclude if airports' inefficiencies could be fully reduced (managerial decision process) or not (external factors beyond management's control) or a combination of both (some of the inefficiencies are possible to be reduced partially by AENA, some of them may not)

In order to achieve these specific objectives, the same inputs and outputs are used within the same regulatory framework and period of time (2009 to 2013) but two differentiated

[1] Although AENA was partially privatised in 2015, the majority of shares (51%) still remain in the Spanish Government and there is no longer intention to privatise AENA further (Europapress, 13th of July 2018)

benchmark methodologies: Data Envelopment Analysis (DEA) classified as non-parametric technique and Stochastic Frontier Analysis (SFA) as parametric. Different approaches to the conventional models are used (i.e. visualisation and centralised DEA; or the inclusion of fixed effects within the stochastic production function in SFA). The application of different methodological approaches ensures robustness and reliability of the individual efficiency levels (consistency of the efficiency frontier). Additionally, the usage of more than one model evidence and conclude if the overall airports' inefficiency is changeable by the management (AENA). Alternatively, if the inefficiency cannot reduce since is caused by exogenous variables not controlled by the airports' management. The main objective when using two models is to overcome potential gaps shown in one methodology but met by the other: these complement each other assuring the reliability of the research findings. For example, DEA does not require to establish a relation between variables (inputs and outputs) assuming that all the variables contribute to the efficiency scores. Decisions to improve the current efficiency levels are usually highly optimistic difficult to achieve in the short-term, but essentially when airports are managed centrally. DEA provides an efficiency benchmark without explaining how the decision making units have reached that level of efficiency. Therefore, further analysis must be performed to confirm the consistency of the frontier. On the other hand, SFA provides information on the individual impact of inputs and outputs (and iterations). On this basis, not all the variables may contribute to the efficiency, and when some variables do not have significance in the efficiency scores an overall inefficiency is generated. Different assumptions of the distribution of the inefficiency term are required to separate noise (v_{it}) from the inefficiency (u_{it}) that may not be realistic.

This thesis is based on a compilation of papers (empirical analysis) on the airport industry and more specifically in the case of the Spanish airports. The singularities of the Spanish regulatory framework underpins that the research framework does not enclose other countries (i.e. for comparative purposes). As previously discussed the Spanish airports are managed by AENA with a strong degree of centralisation. The fact that the individual airports' managers do not have the flexibility to decide commercial policies implies the no differentiation of the product offered. Consequently, airports' competition is non-existent and airlines and routes are not that clearly established as an answer to the demand. Usually, there are geographical areas with more than one airport within an amenity distance known as catchment areas (European Court of Auditors, 2014) but without congestion. Additionally, the Spanish government (owner of the Spanish airports) does not publish dis-aggregate financial data nor airports' capital cost. The only public data refers to a five-period time (2009-2013) and at times shows a high correlation between some of them, suggesting that may not be a fair view of how airports are performing: how the infrastructure is used in the main aeronautical activity (i.e. depreciation and operating costs). The Spanish airports are organised under an airport system structure. Consequently, non-profitable airports are cross-subsidised by the profitable ones. An airport could be technically efficient (inefficient) meaning that the usage of the resources (inputs) to produce the actual level of traffic (outputs) is adequate. When an airport is technically inefficient implies having/using excessive inputs (e.g. infrastructure) for the actual production level or that with the given inputs the airport could achieve a higher level of production (traffic). Note that an airport being efficient (inefficient) does not imply that the airport is necessarily profitable (no-profitable). This depends on managerial decisions such as the aeronautical fees and other airport charges decided usually by airports. Nevertheless, these are decided centrally by AENA. Due to the strong centralised management, this analysis refers to technical efficiency (inefficiency), but not to profitability that could involve price and investment decisions, which are not publicly shared. Airport charges usually depend on the quality of the service provided by an airport potentially influenced by the degree of competition in the market as well. Regulators such as the Civil Aviation Authority (CAA) in the UK ensure non-monopolistic practices by avoiding excessive airports charges when an airport has market power (Competition Commission, December 2008)[2] In the Spanish case not only there are not regulators, but as discussed AENA decides the airport charges and other price policies[3]. From a research perspective this relation between price and passengers rather than considering the quality and type of services provided along with the competition in the market could be causing an endogeneity problem: are the airports' aeronautical charges decided by AENA based on the number of passengers or is the level of passengers a consequence of airports charges?[4] Consequently, aeronautical revenues are not considered as output since their value depends on the prices fixed by AENA.

The co-authors of the papers enclosed in this thesis are well-known international researchers in operations management and tourism. I have meticulously chosen specific directors based on their respective field of expertise per each chapter (paper) where I have enclosed their names. Although the fourth chapter considers tourism indicators as a second stage regression, and tourism is not the main core of the Thesis, I thought it was essential to increase the awareness regarding external factors related to airports' geographical position. These are potentially affecting the air travel demand, therefore influencing airports' technically efficiency. The researchers I have been liaising with are not limited to the specific co-authors named in this thesis. Due to the time constraints of my Ph.D., and my and their professional commitments, it has not been possible to have further papers enclosed in this thesis at the submission. The outcome of our extensive discussions, liaison, knowledge, experience, and networking clearly show a pathway with future references and prospective work.

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[2] For example, BAA the owner of Heathrow was forced to sell Gatwick, Stansted and Edinburgh.

[3] Aeronautical charges (e.g. landing and aerodrome service; aircraft parking; usage of bridged; fuel; passengers and security charges related to passengers including with reduce mobility; usage of handling infrastructures, etc.) and private services (e.g. checking desks; parking; hangars; surfaces; advertisement, etc.)

[4] The only taxes and charges not decided by AENA are the safety and security taxes, but by *Agencia Estatal de Seguridad Aérea* (AESA), and the slot allocation charges that is established by the Spanish Slots Coordinator *Asociación Española para la Coordinación y Facilitación de Franjas Horarias* (AECFA) relating to the slots allocation at coordinated and schedules facilitated airports (AENA, 2018)

Regarding the aims of each paper, these are underpinned by the limitations found in previous research in order to answer comprehensively the research questions posed. All chapters of this thesis (research papers) have been agreed to be presented at relevant conferences in the air transport industry and operational research and methodological fields. These are the annual Air Transport Research Society (ATRS) conferences held in Singapore (July 2015); Rhodes (July 2016), Antwerp (July 2017) and in Seoul (July 2018); the annual International Conference of DEA (DEA#) held in Birmingham (DEA40, April 2018); the biannual European Workshop on Efficiency and Productivity Analysis (EWEPA#) held in London (the XV, June 2017); the annual Operational Research Society Conference (OR#) held in Leicester (OR59, September 2017) and in Lancaster (OR60, September 2018). Additionally, the papers have been presented in annual workshops organised by professional bodies such as the German Aviation Research Society (GARS) and in more than several meetings of the COST-Action TU1408 ATARD (Air Transport and Regional Development) aligned with the European strategy (Horizon 2020) regulated by the European Commission. This action congregates prestigious researchers, academics and professionals from the industry in order to seek synergies between academia and industry and to produce research according to the needs of the industry in different European areas (Amsterdam, June 2015; London, November 2015; Azores, March 2016; Amsterdam, November 2016; Bergamo, February 2017; Dublin, November 2017; Ruse, April 2018; and prospective conferences in Poznan, September 2018; Rhodes, November 2018 and Gran Canaria, March 2019). Relevant comments have been provided by worldwide well-known researchers in the airport industry and/or in the methodological approaches (DEA and SFA). This feedback has been essential to improving the current work in progress prior to being submitted to the respective specific scientific journals. With the exception of the fifth paper (work in progress), all the papers are currently under review in peer-reviewed journals with a high impact factor as listed in the 2017 Journal Citation Reports (JCR); in the 2016 SCImago Journal Rank (SJR) and in the 2015 Association of Business Schools Academic Journal Quality Guide (ABS) For example, Annals of Operations Research (ANOR) special issue on advances in DEA; Transport Policy (TP); Transportation Science (TS) and Tourism Management (TM)[5]. Additionally, at least three research papers have been previously published as working papers for dissemination and networking purposes (i.e. in Funcas). Extractions of the research papers have been tailored for non-specialist audiences avoiding the usage of technicalities and overloading with methodological and statistical analysis (articles; case studies, etc.). These extractions address the requirements of practitioners enhancing the link between academia and industry (Inside O.R., March 2018; *Diari Gran del Sobiranisme*, August 2017; The Public Sphere Journal, March 2017; *El Diario de Leon,* a prospective compilation of articles).

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[5] JCR-2017 (ANN OPER RE, page 26; TRANSPORT POLICY and TRANSPORT SCI, page 340; TOURISM MANAGE, page 338); ABS-2016 (ANOR, B; TS, A*); SJR-2016 in Transportation (TM, Q1 2.580; TS, Q1 2.567; TP, Q1 1.241) and in Decision Sciences (ANOR, Q2 1.009)

Additionally, by liaising with colleagues from different disciplines a relevant network has been established with prospective work for further analysis of the Spanish airport system and methodological approaches (e.g. centralised DEA applied to human resources transferrable skills, co-authors Gimenez, V. and Martinez, C. both from the Universitat Autònoma de Barcelona; airports' strategic management factors, co-author Huderek-Glapska, S. from Poznan University; network DEA in the Spanish airports, working with Lozano, S. from Universidad de Sevilla; returns to scale and zero weights, co-authors Mar-Molinero, C. from Kent Business School, and Portillo, F. from Universidad de La Rioja)

The next section discusses the literature review regarding methodological approaches and specifically in the Spanish airport industry.

1.1. Literature Review

1.1.1. Methodology

In this Thesis, two frontier methodological approaches are used classified overall as parametric and non-parametric methods (see figure 1). Parametric functions are pre-defined before analysing the characteristics of the observations. Therefore, an established relation between dependent and independent variables is defined ex-ante (predicted function). Non-parametric models do not define a specific function form and assumptions of parameters for the population studied are not made. Stochastic cost and production functions are parametric typically requiring the specification of a particular statistical distribution. The production function is the result of the association between variables based on the information across the observations. In this Thesis, some papers use stochastic frontier analysis (SFA) based on time-varying firm inefficiency models with the inefficiency defined as the product of two components. Previously to decide the specific SFA models, several time-varying inefficiency models have been tested to see the adequacy of the predicted production function and the data collected: Battese and Coelli (1992) where the inefficiency is function of an individual specific effect $u_{it} = u_i . f(t)$ and $f(t) = \{\exp[-\eta(t - T_i)]\}$; Battese and Coelli (1995) with the inefficiency as function of environmental variables, $u_{it} = z_{it}\delta + \omega_{it}$ and Kumbhakar (1990), assuming that inefficiency is function of time $u_{it} = u_i . f(t)$, with $f(t) = (1 + \exp(at + bt^2)^{-1}$. Nevertheless, in these models, the time-varying pattern of inefficiency is the same for all the decision making units (firms). Therefore, the inability to separate inefficiency and individual heterogeneity remains. Previous suggestions such as Schmidt and Sickles (1984) fixed effects formulation or Pitt and Lee's (1981) random effects model treat the inefficiency term as time-invariant as well. Consequently, not only there is no distinction a priori between inefficiency effects and noise, but the inefficiency remains indecomposable ($\propto_i - u_{it}$). Greene (2005) proposes the true-fixed effect (TFE) model for panel data with the inefficiency effect (u_{it}) variant over time and across individuals in the model and with time-invariant unmeasured heterogeneity ($\propto = \propto_i$). The subsequent model developed by Greene (2005) with the inclusion of individual dummies for the fixed effects in the production function avoids incidental parameters problems (Neyman and Scott, 1948).

Other papers use Data Envelopment Analysis (DEA) a non-parametric technique. Data Envelopment Analysis (DEA) outlined by Farrell (1957) and modelled by Charnes et al. (1978) estimates production frontiers and evaluates the relative efficiency of Decision Making Units (DMUs). Apart from DEA, non-parametric methods include partial and total factor productivity indexes (TFP) as well (see figure 1). Partial factor productivity indexes (labour, capital, etc.) are usually chosen when the aggregation of inputs and outputs is not possible due to, for example, being measured in different units and in absence of information regarding prices. With this regard, DEA is advantageous since does not require price/cost information or units disaggregation. Therefore, DEA is really useful in sectors with no access to data (e.g. hospitals, councils, banks, etc.) Furthermore, DEA allows the aggregation of multiple inputs and outputs compared to partial productivity indexes and different feasible combinations of inputs-outputs. DEA draws the relationship between outputs and inputs as an efficient production surface that can be achieved with the current technology or management strategy applied by the company (Gillen and Lall, 1997). However, this implies a static efficiency benchmark and changes in efficiency due to changes in technology (investments) require further analysis such as Malmquist Index (Färe and Grosskopf 1996) or a robust second stage (Silmar and Wilson, 1998). This is to avoid the explanatory factors and the efficient units being correlated by bootstrapping the DEA scores with a truncated regression (Silmar and Wilson 2007). Regarding SFA, certain models allow the introduction of explanatory factors in one single estimation stage (e.g. Battese and Coelli, 1995). The advantage of DEA over parametric stochastic frontier methods has been its flexibility in a multi-inputs and multi-output environment, and robustness with respect to the specification of the functional relationships between inputs and outputs (Aigner et al., 1977; Meeusen and van der Broeck, 1977). However, since DEA relies on identifying best practice reference units, it can be extremely sensitive to outliers in the data set. Additionally, provides unreliable results when the number of inputs and outputs are much larger compared to the observations (Nyshadham and Rao, 2000). On the other hand, an important advantage of SFA is that the inclusion of a variable that is not relevant will contribute with a very low weight compared to others. In DEA the weights relative to a variable are usually unconstrained. SFA allows splitting deviations from efficiency values between the pure inefficiency (u_i) and the stochastic shocks, commonly known as noise (v_i). The disturbance noise is the variance not explained by the variables used in the production function (i.e. inputs and outputs). Different indicators are used to compare the noise to the inefficiency explained by the model such as lambda ($\lambda=\frac{{\sigma_u}^2}{{\sigma_v}^2}$) and gamma ($\Upsilon=\frac{{\sigma_u}^2}{{\sigma_v}^2+{\sigma_u}^2}$). Note that when gamma is equal to the unity, the SFA is equivalent to apply DEA since the absence of noise is assumed. Consequently, SFA is more restrictive compared to DEA discriminating between variables not contributing significantly to the efficiency score. This is DEA classifies the overall deviation as inefficiency. The DEA efficiency score assumes that all the inefficiency is explained by the variables used (inputs and outputs). Consequently, the results of DEA may be potentially biased due to the lack of experience and professional judgment of the researcher. One clear example is the usage of DEA in the same sectors to compare different countries potentially subject to different regulatory frameworks as the case of the Spanish airport industry. Further insights regarding both approaches are summarized in Table 1 for comparative purposes.

In order to overcome the limitations shown by the models, this Thesis uses both approaches with certain variations from the conventional models. There are more than several stochastic frontier models. These depend on the assumptions made on the inefficiency term (u_{it}) in terms of distribution (e.g. assuming zero or non-zero mean) and the flexibility for the inefficiency to be time-varying. There are different options for cross-sectional data (Aigner et al., 1977; Meeusen and van der Broeck, 1977; Stevenson, 1980 and Greene, 2003) and panel data (Pitt and Lee, 1981; Battese and Coelli, 1988, 1992 and 1995; Schmidt and Sickles, 1984; Cornwell et al., 1990; Kumbhakar, 1990; Lee and Schmidt, 1993; Greene 2005). The models use alternative estimation methods (maximum likelihood; simulated maximum likelihood; maximum likelihood dummy variable; generalised least squares; iterative least squares; within group and modified within group). Regarding panel data, Battese and Coelli (1995) and Greene (2005) are the only models allowing heterogeneity in both the inefficiency and noise. The specification following Battese and Coelli (1992 and 1995) with the consideration of fixed effects in the production function has allowed controlling for unobserved heterogeneity potentially affecting the stochastic shock (noise). Regarding DEA, a visualisation technique has been used to learn from the intrinsic characteristics of the observations that are usually unobserved, and not reflected in the DEA outcome. The use of the centralised DEA model addresses the fact that all the Spanish airports are managed under the same authority (AENA) and resources allocation is possible attempting to increase the overall production of the airport system. Finally, the use of several techniques assures the robustness regarding the reliability of the variables (inputs and outputs) as factors determining airports' inefficiencies and the research findings: the individual efficiency values and the confirmatory explanations behind these values.

With the exception of the first paper (DEA visualisation) and the third paper (centralised DEA) based on a cross-sectional analysis (2013), the rest of the papers use panel data for a five-year period (2009-2013). There are several disadvantages of estimating the production frontier with cross-section data compared to panel data (Pitt and Lee, 1981; Schmidt and Sickles, 1984) For example, the cross-sectional data require a distribution assumption on each error component in order to separate the technical inefficiency from the statistical noise, especially when using the maximum likelihood method (MLE). Additionally, the MLE estimator requires the inefficiency to be independent of the regressors. The technical efficiency values estimated by the alternative models for the decision making units across the years will confirm the consistency in the results (efficient frontier). Additionally, potential insights regarding the specific behaviour of certain DMUs over time (changes in the pattern term).

To summarize, in this Thesis within the DEA methodology less conventional approaches have been used, namely DEA visualisation (paper one and two) and centralised DEA (paper three). DEA visualisation has been previously used in industry to analyse micro-finance units (Gutierrez-Nieto, 2007) and higher education institutions (Sagarra et al., 2017). To the best of our knowledge, centralised DEA has been mainly used in finance and banking studies sectors, but not in the airport industry where there is one study based on human resources allocation (Yu et al., 2013) Regarding SFA, the literature shows the lack of empirical studies and external factors to explain the technical inefficiencies of the decision making units. There are several stochastic frontier models for panel data, nevertheless, there are few studies applied to empirical research (Kumbhakar et. al 2014). Following the specification of Battese and Coelli (1992), time-invariant fixed effects (Greene, 2005) have been enclosed in the production function (paper four). Finally, following Battese and Coelli (1995) environmental variables are introduced as a function of the inefficiency term (paper five).

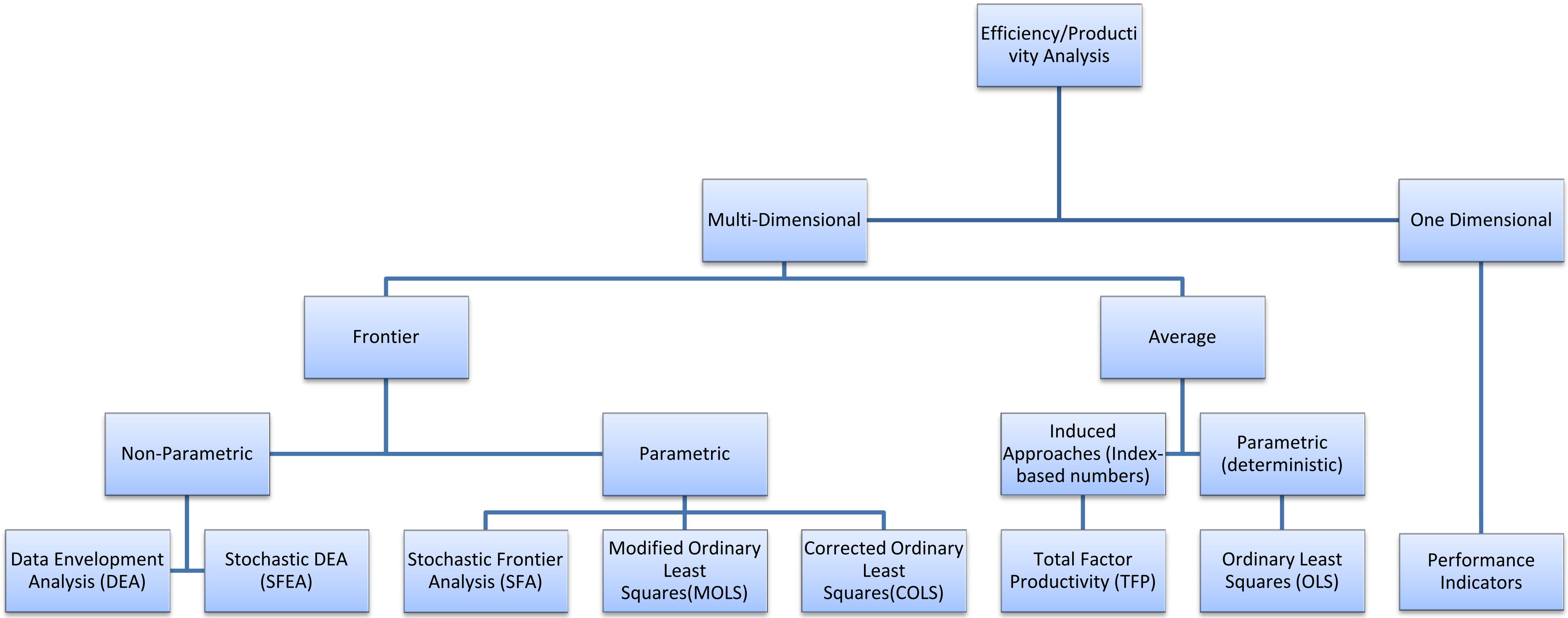
1.1.2. The Airport Industry

DEA has been applied in multiple airport studies over the last 20 years. Data Envelopment Analysis (DEA), originally developed by Charnes et al. (1978) and subsequently extended by Banker et al. (1986), is a non-parametric linear programming-based method to evaluate the relative efficiency of a set of homogeneous decision making units (DMUs). In DEA there are two fundamental approaches: radial and non-radial. Both approaches are related to the path that inefficient units must follow to reach the competitive frontier, and so become efficient. The radial projections introduced by Debreu (1951) and Farrell (1957) are based on the proportional reduction in inputs (or an overall increase in outputs) in order to improve the efficiency of the units analysed. Non-radial projections were introduced by Koopmans (1951) and Russell (1985). Charnes et al. (1985) were the first authors who proposed an additive model, non-oriented DEA, to estimate efficiency scores based on a proportional reduction (increase) of inputs (outputs). The basic model has been modified to propose improvements to the basic formulation (Brockett, 1997; Cooper et al, 1999; Tone, 2001; Asmild and Pastor, 2010; Färe and Grosskopf, 2000). The majority of studies of airport benchmarking using Data Envelopment Analysis have been based on radial models, sometimes with constant returns to scale (Bazarghan and Vasigh, 2003; Fung et al., 2008; Sarkis and Talluri, 2004) and sometimes with variable returns to scale (Adler and Berechman, 2001; Fernandes and Pacheco, 2002; Martin and Roman, 2006). Some other studies use both types of returns in order to estimate technical and scale efficiency levels in the airport operations (Abbot and Wu, 2002; Assaf, 2010a; Martin and Roman, 2001).

Table 1: Methodological approaches: conventional DEA and SFA models (Source: Author)

Data Envelopment Analysis (DEA)	**Stochastic Frontier Analysis (SFA) Panel Data**
• Non-Parametric	• Parametric
• Efficiency $(\boldsymbol{\theta}_i)$: inputs and outputs contribute to the efficiency score	• Inefficiency (u_{it}): inputs and outputs may not contribute to the overall efficiency score
Radial (Farrell, 1957) and non-radial (Färe and Lovell, 1978)	The inefficiency is estimated given the compounded error (Ɛ) (Jondrow et al., 1982; Battese and Coelli, 1988)
Non-oriented (changes in inputs and outputs) and oriented: input orientation (decisions among inputs given the outputs) and output orientation (decisions among outputs given the inputs)	$TE_{it} = \exp(-u_i)$ $Noise_{it} = (v_{it})$
Sensitive to extreme cases (Mavericks; Outliers)	
Unreliable results if inputs/outputs > data (Nyshadham and Rao, 2000)	
• Linear functional form	• Different functional forms (linear; Cobb-Douglas; quadratic; normalised quadratic; translog)
	Different distributions of the inefficiency term (truncated-normal; half-normal; exponential; gamma)
• Static analysis (cross-sectional) Additional analysis required (Malmquist Index)	• Time-invariant inefficiency $(u = u_i)$ Pitt and Lee (1981) with half-normal distribution; Battese and Coelli (1988) with truncated-normal
	Time-varying inefficiency $(u = u_{it})$ Battese and Coelli (1992) with truncated-normal distribution; Battese and Coelli (1995) truncated normal; Kumbhakar (1990) half-normal; Greene (2005a) with the inclusion of time-invariant heterogeneity $(\propto = \propto_i)$**:** fixed effects (FE) and random effects (RE) half normal; truncated normal and exponential distributions
• Assumption returns to scale: constant returns to scale-CRS (CCR Model Charnes, Cooper and Rhodes, 1978); variable returns to scale-VRS (BCC Model Banker, Charnes and Cooper, 1984)	• Returns to scale to be tested
• Benchmark against the 'best practice' requiring a second stage analysis (sampling distribution): bootstrap or truncated regression (Simar and Wilson, 1998; 2007)	• Potential use of environmental variables to explain inefficiency (Battese and Coelli, 1995); unit-specific intercepts (Greene, 2005) in one stage analysis (Wang and Schmidt, 2002)

Figure 1: Benchmarking Techniques (Source: based on Von Hirschhausen and Cullmann, 2005)



As previously discussed, the literature in the airport industry rarely shows stochastic frontier analysis research, but most of the studies are based on DEA. A thorough summary of previous empirical work in DEA is available in Wanke et al. (2016). The idea of SFA was initially applied to a cross-sectional framework, but it was later extended to panel data (Battese and Coelli, 1992; Cornwell et al., 1990; Kumbhakar, 1990). Pels et al. (2001) using physical data (stochastic production function) and Barros (2008) using costs (stochastic cost function) both applied a homogeneous stochastic frontier model for panel data. Other studies using cost functions are Martin-Cejas (2002) with a translog cost frontier model for 40 airports between 1996 and 1997; Barros (2008a) using a homogeneous SFA translog model on 10 Portuguese airports for 1990-2000; Barros (2008b) a random stochastic frontier model to rank the UK airports according to their productivity from 2000 to 2005; Barros (2009) with a latent class stochastic frontier analysis for the UK airports between 2000 and 2006 to capture airport heterogeneity and obtain more precise cost efficiency estimates; Oum et al. (2008) studying the effects of ownership forms in the world's major airports; Martin et al. (2009) using a cost stochastic frontier following a Bayesian approach to estimate the efficiency of 37 airports Spanish airports from 1991 to 1997; Assaf (2010b) also used a Bayesian panel stochastic frontier model for Australian airports to estimate the cost efficiency after privatisation. Additionally, Pels et al. (2001, 2003) compared the efficiency values obtained using the two approaches DEA and SFA based on a production function for 34 and 33 European airports and panel data (1995-1997). The models more commonly used follow the specifications stated by Battese and Coelli (1992; 1995) and Greene (2005) allowing time-varying inefficiencies and time-invariant heterogeneity respectively. Additionally, the inclusion of environmental variables to explain the inefficiency assumed to be beyond managerial control (Battese and Coelli, 1995). In the Spanish case, the specific airport's environment is relevant to be taken into account. The airports do not operate under the same circumstances for example regarding size (airport scale); geographical location (population, density, wealth, the number of competitors in the catchment area, etc.); demographic characteristics (education level, family size, etc.) or social factors (personal attitudes, lifestyles, etc.) These are environmental factors that the airports' management (in this case AENA) cannot influence in a relatively short period of time, but still, these may be affecting the airports' technical inefficiencies. SFA allows accounting for the factors controlled by the management. Therefore, to separate the part of the inefficiency changeable from the inefficiency caused by factors not-controlled (unchangeable).

Within the Spanish framework, the literature review shows most of the studies based on DEA rather than SFA (see Table 2). One matter is the access to public information, presented individually per airport. As previously stated, the only data available is financial data corresponding to a five period of time (2009-2013). At the same time, the reliability of the data should be critically questioned. Authors usually include the information provided by AENA, without critically assessing if these data is a fair representation of the Spanish airports. The researcher found that the cost of capital values (depreciation charges) used by AENA are highly correlated with the operating costs also provided by AENA (+0.9945) From a statistical point of view this information has not been possible to be used, but new depreciation charges have been estimated (see Ripoll-Zarraga and Mar-Molinero, 2017). The inadequacy of the cost of capital measures published by AENA has been evidence from an empirical perspective as well. Meetings with managers have confirmed the aggressive accounting methods used implying accelerate depreciation at the beginning of the usage of the assets.

Another example is the aeronautical revenues that based on the information provided by AENA increased by 67% between 2009 and 2013. Nevertheless, the traffic did not increase accordingly (passengers -0.12%; ATM -17.41% and cargo, 13.13%). The Spanish airlines' professional body (ACETA) has confirmed discriminatory air fees policies to the extent of being +4,004% (Madrid Barajas) and + 3,663% (Barcelona)[6]. This applies for general aviation and training of professional pilots' aircraft operations. ACETA recalls that the cumulated increase has been 67.49% for the same period (+20.43% in 2011; +14% in 2012 and +22% in 2013). Overall these increases represent a +18% per year. The European Union regulation approved in 2009, in its specific recommendations to Spain, states that air fees can be increased to no more than the inflation rate plus five perceptual points. Only in September 2012, the inflation rate was 3.5%. ACETA recalls that from 2011 to 2013, the fees approved by the Spanish government (AENA) overcomes the cap in a 43%. The Chair of the Spanish national commission for competition (CNMC)[7] has requested another air fee reduction of 2% to be applied by AENA from 2017-2021, but AENA is determined to freeze them (June 2016). The Chair has also called for the airport charges to be decided by an independent regulator as usual practice, instead of the Spanish Government that currently holds 51% of AENA's shares. A review of the economic regulatory framework is performed in the next section.

The Spanish airports DEA studies are usually performed for a short time frame. The research findings should be questioned in terms of robustness: the consistency of the efficiency frontier and reliability of the pathways to follow by the inefficient units. Overall few studies attempt to find explanations supporting the efficiency scores. The findings refer to airports with more passengers being more efficient, but this may be highlighting an endogeneity issue. Other results referred to the existence of low-cost carriers (LCCs) or geographical position as potential explanations of airports' efficiencies. It is important to bear on mind that AENA negotiates directly with the airlines, and airports' managers do not have decision power regarding routes or types of airlines to be operating. If airports competed with each other the market would become more attractive to airlines and passengers. Consequently, specifically in the Spanish case, the significance of the number and type of airlines (e.g. LCCs) could change if airports were managed individually and competition was allowed. Therefore, the type and number of airlines may not be a consistent reason for airports to become more efficient but circumstantial. In the same way, the type of management (based on a strong centralisation of decisions) could be influencing the overall Spanish airports' inefficiency.

[6] ACETA is the airlines professional body. From 2010 to January 2011 the air fees were increased in a 2,368% for Barcelona (from 6.36 euros to 156.94 euros) and 2,702% for Madrid (from 6.36 euros to 178.18 euros)
[7] *Comisión Nacional de los Mercados y Competencia* (CNMC) is the Spanish competition authority and macro-regulator.

Table 2: Summary of Spanish airports' studies (Ripoll-Zarraga and Mar-Molinero, 2017)

Author/s	Outcome	Methodology	Findings
Murillo-Melchor (1999)	Technical Efficiency 33 Spanish airports (1992-1994)	Data Envelopment Analysis (DEA) Total Factor Productivity (Malmquist Index)	Airports with more passengers are more efficient
Salazar de la Cruz (1999)	Technical Efficiency 16 Spanish airports (1993-1995)	Data Envelopment Analysis (DEA)	Airports with more passengers are more efficient
Martin and Roman (2001)	Technical Efficiency 37 Spanish airports (1997)	Data Envelopment Analysis (DEA)	Airports with larger size are more efficient. Airports' geographical location affects efficiency
Martin and Roman (2006)	Technical Efficiency 34 Spanish airports (1997)	Different variations based on Data Envelopment Analysis (DEA)	Airports with more passengers are more efficient. Airports' geographical location affects efficiency
Martin-Cejas (2002)	Technical Efficiency 40 Spanish airports (1996-1997)	Deterministic Cost Frontier (DCF)	Airports with 1 to 3 million passengers show a higher average of efficiency
Coto-Millan et al. (2007)	Economic Efficiency 33 Spanish airports (1992-1994)	Cost Stochastic Frontier Analysis (SFA)	Airports with more passengers are more efficient
Tapiador et al. (2008)	Technical Efficiency 29 Spanish airports (2006-2007)	Data Envelopment Analysis (DEA)	Larger and small airports are more geographically efficient
Martin et al. (2009)	Economic Efficiency 37 Spanish airports (1991-1997)	Cost Stochastic Frontier Analysis (SFA) Bayesian Inference	Larger airports are more efficient
Tovar & Martin-Cejas (2009)	Technical Efficiency 26 Spanish airports (1993-1999)	Stochastic Frontier Analysis (SFA) Distance Function	Airports outsourcing some services are more efficient
Tovar & Martin-Cejas (2010)	Technical Efficiency 26 Spanish airports (1993-1999)	Stochastic Frontier Analysis (SFA) Distance Function. Total Factor Productivity (Malmquist Index)	Hub airports are on average more efficient. Northern airports are more efficient
Lozano & Gutierrez (2011)	Technical Efficiency 39 Spanish airports (2006-2007)	Target-setting DEA Slack-Based Measure (SBM)	Passengers and Cargo are directly related to efficiency
Martin et al. (2011)	Economic Efficiency 36 Spanish airports (1991-1997)	Cost Stochastic Frontier Analysis (SFA)	Airports within the same catchment area are cost-inefficient unless congested
Lozano et al. (2013)	Technical Efficiency 39 Spanish airports (2008)	Network DEA	Network DEA shows higher discriminatory power to detect inefficiencies
Coto-Millan et al. (2014)	Technical Efficiency 35 Spanish airports (2009-2011)	Data Envelopment Analysis (DEA) Total Factor Productivity (Malmquist Index) Regression (Airport's size; LCCs)	Larger airports are more technically and scale efficient LCC increases scale efficiency
Coto-Millan et al. (2016)	Technical Efficiency 35 Spanish airports (2009-2011)	Data Envelopment Analysis (DEA) Tobit Regression (Airports' size; Cargo; LCCs)	Airports with more cargo are more technically and scale efficient

The review of the literature shows a requirement of firstly using alternative approaches to the DEA conventional models and empirical applications of SFA and secondly, to seek further explanations of the airports' technical inefficiencies.

1.2. Regulatory Framework

The liberalisation of air transport in Europe has been progressively achieved between 1987 and 1992 with three packages of regulation[8]. AENA (*Aeropuertos Españoles y Navegación Aérea)* is created in the middle of this process (June 1990) as a government-owned and managed company. AENA depends on the Ministry for Development and operates within the framework of the Spanish government general transport policy. All the 49 Spanish airports are managed under a single airport network directive. From November 1992 AENA is in charge of the provision of air navigation services until July 2014[9].

The liberalisation of the air transport aims for airlines to have free access to the European market. The allocation of slots and its regulation is critical to assure the competitiveness of the market[10]. Historical slots are prioritised as well as their changes over new requests for the same slot (IATA, January 2018). Initially, historical slots are to be earned by airlines after more than several operating years. Nevertheless, it seems that legacy carriers tend to have these rights. This is due to the grandfather rights where an airline having operated its particular slots for at least 80% during the summer/winter scheduling period, is entitled to the same slots in the equivalent scheduling period of the following year. The European Commission regulation 95/93 (Council Regulation EEC 95/93) ensures that the available landing and take-off slots are used efficiently and distributed in an equitable, non-discriminatory and transparent way. The amended regulation (793/2004) introduces new provisions with regard to market access and new entrants, enforcement and the independence of the coordinator. The airport coordinator plays a key role in the allocation of slots. Although the privatisation of Iberia (the Spanish legacy carrier and state-monopoly) started in December 1999, AENA has been responsible for the slots allocation from 1993 to September 2014. Consequently, the current slot distribution could be the heritage when legacy carriers used to be public utilities. For example, Iberia and from 2009 its subsidiary Vueling (45% ownership) charge a significant amount for a national return ticket, but this is not in accordance with the quality of the service provided[11]. Additionally, Vueling has 36.35% of the overall passengers in Barcelona compared to other LCCs such as Ryanair (14.74%) and 6.65% of Easyjet (Source AENA 2017)[12].

[8] With effects for the 17 country members in the European Economic Area (EEA) on the 1st of April 1997
[9] https://www.boe.es/buscar/act.php?id=BOE-A-1991-15530
[10] A slot is a permission given by a coordinator to use the full range of airport infrastructure necessary to operate an air service at a coordinated airport on a specific date and time for the purpose of landing or take off (Regulation EC 793/2004)
[11] Iberia LAE, S.A., and Vueling Airlines, S.A.

[12] The same ranking and percentages apply when considering Barcelona El Prat as the origin or the destination http://www.aena.es/csee/Satellite?pagename=Estadisticas/Home

This implicitly implies that Vueling controls a significant number of routes even not operating efficiently[13]. Delays and cancellations are a usual practice without an apparent reason except for peaks of demand (i.e. summer). Therefore, the distribution of slots in Spain may not be fairly allocated but due to heritage inherent rights. It is not clear if these correspond to historical rights of airlines earn in a competitive market, or due to the power granted to specific airlines (number of routes; origin-destination and timing) during the years that these were a state-monopoly.

It is unlikely that airports' operators can compete in slots, but the price, quality, and the range of services compared to other infrastructures (CNMC, July 2014). Price policies are a clear indicator to what extent a market is competitive. Evidence shows a significant increasing competition between airports reflected in the price adjustments during the latest 20 years. According to the Airports Council International (ACI, 2012), in 2009 a 50% of the European airports decreased their airport charges compared to a 31% that increased them[14]. During 2010, a 36% increased the charges and 47% remained the same. In 2011 with the beginning of the recuperation of the economic crisis, 75% of airports increased their charges. Nevertheless, this is due to continued pressures on capital costs. In Spain, the increments on airport charges seem not to correspond to changes in infrastructure and/or the quality and the price of the service provided (2009/12/EC, paragraph 15). The 2009/12/CE clearly states in paragraph 15 that airport charges should correspond to the price/quality ratio. Additionally, any differentiation in airport charges should be transparent and based on clear criteria. In Spain, these are to the extent of +18% for the network from 2010 to 2011, and 50% and 54% for Madrid and Barcelona respectively. Consequently, some LCCs decided to eliminate routes and move to other airports[15]. Note that this significant increment in airport charges took place prior to the implementation of the law 1/2011 from the 4th of March[16] during 2012. This law intended to introduce a national programme for operational security of civilian transport with a new paragraph regarding airports operators' income regulation. For example, a regulatory regime based on a price cap for airport charges (CPI, +5%) from 2013 to 2016 with a cost recovery formula applicable throughout the whole AENA network. Additionally, there is a partial transposed to the Spanish regulation of the European Commission Directive 2009/12/CE from the 11th of March regarding airport charges[17]. This is completed with the

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[13] Information not shared by AENA due to confidentiality.

[14] Evaluation of Directive 2009/12/EC on airport charges (September 2013) https://travelsdocbox.com/Air_Travel/73787342-Evaluation-of-directive-2009-12-ec-on-airport-charges.html

[15] Ryanair cancels a significant number of routes in Barcelona and Madrid due to the increase in airport charges. These represent 34% of activity in Madrid (11 routes) and 30% in Barcelona (four routes) from November 2012. Additionally, these represent 46 connecting routes (24 in Madrid and 22 in Barcelona). Easyjet was planning to reduce its operations in Madrid by 20% during the same period.

[16] The 1/2011 from the 4th of March amends the law 21/2003 from the 7th of July on aviation security https://www.boe.es/buscar/doc.php?id=BOE-A-2011-4116

11/2011 law from the 26th of August. The 11/2011 law contemplates an airport economic regulatory commission named CREA[18] to ensure the full transposition of the Directive 2009/12/CE as a regulator of the airport charges. The three objectives of the law 11/2011 are clearly specified: to separate the navigation services from the airports' management; to allow private stakeholders' investment and to facilitate airports individual management based on their specific characteristics and geographical environment.

The change of Government led to the creation of a macro regulator in October 2013 named the *Comisión Nacional de los Mercados y Competencia* (CNMC, law 3/2013 4th of June) substituting CREA[19]. The lack of transparency regarding airport charges enhances the law 18/2014 (October 2014)[20] modifying the legal regulatory framework including the creation of the *Documento de Regulación Aeroportuaria* 2017-2021 (DORA, 20th February 2017)[21]. The regulatory course of action defined in this report seeks to increase the competitiveness, the growth, and efficiency (law 18/2014). Therefore, it becomes a managerial guidance for AENA, S.A. as the airports' operator for the next five years. One clear critical aspect is the airport charges and pricing policies. In fact, the CNMC rejects in June 2016 the proposal of AENA of not changing airports' charges from 2017 to 2021 (approved on the 22nd of December 2015) and imposes the requirement of reducing the fees in 2.02% annually until 2021. This is based on discrepancies on the forecast demand and the method used to estimate the cost of capital by AENA[22]. In the same way, AENA is determined to freeze the airport charges in 2019 rather than reducing by 2.22% as finally did during 2017 and 2018 (July 2018). On the other hand, AENA has confirmed that will apply commercial incentives to airlines to open routes with new destinations during 2019.

The law 1/2011 from the 4th of March also contemplated a gradual change from the single to the dual till from 2014 within five years. The consideration of using a single versus a dual till is still an ongoing matter at an international level. IATA[23] argues that single till is the fairest approach to calculate airport charges. This is based on being the pricing mechanism that airports would apply under real competition. Therefore, the decisional variable to apply the single till principle is the existence of factual competition in the market. The single till implies that the overall airport activities (aeronautical and commercial) are considered to determine the airport charges. The centralised management of AENA goes in detriment of airports' competition. Meanwhile, with the appropriate economic regulation the single till approach

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17 https://publications.europa.eu/en/publication-detail/-/publication/b3f91d83-d246-449e-888f-4665d194b3f2/language-en

18 *Comisión de Regulación Económica Aeroportuaria https://www.boe.es/buscar/doc.php?id=BOE-A-2011-14221*

19 https://www.boe.es/buscar/doc.php?id=BOE-A-2013-5940

20 https://www.boe.es/buscar/act.php?id=BOE-A-2014-10517

21 https://www.boe.es/buscar/doc.php?id=BOE-A-2017-2052

22 The airport charges are determined based on the recovery of the future (expected) costs. Therefore, the estimated costs and the expected traffic (demand) are used to estimate the airport charges for the next five years (2017-2021)

23 https://www.iata.org/policy/Documents/single-till.pdf

enables lower charges, and therefore, increases in traffic, the Spanish airports' charges are likely to be decided discriminatory. This is evidenced by the inability to access data per airport and the questionable fairness of the data published by AENA from 2009 to 2013. Consequently, the Spanish competition authority reported the requirement of changing from single to dual till in order to differentiate costs (CNMC, July 2014). Due to the lack of real competition between Spanish airports, the inadequacy of using the single till to decide fair airport charges at least, in the Spanish market, is evidenced. The methodology is based on the dual till principle for the whole network. Therefore, the overall aeronautical costs must be financed with the aeronautical income only. DORA regulates the adjusted maximum annual income per passenger related to basic aeronautical activities (price cap)[24]. The maximum annual revenue per passenger and the forecast demand are the essential factors to estimate the airport charges for the coming years. The regulation establishes that any other non-aeronautical activity not considered essential such as commercial, publicity, finance and operating leases among infrastructure, etc. are not subject to regulation. DORA also establishes reductions of airport charges in airports located in remote areas for connectivity purposes, and to enhance the internationalisation of the passenger and cargo air transport (in the Canary and Balearic Islands, Ceuta and Melilla)

Pursuing the first and second objectives of the law 11/2011, in February 2011 a trading company (AENA Aeropuertos, S.A.) is created with responsibility in employment, fiscal, and freedom to incentive the investment and creation of employment[25]. In June 2011, AENA Aeropuertos, S.A. is granted with the Spanish airports' management[26] In July 2014, AENA *Aeropuertos Españoles y Navegación Aérea* is named ENAIRE. ENAIRE is the parent of AENA Aeropuertos, S.A. (100%) named since then as AENA. ENAIRE becomes the provider of navigation services (in route, approach, and aerodrome services).

The operational conditions regulated at DORA affect the investment, capacity, and quality of the service to be provided for the basic aeronautical services. In terms of capacity, DORA must ensure that is sufficient to meet the forecast needs of airlines and passengers. This becomes a requirement due to the expected increase in air traffic demand in 50% by 2035 in Europe, and the requirement of meeting the market and societal needs by 2050 (European Commission, March 2011)[27]. The lack of airport capacity in Europe implies that 12% of air transport demand will not be accommodated (ACI, October 2015). Airport capacity is a key aspect for the efficiency of the European aviation systems and if not managed efficiently, a threat to the

[24] The price cap is known as IMAAJ *Ingreso Máximo por pasajero Ajustado*, this is the adjusted maximum annual revenue per passenger.

[25] The Labour party plan was to provide concessions between 30 to 40 years of the management of Barcelona and Madrid to private companies (December 2010). With the new Government, the proposal was stopped.

[26] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2011-9926

[27] Essentially the requirement of door-to-door within four hours for 90% of travellers by 2050 https://ec.europa.eu/transport/sites/transport/.../flightpath2050.pdf

competitiveness of the European economy[28]. The lack of capacity implies flight delays increasing and cancellations and a key challenge for connectivity. Privatisation is one option for governments to fund the required infrastructure investment rather than provide it themselves. On this basis ENAIRE guides the partial privatisation of AENA (49%) culminated the 11th of February 2015 in the stock market[29]. Regardless of airports' ownership forms, airports require more investment in order to meet the growing passengers and cargo traffic. Whilst the private capital may enhance or accelerate an increase in airports' capacity, this is likely to happen in the long-term. An efficient slot allocation can avoid the requirement of investing in infrastructure at least in the short and medium term. The calculation of airports' capacity based on an objective analysis to accommodate air traffic is essential. Therefore, in order for the market to work efficiently, airlines must provide relevant and objective information to the coordinator. At the same time, it is possible to privatise certain aspects of airports' infrastructure (ACI Policy Brief, 2018)[30]. Nevertheless, the issue of shortfalls does not apply to all the Spanish airports. The inexistent competition leads to regional airports with very low traffic, with over-capacity (capacity underused). It is clear that the expansion of infrastructure is essential to meet the demand, essentially for international hubs. Nevertheless, in the short and medium-term is necessary an optimum use of the current infrastructures. Therefore, an optimal slot allocation and rules are required to be implemented to ensure effective competition. Air carriers granted with grandfather rights may decide to cancel flights to the extent that the 80% rule is fulfilled. The consequences of no-shows are slot-loss in coordinated airports that could be used by other airlines.

Within Europe, the existent diversification of ownership forms and participation of private capital correspond to specific regional needs. The positive aspect of airport systems and networks are the economies of scale. Airport networks assure connectivity with remote areas without alternative travel modals; feed large airports (hubs) or may be used as alternative airports to support congested airports or bad weather conditions. Airport systems with an efficient and flexible centralised management can also create economy of scales for example by sharing airport infrastructure or labour force; cheaper borrowings through risk diversification; provide access to air transportation network to ensure regional development, etc. Nevertheless, the critical aspect of the Spanish airport system is the strong degree of centralisation not only regarding the airports' management but essentially the standardization of internal control procedures. Additionally, a key aspect of the negative impact of the AENA's centralised management is the inexistent competition between airports. Consequently, due to the special features in which the Spanish airports must operate does not allow airports with the necessary flexibility in their business to ensure that airports users

[28] The lack of capacity means a significant 1.9 million flights not taking off and 237 million passengers not flying (ACI, October 2015)

[29] The remaining 51% is held by the Spanish government through ENAIRE.

[30] https://aci.aero/about-aci/priorities/economics/documentation/

are protected (ICAO, 2006). Additionally, avoids the possibility of comparing efficiency analysis with other European airports unless the impact of the degree of centralisation is controlled in the models.

Although from 2013 the setting of airport charges seems to follow the current regulation, there are more than several issues not resolved (Evaluation of Directive 2009/12/EC, September 2013). The most relevant is the article 7(1) on transparency requirements not being applied. This refers to individual financial data (income and costs) per airport to be accessed publicly (7.c). Additionally, forecasts of the situation at each airport regarding charges, traffic growth and proposed investments (7.f). Without this information, it is impossible to establish the relationship between an airport's costs and the airport's charges. Therefore, to assure if airport charges are cost-related and pricing policies are or not discriminatory. ACETA reports that the cost recovery formula is applied to the overall costs of the whole network rather than on an individual basis. Therefore, specific airport's charges are not based on its individual costs.

The economic regulatory process seems to have met the first and second objectives of the law 11/2011. Nevertheless, there is a discrepancy to what extent the third aim based on providing a more individual management depending on the airports' regional needs has been accomplished yet. Additionally, the common rules for the allocation of slots (and coordination) at European airports (EEC 95/93) in order for the airlines having access to the busiest airports in a transparent and no discriminatory manner (IATA Worldwide Scheduling Guidelines) remain questionable. On this basis, the deregulation and the measures use to enhance competition, including the apparent competitive slot allocation, seems not to be accomplished. The distribution of slots does not allow factually a free access to airlines in the Spanish market but becomes an entry barrier for airlines, and a restriction for airports' competition.

1.3. Data Description

The Spanish airport-system contains 49 civilian airports including four general aviation airports (Madrid-Cuatro Vientos; Madrid-Torrejon; Sabadell and Son Bonet) and two heliports (Algeciras and Ceuta). General aviation (GA) is all non-commercial civil aviation operations: scheduled and non-scheduled air transport operations (ICAO). Madrid Torrejon allowed general aviation operations until January 31st, 2013 becoming a full military base since then. On this basis from 2013, the network contains 48 airports. For the purpose of this Thesis since 2013 is the latest period of study, the assumption made is that AENA manages the 49 airports (the population).

Table 3 lists the airports after grouping them into three categories according to size and shows summary statistics for the different size groups. The size is measured by the number of passengers in one year (PAX). According to AENA's classification from January 2011, airports are classified according to the volume of passengers into four groups[31]. The first three groups are overall large airports and medium airports with a potential season effect: group I (Barcelona and Madrid); group II airports with six million passengers or more; group III airports with two million passengers or more and less than six million; group IV airports with more than 500,000 passengers and less than two million; group V airports with 500,000 passengers per year or less. Airports can be classified in a different group from one year to another year[32]. In order to have enough representation in each group, and to avoid assuming from the beginning Barcelona and Madrid as outliers, or moving airports from one group to another group, the classification has been done into three groups following the approximate ranges provided by AENA. Notice that the airports are classified in one category when there is consistency in the number of passengers across the years. For example, the lowest level of passengers for medium-sized airports corresponds to Granada in 2013 (i.e. lower than 750,000). Nevertheless, this airport is considered medium due to consistency in terms of passengers across of the years. Following this procedure, it has been identified 14 large airports; 13 medium-sized ones and 22 small ones. It can be seen there is a high variability in terms of numbers of passengers. A wide variability is also found in the amount of cargo transported in one year (the statistic is not given here).

Table 3: Airports Size in terms of Passengers per year (Ripoll-Zarraga and Mar-Molinero, 2017)

Airports	**Size**	**Min PAX**	**Max PAX**
LARGE AIRPORTS Alicante; Barcelona; Bilbao; Fuerteventura; Gran Canaria; Ibiza; Lanzarote; Madrid Barajas; Malaga; Palma de Mallorca; Sevilla; Tenerife-North; Tenerife-South; Valencia	> 3,500,000	3,524,470	39,735,618
MEDIUM SIZED AIRPORTS A Coruña; Almeria; Asturias; Girona; Granada; Jerez; La Palma; Menorca; Murcia; Reus; Santander; Santiago; Vigo	≤ 3,500,000 > 750,000	638,288	2,736,867
SMALL SIZED AIRPORTS Albacete; Algeciras; Badajoz; Burgos; Ceuta; Cordoba; El Hierro; Huesca-Pirineos; La Gomera; Leon; Logroño; Madrid-Cuatro Vientos; Madrid-Torrejon; Melilla; Pamplona; Sabadell; Salamanca; San Sebastián; Son Bonet; Valladolid; Vitoria; Zaragoza	≤ 750,000	273	457,595

[31] https://www.boe.es/buscar/doc.php?id=BOE-A-2011-4116

[32] Another more generic classification may apply hubs (more than 30 million passengers); touristic airports (from 750,000 to eight million passengers); regional airports (between 750,000 and five million), and general aviation airports.

After the revision of the literature, and taking into account data availability, three inputs and four outputs were chosen. The financial data are the same for the five papers, with the inclusion of additional variables depending on the specific research paper aim and the previous research findings. In the inputs side labour costs (excluding air traffic control services); operating costs and depreciation of airports' assets are used. The outputs are the number of passengers; aircraft operations (air traffic movements); cargo handling and commercial revenues. Additionally, the percentage of flights on time as an indicator of the quality of management has been used in the DEA chapters (papers one to three). The percentage of flights on time (or its inverse the delays) reflects the quality of the management regarding arrivals and outgoing operations. This is a significant sub-problem of the more general scheduling and routing of aircraft in the terminal manoeuvring area including the resolution of potential aircraft conflicts (Samà et al., 2013). Therefore, aviation authorities are seeking optimization methods to better use the available infrastructure and better manage aircraft movements (Andreatta et al., 2014; Castelli et al., 2011; D'Ariano et al., 2012; Gardi et al., 2016, and Kim et al., 2009) There are more than several models demonstrating that it is possible to improve the scheduling of flights regarding the aircraft landing problem (ALP). Airports' operators must decide how to land an aircraft in a specific airport. This means to allocate each aircraft to an appropriate runway, and scheduling the landing time in a specific window to meet the separation time requirements with other aircraft (Pinol and Beasley, 2006). Bennell, Mesgarpour, and Potts (2011) provide an extensive review of airport runway scheduling including studies on the aircraft landing problem. Beyond the safety issues, punctuality is a concern for airlines and airports. Airport operations include gate assignments, baggage handling, and passport control. Delays in an aircraft landing may impact the rest of the operations including the subsequent aircraft.

There was no information regarding the type of labour cost (full or part-time; permanent or fixed term). In a few instances, there was missing data. It was preferred making a small estimation error rather than removing an airport from the data set because a particular item was not available. The nearest neighbour approach was inputted (Ripoll-Zarraga and Mar-Molinero, 2017; Ripoll-Zarraga et al., 2017; Ripoll-Zarraga and Lozano, 2018). Additionally, observations with zero value (i.e. cargo and depreciation of landside assets) were substituted by the unity. All the data measured in monetary units was deflated by the Spanish gross domestic product deflator (base Spain, 2010) and standardized by the respective geometric mean, which allows estimating elasticities at sample means (Cuesta et al., 2009).

Note that the percentage of flights on time is a ratio variable. Some authors have warned that this type of variables may cause some issues due to a mix with other types of measures (Dyson et al., 2001) or for example, the violation of the convex production assumption (Olesen, et al., 2015). In order to overcome this potential pitfall, the methodology used in paper three (centralised DEA) is applied to the same dataset, but without a ratio variable. The percentage of flights on time is substituted for two alternative congestion measures, which are considered undesirable outputs. These alternative variables are: the number of flights delayed more than 30 minutes and the total delay of flights with a delay larger than four minutes. The undesirable outputs are considered weakly disposable and modelled as per Kuosmanen (2005). The new results are enclosed in the appendix for comparison purposes and can be considered for future references. It is important to bear on mind that these data were not available at the point of writing the papers compiled in this Thesis. Therefore, the use of ratios as an output is one limitation of the DEA studies.

Apart from the questioned reliability of the aeronautical revenues since these depend on the air fees currently decided by AENA, these have not been selected from a statistical perspective to avoid multicollinearity. The aeronautical income represents the overall value of the total outputs selected. As previously stated, the depreciation of the airports' assets classified in airside and landside assets (Ashford, 1986) has been estimated by the researcher. The first paper (Ripoll-Zarraga and Mar-Molinero, 2017) explains the process of estimating the historical cost (initial cost) of airports assets and how the depreciation charges per year have been estimated. Further variables used are understood as external factors potentially influencing the airports' inefficiencies and beyond AENA's control, at least in the short-term. These refer to tourism variables (fourth paper) and environmental variable as known within the SFA context (fifth paper). The first three papers based on different variations of the conventional DEA do not enclose exogenous variables within the models. Consequently, the first three papers consider airports individual efficiency levels determined by the resources (inputs) used and the traffic develop (outputs). Within the DEA framework, an alternative approach to the conventional DEA is used that includes a temporal pattern term in order to determine insights into the efficiency levels. In some cases, managerial recommendations are to be provided.

With the objective of highlighting the divergence in depreciation values between AENA's and the ones estimated by the researcher, Table 4 shows the descriptive statistics for the 49 airports and five year period deflated by the GDP base Spain 2010, except for Algeciras that was under construction in 2009.

Note that the aeronautical revenues are shown for information purposes. These are not used in the analysis since they are the overall value of traffic (passengers, movements, and cargo)

Regarding the evolution of the traffic and the revenues, Table 5 shows that overall the main outputs passengers, air traffic movements, and cargo have decreased significantly from 2011 (data deflated by the GDP deflator base Spain, 2010)

Table 4: Summary Statistics (Source: AENA except for Depreciation Airside-Landside and Runways surface, 2009-2013)

Variable	Observations	Mean	Standard Dev.	Minimum	Maximum
PAX	244	3,960,844	8,526,221	0	49,866,113
ATM	244	41,575	71,690	476	435,187
Cargo (t)	244	13,031,236	52,431,345	0	394,154,078
Aeronautical Revenues (€)	244	34,289,177	95,722,169	19,871	703,933,777
Commercial Revenues (€)	244	12,964,271	30,674,863	0	186,824,959
Labour Costs (€)	244	8,001,234	11,225,979	119,228	81,826,474
Operating Costs (€)	244	21,064,865	54,964,546	367,621	350,817,645
Depreciation AENA(€)	244	15,945,982	43,339,885	200,000	291,837,149
Depreciation Airside (€)	244	4,351,957	12,473,722	34,194	84,888,708
Depreciation Landside (€)	244	5,540,086	16,008,274	0	128,729,047
Depreciation Airside without Runways (€)	244	2,165,091	5,466,260	0	31,100,244.71
Runway Length (m^2)	244	171,514	160,857.48	2,400.00	927,000

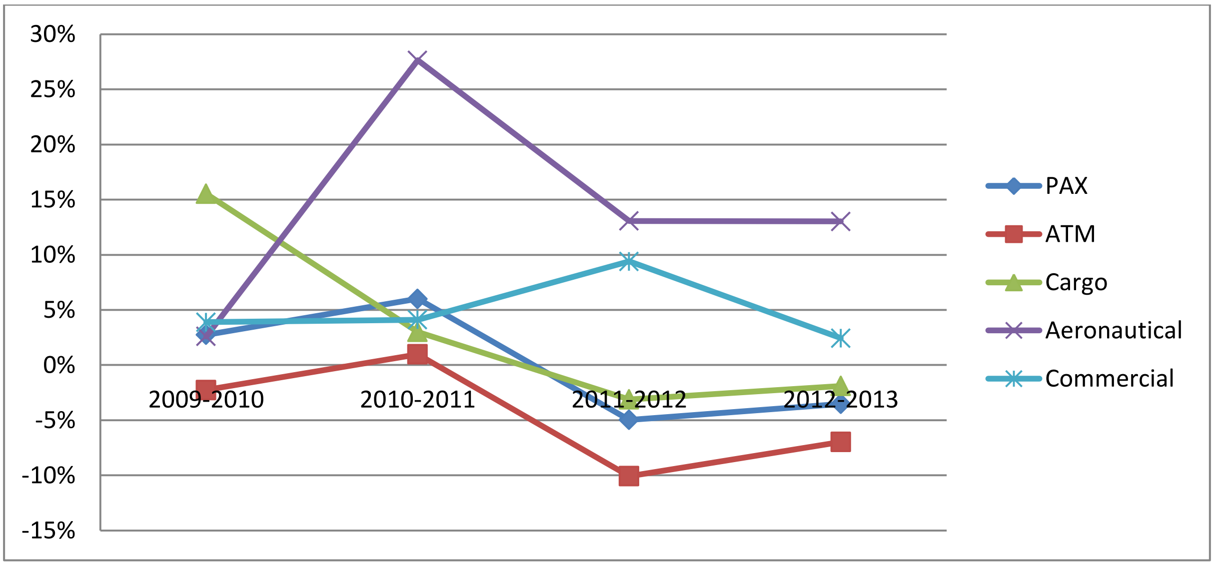
Table 5: Evolution of Traffic and Revenues 49 airports (Source: AENA, 2009-2013)

Variable	2009-2010	2010-2011	2011-2012	2012-2013
PAX	2.75%	6.01%	-4.97%	-3.51%
ATM	-2.26%	0.97%	-10.07%	-6.96%
Cargo	15.53%	3.01%	-3.11%	-1.88%
Aeronautical Revenues	2.60%	27.63%	13.07%	13.02%
Commercial Revenues	3.90%	4.11%	9.40%	2.44%

The aeronautical revenues increase significantly from 2010 to 2011. This seems paradoxical when the changes in passengers, movements, and cargo are not significant. Additionally, even being the change in cargo significantly higher from 2009 to 2010 (15.53%), the change in aeronautical income is very low (2.60%). This period corresponds to the finalisation of expansions of some of the large airports such as Malaga, with a new terminal finished in 2010. The new terminal was estimated at 30 million passengers. Nevertheless, the number of passengers before and after the expansion is similar (12.8 million and 12 million respectively, +6.2%. In 2017, 18.6 million passengers). Consequently, the depreciation charges are to be reflected in the profit account. In order to overcome the investment, since the traffic has not been increased accordingly, AENA decided to increase the airport charges to some airports. These increments in air fees did not correspond to improvements in commercial policies (e.g.

the quality of the service provided). Hence, the increment in aeronautical revenues due to changes in prices rather than in quantity of traffic. The Directive 2009/12/EC clearly specifies in paragraph 14 that airport managing bodies should inform airport users about major infrastructure projects as having a significant impact on the airport charges. And in article 8 requiring consulting with airport users before plans for new infrastructure projects are finalised.

Figure 2: Evolution of Traffic and Revenues for 49 airports (Source: AENA, 2009-2013)



1.4. Results and Discussion

The first paper attempts to determine the efficiency scores structural characteristics in terms of explanatory causes of the efficiencies. This is done by combining DEA and multivariate statistical techniques first proposed by Serrano-Cinca and Mar-Molinero (2004). The first paper is based on a cross-sectional analysis (2013). DEA allows estimating the efficiency levels of decision making units by benchmarking the units enclose in the sample. Nevertheless, DEA does not provide reasonable explanations of how this score is achieved. The distinctive feature of this approach allows visualising in bi-dimensional maps the location of the decision making units (airports) across the different factors generated by the model. The visualisation of the main characteristics of the results provides insights regarding why a particular unit achieves a certain level of efficiency. This procedure also allows for ranking the decision making units even when they are fully efficient. This research overcomes some gaps not covered by the DEA literature (conventional models) in the Spanish airport system and worldwide in the airport industry. To seek explanatory reasons justifying the individual efficiency requires second stage procedures potentially biased (Simar and Wilson, 1998; 2007). This is a matter when having information of the sample (sampling distribution) rather than the population (population distribution). Although in the studies enclosed in this Thesis, the information refers to the whole population, the researcher contributes to the existing literature with alternative approaches to overcome potential issues for future references. The visualisation procedure requires estimating efficiencies under a variety of specifications: combinations of inputs and outputs. This overcomes the 'zero weight problem'. The conventional DEA discriminates a unit when is inefficient overall (no frontier). Nevertheless, DEA visualisation highlights different aspects of the production process by splitting into sub-activities potentially sharing the same inputs, but being oriented to different outputs. For example, when comparing higher education institutions one university could be labelled as being technically inefficient overall. Nevertheless, this is considering all the outputs together (e.g. teaching and researching). When evaluating research and teaching activities separately, the same university could end being efficient doing research, but not in teaching. In the same way, some institutions are more efficient in teaching, but not in researching. This issue has been in part addressed by network DEA models (introduced by Färe and Grosskopf, 1996), the difference here is that firstly the inputs used to produce the different outputs are the same and these are used at the same time. Different processes and linking activities are not identified (assumed). Therefore, there are not intermediate outputs (Färe, 1991), but a final outcome with a potential different degree of production. With this regard, the visualisation maps help identifying the benchmark of DMUs oriented to produce a specific product with the rest specialised in the same output (clusters), rather than with all the units of the sample (the efficient unit) The number and type of DMUs specialised in producing one (or more) final output is unknown (intrinsic). The assumption made is that all the DMUs produce the same outputs. The model finally predicts (visualises) if this assumption is right and for which units.

The second paper is an extension of the first paper following the same methodological approach, but for panel data (2009-2013). The idea is to conclude the reliability of the results found in the first analysis performed for 2013 and to introduce the effect of time (time dimension). To confirm if airports' intrinsic characteristics change or do not change over time depending on unknown external factors (e.g. the economic cycle). These may potentially force airports to diversify activities (e.g. from air transport to cargo or from aeronautical to commercial activities). Diversification towards commercial activities is normally associated with privatisation processes (Humphreys, 1999). In the Spanish case, commercial revenues are as important as aeronautical revenues (ICAO, 2013). As previously discussed, extreme cases are a problem in DEA since they may have considerable influence on the results (outliers). Nevertheless, an extreme efficiency value may just be a consequence of the particular choice of inputs and outputs considered (Serrano Cinca et al., 2016). This approach overcomes this problem by locating the outliers (or mavericks) in the maps across the different dimensions that can be easily visualised. With this regard, there is no need to remove outliers from the sample that could imply a loss of a significant amount of information.

The first two papers based on DEA assume that airports are independent decision making units, without considering the impact of the specific management in the Spanish case. On this basis, airports' efficiency is assumed to be caused by the way that airports use their resources (inputs) developing the operating main activity (namely traffic). Efficiency is the relation between maximising the level of production given the inputs (output oriented) or minimising the consumption of resources given the traffic (input oriented). This definition implies implicitly that the airports are able to decide between the outputs to be increased and the inputs to be decreased. Nevertheless, the Spanish airports are managed under a strong centralised management. The conventional DEA models do not address the impact of the type of management and degree of centralisation in the airports' efficiency. A strong assumption is made since the individual efficiency levels can be improved without restrictions. This is unlikely to happen due to the degree of management centralisation of the Spanish airports.

The third paper attempts to overcome the limitations shown in previous studies such as reconsidering the impact of the type of management in the airports' individual efficiencies. The idea is to determine the optimum size without considering the airports' location. With this regard, a modification of the conventional DEA model is applied particularly relevant when the decision making units are managed under the same authority. In the case of the Spanish airports the centralised DEA model is particularly useful since the optimisation of resources utilisation, applies for all the airports as a whole rather than optimising each airport separately (in Ripoll-Zarraga and Lozano, 2018). The third paper is based on a non-oriented and non-radial model in two-stage analysis following the Slack-Based-Inefficiency (SBI) approach. Trade-offs between inputs (or outputs) cannot be identified through radial efficiency measures. The results show individual pathways for each inefficient airport and for each input and output. Since all the airports are centrally managed, the aim of the model is to increase the overall traffic of the system and potentially to reduce the consumption of inputs. As previously discussed, another relevant issue of the conventional DEA is the effect of the extreme cases (outliers versus mavericks). Outliers distort the efficiency frontier and individual targets of the decision making units. These lay outside of the true production set due to different undetected reasons (e.g. data error; heterogeneity of the decision making units; error in the production assumptions, etc.). The detection of outliers relies on assessing the impact of excluding observations from the data set (Wilson, 1995). Other approaches proposed to assess robustness (e.g. Charnes et al., 1992; Zhu, 1996). Overall, all of them rely on the ability of the researcher and familiarity with the data set and essentially the follow-up inspection (Wilson, 1995). The methodology used in the third paper does not seem to be affected by the presence of extreme cases in inputs and outputs potentially biasing the efficiency frontier as may happen in general in DEA. A sensitivity analysis is performed by removing two cargo-oriented airports from the sample to test the consistency of the efficient frontier and to settle more realistic cargo targets for the inefficient units.

The results in terms of airports being more efficient in the first paper (2013) compared to the second paper (2009-2013) show a consistency for certain airports. For example, large airports such as Barcelona (BCN), Madrid Barajas (MAD) and Palma de Mallorca (PMI) remain highly

efficient (i.e. > 90%), not only for one specific year but for the five-year period (see figures one and two). This also happens for other airports less efficient with a range of size. Large airports such as Fuerteventura (FUE); Tenerife North (TFN) or Valencia (VLC) show consistently scores between 50% and 62.5%; also medium airports such Girona (GRO) (50%-62.5%) and Murcia (MJV) (25%-50%) and small airports such as Cordoba (ODB) and Santander (SDR) (25%-50%) or Vitoria (VIT) and Zaragoza (ZAZ) (50%-62.5%). Nevertheless, in most of the cases, airports change their range of efficiency when considering a wider frame of time. Since DEA is a snapshot of the current situation of efficiencies, these results confirm that using the DEA outcome for one period could lead to wrong managerial decisions. On this basis, the 2013 visualisation map for the first component identified as the overall measure of efficiency generating income (see figure one) shows Sevilla (<50%); Alicante (62.50%) and Tenerife South (62.5%-75%) as not highly efficient. This is not consistent across the years, but circumstantial for 2013. The same map for the five-year period shows these airports with scores between 87.50% and 93.75% (see figure two and table A1 in the appendix, for the airports' codes)
In the same way, the visualisation map for 2013 shows Madrid-Torrejon (TOJ) highly efficient (93.75%), but performing badly (<25%) for the five years visualisation map. The opposite situation for Sevilla (SVQ) labelled unfairly as very inefficient in 2013 (25%-50%), but frontier for a five year period of (93.75%). This is sensible since Madrid-Torrejon stops civilian air transport from February 2013 becoming a fully military base with no passengers or cargo. Since the DEA score is estimated with the number of passengers, this change in the operating activity generates a drastic impact on the technical efficiency score and labelled as highly efficient unfairly if only 2013 was considered. Small airports that are also not consistent when comparing the two maps are: Albacete (ABC), Burgos (RGS), Huesca-Pirineos (HSK), La Gomera (GMZ) and Logroño (RJL) (with scores between 50% and 62.50% for 2013, but lower than 25% from 2009 to 2013); medium airports such as A Coruña (<25%; ≈50% respectively) and Jerez (≈50%; ≈75%). In the same way, the two general aviation airports Madrid-Cuatro Vientos and Sabadell show scores between 62.50% and 75% for 2013 and are efficient consistently when including more years in the analysis (100%; ≈87.50%). These results confirm that using DEA for one period of time is not reliable enough to draw some conclusions regarding the efficient frontier. Secondly, an alternative methodological approach is required to learn insights into the main reasons for the individual efficiency level of the airports and the peer group.

The centralised DEA results confirm previous findings regarding highly efficient airports that now are frontier. For example, large airports such as Barcelona, Madrid Barajas and Palma de Mallorca and Lanzarote as well as general aviation airports (Madrid-Cuatro Vientos and Sabadell) are technically efficient. There are some exemptions of the smallest airports found technically inefficient in the first paper, but now are frontier (see figure 2)[33] Note that the efficiency defined in the second paper (dimension 1) refers to the ability of using airports' investments to generate traffic (passengers) rather than an overall efficiency measure (conventional DEA). In other words, the results found in paper two confirms that the small airports' investments are an explanatory reason for their inefficiency due to their low traffic. Consequently, these airports are factually underused (over-capacity). DEA visualisation has captured the over-capacity locating the smallest airports in the left-hand side of dimension one (efficiency using investments) and in the top left-hand side quadrant (dimension two identified as cost efficiency). Although the small airports deal with traffic in a cheap way, there is not enough traffic to reflect a better usage of infrastructures, to become technically efficient. With the exception of Girona and Jerez, this is also confirmed for the rest of the medium airports. As shown in figure two (blue buffer), these are located on the left-hand side of dimension one close to the zero value (50%).

On the other hand, in the centralised DEA model, the cost of capital (depreciation) is considered a non-transferable and non-discretionary input. Consequently, the model is unable to capture the relation between airports' infrastructure and traffic (over-capacity). Overall the results confirm the previous findings discriminating between efficient and inefficient airports. The relevant results of centralised DEA correspond to the inefficient units and the overall improvement of traffic for the airport-system. There is also an adequacy of the degree of employment (labour costs) and infrastructure even airports performing badly. This is based on the current infrastructures, but independently of the traffic. As previously discussed, taking into account the relation of airport infrastructure and traffic and also employment, it is not possible to address the question regarding over-capacity of the Spanish airports since depreciation is assumed to be unchangeable in the short-term.

Another important reflection is the impact of the type of variables (selection of inputs) in the DEA models. It is clear that in the first two papers (DEA visualisation) the airports' assets have a negative impact on efficiency for those having low traffic. This is sensible since based on the airports' capacity determined by the value of the physical (tangible) assets and measured through the depreciation (input), some airports could certainly increase the production level, generate more traffic. On the other hand, assuming that airports' infrastructure is non-changeable, these airports found technically inefficient suffering from over-capacity (papers one and two) are now technically efficient (paper three)

[33] For example, Albacete; Burgos; La Gomera; Logroño; Vitoria and Zaragoza are technically efficient (paper two) Additionally, Badajoz and Murcia are both technically efficient even performing very badly according to the previous findings.

Figure 3: DEA Visualisation (2013) Common map (Ripoll-Zarraga and Mar-Molinero, 2017)

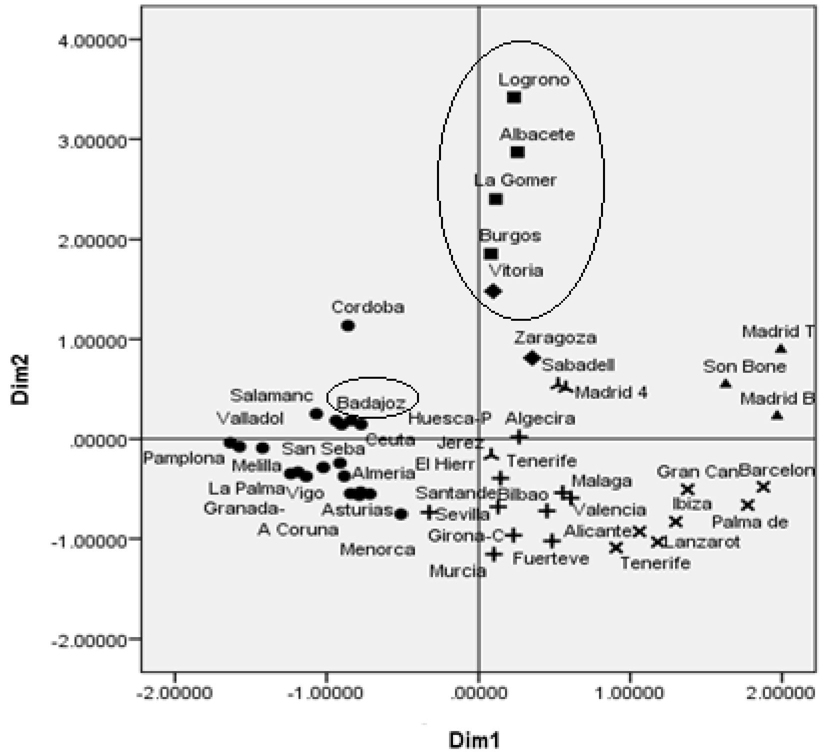
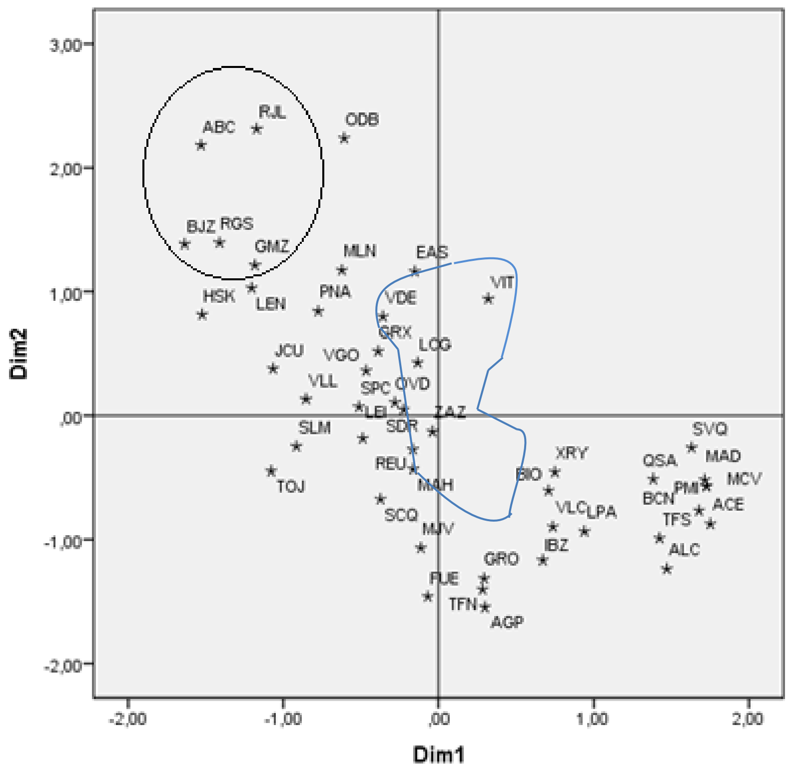


Figure 4: DEA Visualisation (2009-2013) Common map (Ripoll-Zarraga et al., 2017)



The fourth and fifth papers are based on Stochastic Frontier Analysis (SFA) for a five-period of time (2009-2013). DEA does not have significance tests of omitted variables. With this regard, more than several variables not previously used in the DEA studies have been tested. The aim is to confirm the consistency of the most efficient airports and to provide further explanatory reasons to show evidence of the efficiency levels of the Spanish airports not confirmed by previous findings (paper one to three). One relevant contribution is the application of SFA multi-input and output models (i.e. a translog distance function) to an empirical and not-simulated case. Other relevant findings are the fact that the SFA approach suffers from problems of precision in the estimates, and of the power of the statistical tests carried out. Both problems are due to the flatness of likelihood functions used in SFA. The algorithm finishes prior to finding the optimum, and in some cases provides different solutions when altering the order of the variables. The second problem relates to wide parameter confidence intervals provided, which decrease the power of the test. Consequently, it is very difficult to find significant results. The existing software STATA does not allow changing the programming commands. Alternatively, a larger database could be used, but this would imply using information from other European countries implying different regulatory frameworks, ownership and management forms.

The fourth paper follows the inefficiency term specification of Battese and Coelli (1992) with the inclusion of fixed effects in the production function (Greene, 2005). Airports' special features are found relevant to avoid model misspecifications and mistaken managerial decisions regarding inputs and outputs. These features are not captured by DEA models, but potentially intrinsically affecting the efficiency scores. Airports with firm-effects have been identified when showing a significant and relevant individual impact on the production function in comparison with the rest. On this basis, six airports were found having individual fixed effects in a pre-analysis: Barcelona; Madrid Barajas; Malaga; Palma de Mallorca; Huesca-Pirineos and Vitoria.

In terms of efficiency, the results show consistency with the outcome of centralized DEA (paper three), especially for small and medium airports being highly efficient (e.g. Algeciras; Badajoz; Burgos; Ceuta; El Hierro; Girona; Sabadell; Zaragoza). But, not for paper one and two based on DEA visualization where the results showed these airports being inefficient (except for Sabadell). Other airports highly efficient are usually chosen as a touristic destination (e.g. Barcelona; Bilbao; Fuerteventura; Ibiza; Lanzarote; Palma de Mallorca and Sevilla). Further analysis with tourism variables indicates that airports geographically located in touristic areas are clearly impacted by the type of accommodation. The number of apartments and essentially the number of campsites in a popular tourist destination affect significantly and negatively the airports' technical efficiency. This is independent of the expenditure, the length of stay or the number of arrivals to the city where the airports are located. Cities with a higher number of hotels compared to campsites contributing positively to the airports' technical efficiency levels. Being the type of accommodation an external factor, the results confirm that the airports' inefficiency in areas not usually chosen as a touristic destination is due to the management. This is AENA's decisions among resources (e.g. investment decisions in airport infrastructure) and commercial policies affecting traffic (e.g. airport charges; negotiation with airlines to open routes; etc.). The results also show that small airports contribute to the financial aspect of the system when specialized (e.g. cargo activities; general aviation; heliport, etc.). This is also found in paper two (dimension two), where most of the small airports are certainly more cost efficient compared to medium or large airports.

The last chapter is an ongoing work based on stochastic frontier analysis (SFA). Two models specifications are used: Battese and Coelli (1992) with the inclusion of fixed effects (Greene, 2005) in the production function and Battese and Coelli (1995) accounting for environmental variables. The aim is to identify the potential causes of the Spanish airports' inefficiencies that are not controllable by AENA. The analysis also assesses the number of airports within their respective catchment areas in order to recommend the closure of the most inefficient airports minimizing the impact on connectivity. The results show a clear impact on the estimated technical efficiency when fixed effects are not enclosed versus when including them in the production function. The initial conclusion drawn is that unobserved heterogeneity (firm-effects) clearly biases the efficiency results of the decision making units: lower efficiency scores compared to the situation when fixed effects are identified and controlled. Overall there are not environmental variables affecting the airports' efficiency levels, except for airports with train facilities incrementing the overall inefficiency of the system significantly.

A summarize of the overall efficiency results are shown in Table 6 for comparison purposes.

This Thesis is organised as follows. Chapter two to five contains four research papers currently under review in scientific journals referenced in the 2017 Journal Citation Reports (JCR). Chapter six contains a prospective paper (work in progress). Chapter seven summarizes the main findings, remarks, and conclusions.

Paper	Methodology	Inputs	Outputs	Non-controllable	Period	Number of Airports	Efficient Airports	Cause (+ increase efficiency/- decrease efficiency)
Paper one	DEA Visualisation	Labour costs Operating costs Depreciation airside assets	Passengers ATM Cargo Commercial revenues X% of flights on time	None	2013	49	>80% (eight airports) ▪ Large (Madrid Barajas; Barcelona; Palma de Mallorca; Gran Canaria; Ibiza; Lanzarote) ▪ GA (Son Bonet) ▪ Army base (Madrid Torrejon) >70% <80% (two airports) ▪ Large (Alicante; Tenerife South)	+ Geographical location (seaside) + Mavericks (hub; GA; army base)
Paper two	DEA Visualisation	Labour costs Operating costs Depreciation airside assets (excluding runways) Runways length	Passengers ATM Cargo Commercial revenues X% of flights on time	None	2009-2013	47	>80% (nine airports) ▪ Large (Madrid Barajas; Barcelona; Palma de Mallorca; Lanzarote; Alicante; Tenerife South; Sevilla) ▪ GA (Madrid Cuatro Vientos; Sabadell) >70% <80% (five airports) ▪ Large (Gran Canaria; Ibiza; Bilbao; Valencia) ▪ Medium (Jerez)	+ Geographical location (seaside or inland) + Length of runways + Mavericks (hub; GA) + Trend
Paper three	Centralised DEA	Labour costs Operating costs	Passengers ATM Cargo Commercial revenues X% of flights on time	Depreciation airside assets & terminals (non-transferrable)	2013	49	=100% (21 airports) ▪ Large (Madrid Barajas; Barcelona; Palma de Mallorca; Gran Canaria; Ibiza; Lanzarote; Alicante; Tenerife South) ▪ Medium (Murcia)	- Over-capacity (idle infrastructure; idle employees) - Low aircraft movements (small airports)

							▪ Small (Albacete; Badajoz; Burgos; La Gomera; Logroño; Vitoria; Zaragoza) ▪ GA (Son Bonet; Madrid Cuatro Vientos; Sabadell) ▪ Army base (Madrid Torrejon) ▪ Heliport (Algeciras)	
Paper four	SFA (1992) without/with Fixed Effects Second stage regression with Tourism indicators	Labour costs (dependent) Operating costs Depreciation airside assets Depreciation landside assets	Passengers ATM Cargo Commercial revenues	Type of accommodation: hotels; apartments; campsites Tourists' expenditure Length of stay Arrivals Number of employees (Tourism) Price index (Hospitality and Tourism)	2009-2013	48	Without Fixed Effects: >80% (one airport) ▪ Heliport (Algeciras) With Fixed Effects: >80% (nine airports) ▪ Medium (Girona) ▪ Small (Burgos; Badajoz; Zaragoza; El Hierro; San Sebastian) ▪ GA (Sabadell) ▪ Heliports (Algeciras; Ceuta) Without Fixed Effects >70% <80% (four airports) ▪ Small (Burgos; Zaragoza; Badajoz) ▪ Heliport (Ceuta) With Fixed Effects >70% <80% (21 airports) ▪ Large (Sevilla; Bilbao; Lanzarote; Palma de Mallorca; Barcelona; Ibiza;	+/-Type of Accommodation (touristic areas): + Number of hotels - Number of campsites - Number of apartments

							Madrid Barajas; Tenerife North; Malaga; Fuerteventura) ▪ Medium (A Coruña; Asturias; Murcia; Menorca; Reus) ▪ Small (Vitoria; Valladolid; Cordoba; Pamplona; Huesca;) ▪ Army base (Madrid Torrejon)	
Paper five (prospective)	SFA (1992) with Fixed Effects SFA (1995) with Fixed Effects & Environmental Variables	Labour costs (dependent) Operating costs Depreciation airside assets Depreciation landside assets	Passengers ATM Cargo Commercial revenues	Catchment area PSOs Airport accessibility Airport capacity Type of airport	2009-2013	48	No environmental: > 80% (nine airports) ▪ Medium (Girona) ▪ Small (Burgos; Badajoz; Zaragoza; El Hierro; San Sebastian) ▪ GA (Sabadell) ▪ Heliport (Algeciras; Ceuta) >70% <80% (19 airports) ▪ Large (Sevilla; Bilbao; Lanzarote; Palma de Mallorca; Barcelona; Ibiza; Madrid Barajas; Tenerife North; Malaga; Fuerteventura) ▪ Medium (A Coruña; Asturias; Murcia; Menorca) ▪ Small (Vitoria; Valladolid; Cordoba; Huesca) ▪ Army base (Madrid Torrejon)	- Railway infrastructure (Airport accessibility) + Military activities share with civilian transport (Type of airport) Fixed effects: + Small airports have a similar impact than large airports in generating financial resources if are specialised + Mavericks (hubs) - Small airports not specialised

	Environmental: > 80% (eight airports) ▪ Medium (Girona) ▪ Small (Zaragoza; Badajoz; Burgos) ▪ GA (Sabadell; Madrid Cuatro Vientos) ▪ Heliport (Algeciras; Ceuta) >70% <80% (10 airports) ▪ Large (Bilbao; Lanzarote; Malaga) ▪ Medium (Girona; Murcia; A Coruña; Asturias) ▪ Small (San Sebastian; El Hierro; Cordoba)	

Table 6: Summary of results

Chapter two

Spanish airports: a Visual Study of Management Efficiency

Ripoll-Zarraga, A.E. and Mar-Molinero, C. (2017): 'Spanish airports: a Visual Study of Management Efficiency'. *Transport Policy* (second round, under review)

List of Tables

List of Figures

Spanish Airports: a Visual Study of Management Efficiency

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Abstract

In recent years the Spanish government has invested significantly in the infrastructure of airports. It is not clear if this investment has been efficiently applied. The Spanish airport system is centralised. Airports operate as independent profit centres but are under the control of a central authority, AENA. This means that, in Spain, non-profitable airports are subsided by profitable airports, and that non-profitable airports are a burden on financial resources. This calls for an assessment of the real reasons behind any inefficiency. We study airport efficiency using Data Envelopment Analysis (DEA). In standard studies, DEA summarises the efficiency of a unit by means of a single number. Here we go beyond the efficiency score by combining DEA with multivariate analysis techniques. In this way we are able to establish why a particular airport reaches a given efficiency level, and what is its approach to the use of resources and the achievement of results. The combined use of DEA and multivariate statistical analysis permits the visualisation of the results and the addition of qualitative information to the interpretation of the results.

Keywords: *Data Envelopment Analysis (DEA); Multidimensional Scaling (MDS); Visualisation; Technical Efficiency; Benchmarking; Spanish Airport-System*

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1. Introduction

This paper focuses on visualising the technical efficiency of the Spanish airports in order to assess the effectiveness of public resources management. Spanish airports are government owned and managed through a public company (AENA) under a system where non-profitable airports are cross-subsidized by profitable airports. The European Commission in a recent report (European Court of Auditors, December 2014) has identified an excess of investment in public infrastructures in Europe, and has called for an investigation of (i) the impact of management decisions and (ii) the effectiveness of governments in managing public resources. Investigating these issues has been the motivation behind the research reported here.

Decision-making in Spanish airports is fully centralised. Spanish airports have no flexibility when negotiating with airlines or in managing airports' resources. AENA has the legal power to decide air fees to be charged to the airlines in each airport. Additionally, the Spanish airport industry does not have an independent regulatory body to ensure good practices and enhance competition in order to make the Spanish market attractive to airlines. It is, however, important to highlight inefficiency in the allocation of resources, in the process of price setting, and in the achievement of results in order to improve the management of the system. If inefficiencies are identified and their reasons exposed, the overall management body can take action in order to improve the overall system.

Historically, airports used to be considered as natural monopolies fully owned by governments and therefore treated as a public utility. In Spain there has been pressure from the part of local governments, professional bodies and the general public requesting the transfer of the individual airports' management to local control. This pressure met with some success. The government took some initial steps with the announcement on the 25th March 2009 of the creation of a subsidiary body (EGAESA). But the impact of the centralisation of decisions still remains an issue. There is evidence from other OECD countries with similar size airport networks and similar political structure that decentralisation and private management increases efficiency (Nombela, G. in Abertis, 2009). Airports are individually managed in most developed countries such as France, Italy, Germany and the UK, Canada and the United States. In some big cities with a high level of commuters and air travellers, airports may have a unique management form (public sector or private sector), this is to ensure competition in the airport market. Examples are London, Paris, Rome and Milan.

The 'singular airport' topic has been publicly discussed by the Spanish Government in January 2010 (Cambra de Comerç de Barcelona, 2010)

The Spanish airport-system ensures the transfer of financial resources from profitable to non-profitable airports (cross-subsidisation). Non profitable airports tend to have a low level of traffic, but they still remain open since they are financed by excess income in profitable airports. An airport-system similar to the Spanish is also found in Norway, but in Norway, airports must be kept open since air transport is the only travel-alternative for citizens who live in remotes areas.

Competition starts with rivalry within the industry. According to Porter (1979), markets are competitive when barriers to entry are low. Competition implies flexibility in the negotiation process with airlines with respect to prices and quality of the services. But Spanish airports do not compete against each other since managers do not have decision power in such variables as passenger choice; service provided and price. The Spanish National Board for Markets and Competition (CNMC, 2014) argues that some Spanish airports could compete if they had the ability to manage their own resources. This calls for an analysis of the efficiency of Spanish airports from the point of view of resources used and results obtained. In this paper we use Data Envelopment Analysis (DEA) in order to perform such an analysis. The DEA technique is fairly standard within the scientific management literature. Charner et al. (1993) and Cooper et al. (2000), amongst others, provide an extensive introductory literature regarding DEA and its applications.

In DEA a unit of assessment (UOA) uses inputs in order to generate outputs. A major problem in DEA is the specification of the model, this is to say, identifying which inputs and which outputs are to be included in the model. This issue has been long debated. For example, Farrell (1957) observed that input and output selection is a highly subjective matter. If not all the variables are included, important aspects of the problem may be omitted, but if many variables are included in the specification, some units may become efficient just because they are "special cases". A further problem, known as the zero weights issue, appears when UOAs ignore a particular input or output in order to show themselves in a better light. Besides, DEA generates just a score, and we would like to know what is behind the score, how do the different units achieve a particular efficiency level. This problem was addressed Serrano-Cinca and Mar-Molinero (2004) who suggested that DEA specification search should be embedded within a multivariate analysis framework. This is done in the current paper. We estimate a variety of models and analyse the DEA efficiency obtained from each of model for each airport using Factor Analysis, Cluster Analysis, and Property Fitting techniques. All these are standard tools in Multivariate Statistical methods.

The next section presents a review of the literature on airport efficiency. This is continued with a discussion of data issues. The analysis and interpretation of the results follows next. The paper ends with a discussion of the findings.

2. Literature Review

Data Envelopment Analysis (DEA) originally developed by Charnes et al. (1978) and subsequently extended by Banker et al. (1984), is a non-parametric linear programming-based method that evaluates the comparative efficiency of a set of homogeneous UOAs.

DEA has been applied in multiple airport studies over the last 15 years. In DEA there are two fundamental approaches: radial and non-radial. Both approaches are related to the path that inefficient units have to follow in order to reach the competitive frontier, and so become efficient. The radial projections introduced by Debreu (1951) and Farrell (1957) are based on the proportional reduction in inputs (or increase in outputs) in order to improve the efficiency of the units analysed. Non-radial projections were introduced by Koopmans (1951) and Russell (1985). Charnes et al. (1985) were the first authors who proposed an additive model, non-oriented DEA, to estimate efficiency scores based on a proportional reduction (increase) of inputs (outputs). The basic model has been modified to propose improvements to the basic formulation (Brockett, 1997; Cooper et al, 1999; Tone, 2001; Asmild & Pastor, 2010; Fare & Grosskopf, 2000). The majority of studies of airport benchmarking using Data Envelopment Analysis have been based on radial models, sometimes with constant returns to scale (Bazarghan & Vasigh, 2003; Fung et al., 2008; Sarkis & Talluri, 2004) and sometimes with variable returns to scale (Adler & Berechman, 2001; Fernandes & Pacheco, 2002; Martin & Roman, 2006). Some other studies use both types of returns in order to estimate technical and scale efficiency levels in the airport operations (Abbot & Wu, 2002; Assaf, 2010; Martin & Roman, 2001). Table 1 gives details of some relevant studies and their findings.

Author/s	Outcome	Methodology	Findings
Murillo-Melchor (1999)	Technical Efficiency 33 Spanish airports (1992-1994)	Data Envelopment Analysis (DEA) Total Factor Productivity (Malmquist Index)	Airports with more passengers are more efficient
Salazar de la Cruz (1999)	Technical Efficiency 16 Spanish airports (1993-1995)	Data Envelopment Analysis (DEA)	Airports with more passengers are more efficient
Martin & Roman (2001)	Technical Efficiency 37 Spanish airports (1997)	Data Envelopment Analysis (DEA)	Airports with larger size are more efficient. Airports' geographical location affects efficiency
Martin & Roman (2006)	Technical Efficiency 34 Spanish airports (1997)	Different variations based on Data Envelopment Analysis (DEA)	Airports with more passengers are more efficient. Airports' geographical location affects efficiency
Martin-Cejas (2002)	Technical Efficiency 40 Spanish airports (1996-1997)	Deterministic Cost Frontier (DCF)	Airports with 1 to 3 million passengers show higher average of efficiency
Coto-Millan et al. (2007)	Economic Efficiency 33 Spanish airports (1992-1994)	Cost Stochastic Frontier Analysis (SFA)	Airports with more passengers are more efficient
Tapiador et al. (2008)	Technical Efficiency 29 Spanish airports (2006-2007)	Data Envelopment Analysis (DEA)	Larger and small airports are more geographically efficient
Martin et al. (2009)	Economic Efficiency 37 Spanish airports (1991-1997)	Cost Stochastic Frontier Analysis (SFA) Bayesian Inference	Larger airports are more efficient
Tovar & Martin-Cejas (2009)	Technical Efficiency 26 Spanish airports (1993-1999)	Stochastic Frontier Analysis (SFA) Distance Function	Airports outsourcing some services are more efficient
Tovar & Martin-Cejas (2010)	Technical Efficiency 26 Spanish airports (1993-1999)	Stochastic Frontier Analysis (SFA) Distance Function. Total Factor Productivity (Malmquist Index)	Hub airports are on average more efficient. Northern airports are more efficient
Lozano & Gutierrez (2011)	Technical Efficiency 39 Spanish airports (2006-2007)	Target-setting DEA Slack-Based Measure (SBM)	Passengers and Cargo are directly related with efficiency
Martin et al. (2011)	Economic Efficiency 36 Spanish airports (1991-1997)	Cost Stochastic Frontier Analysis (SFA)	Airports within the same catchment area are cost-inefficient unless congested
Lozano et al. (2013)	Technical Efficiency 39 Spanish airports (2008)	Network DEA	Network DEA shows higher discriminatory power to detect inefficiencies
Coto-Millan et al. (2014)	Technical Efficiency 35 Spanish airports (2009-2011)	Data Envelopment Analysis (DEA) Total Factor Productivity (Malmquist Index) Regression (Airport's size; LCCs)	Larger airports are more technically and scale efficient LCC increases scale efficiency
Coto-Millan et al. (2016)	Technical Efficiency 35 Spanish airports (2009-2011)	Data Envelopment Analysis (DEA) Tobit Regression (Airports' size; Cargo; LCCs)	Airports with more cargo are more technically and scale efficient.

Table 1: Summary of Spanish airports' studies

3. Methodology

The calculation of DEA efficiencies requires solving a set of linear programming problems. Linear Programming is not a statistical technique and, as such, there are no standard procedures, such as t-tests, in order to assess if a variable (an input or an output) should be included in the specification of the model. In general, model specification tends to depend on the personal choices made by the analyst. It is perfectly possible for two different modellers using the same data to arrive at different results just because they have included a different set of inputs and outputs in the model. DEA efficiencies may not be reliable if a relevant variable is omitted. Variable omission can take place in a subtle way: the UOA under evaluation can attach zero weight to one of the variables, thus removing it from the assessment set. On the other hand, the addition of irrelevant variables has consequences. The number of fully efficient units depends on the number of inputs and outputs in the specification (Pedraja Chaparro et al., 1999). A UOA can appear to be efficient if an extra input or output is added to the variable set. This is the case because some units of assessment become self-comparators, or special cases.

Specification searches in DEA have a long pedigree. Norman and Stoker (1991) suggested that a DEA model should be first estimated without a potentially important variable, and that the efficiencies calculated should be correlated with the values of the missing variable. If the correlation turns out to be high, the missing variable should be included in the model and the estimation process repeated. This procedure of re-estimating DEA models after the addition or removal of an input or an output was generalised by Pastor el al. (2002). A different approach to specification searches, based on the bootstrap, was proposed by Simar and Wilson (2000a, and b). Sirvent et al. (2005) published a comparison of specification searches.

In this paper we apply a different approach to model selection based on a combination of DEA and multivariate statistical techniques first proposed by Serrano-Cinca and Mar-Molinero (2004). An example of the application of this methodology can be found in Serrano-Cinca et al. (2016). The distinctive feature of the procedure is the visualisation of the main characteristics of the results. This procedure has the added advantages of making it possible to rank UOAs, even when they are fully efficient, and of explaining the reasons why a particular unit achieves a given level of efficiency.

Our procedure requires estimating efficiencies under a variety of specifications: combinations of inputs and outputs. This overcomes the “zero weight problem”. Imagine two UOAs: UOA_1 and UOA_2. Further imagine that both UOAs are compared on the basis of two inputs, I_1 and I_2, and three outputs, O_1, O_2, and O_3. It is possible for UOA_1 to give non-zero weights to all inputs and outputs, whilst UOA_2 gives non-zero weights to I_1 and I_2 but gives zero weights to O_2 and O_3. In fact, we are not comparing like with like, as the efficiency of UOA_1 is calculated on the basis of the specification I_1, I_2, O_1, O_2, and O_3 while the efficiency of UOA_2 is calculated on the basis of the specification I_1, I_2, and O_1. In the procedure presented here, both UOA will be compared on the basis of the more limited model I_1, I_2, O_1 as well as on the basis of the full I_1, I_2, O_1, O_2, O_3 model (that UOA_2 will simplify). The difference between the two UOAs will be highlighted by the graphical presentation of the results.

In theory, any combination of outputs and inputs can be contemplated but, in practice, some combinations will make no theoretical sense or will not be particularly interesting. In fact, "uninteresting" specifications have been omitted in this study. In this way we obtain a two-way table of specifications by units of assessment. Each cell in the table will contain the efficiency of the unit of assessment under the particular specification being contemplated. This two-way table of efficiencies is then analysed with the techniques of statistical multivariate analysis. In particular, Factor Analysis, Cluster Analysis and Property Fitting. The advantage of using this approach is that the results of the analysis can be presented graphically and interpreted with the addition of information not used in deriving the graphs (external analysis). Examples of this approach can be found in Gutierrez-Nieto et al. (2007) and Sagarra et al. (2015).

For modelling purposes, it is essential to understand what exactly are inputs and outputs. Additionally, DEA requires homogenous data for all the airports. . Homogeneity implies that all airports are well described by the same production function. Overall, Spanish airports differ in terms of infrastructure size as well as financial resources, but we do not consider this to be a source of heterogeneity. Some airports may be included in public services obligation routes (PSOs) where a minimum level of service is required by law.

4. Data description

The Spanish airport-system contains 49 civilian airports including four general aviation airports and two heliports. General aviation (GA) is all non-commercial civil aviation operations: scheduled and non-scheduled air transport operations (ICAO).

Spanish airports are government owned and managed through a public company (AENA). Table 2 lists the airports after grouping them in three categories according to size, and gives summary statistics for the different size groups. In Table 2 size is measured through the number of passengers in one year (PAX). Notice that the airports are classified in one category when there is consistency in the number of passengers across the years. Following this procedure, we have identified 14 large airports; 13 medium-sized ones and 22 small ones. It can be seen there is a high variability in terms of numbers of passengers. A wide variability is also found in the amount of cargo transported in one year (the statistic is not given here).

Airports	Size	Min PAX	Max PAX
LARGE AIRPORTS Alicante; Barcelona; Bilbao; Fuerteventura; Gran Canaria; Ibiza; Lanzarote; Madrid Barajas; Málaga; Palma de Mallorca; Sevilla; Tenerife-North; Tenerife-South; Valencia	> 3,500,000	3,524,470	39,735,618
MEDIUM SIZED AIRPORTS A Coruña; Almería; Asturias; Girona-Costa Brava; Granada; Jerez; La Palma; Menorca; Murcia; Reus; Santander; Santiago; Vigo	≤ 3,500,000 > 750,000	638,288	2,736,867
SMALL SIZED AIRPORTS Albacete; Algeciras; Badajoz; Burgos; Ceuta; Córdoba; El Hierro; Huesca-Pirineos; La Gomera; León; Logroño; Madrid 4 vientos; Madrid Torrejón; Melilla; Pamplona; Sabadell; Salamanca; San Sebastián; Son Bonet; Valladolid; Vitoria; Zaragoza	≤ 750,000	273	457,595

Table 2: Airports Size in terms of Passengers per year (Source: AENA, 2013)

Notice that the lowest level of passengers for medium sized airports corresponds to Granada in 2013. Nevertheless, this airport is considered medium due to consistency in terms of passengers across of the years.

After the revision of the literature, and taking into account data availability, three inputs and four outputs were selected for inclusion in the DEA model. The inputs are labelled with letters and the outputs with numbers. These are summarised in Table 3.

Inputs	Outputs
A Labour	1 Passengers
B Operating Costs	2 Air Traffic Movements
C Depreciation of Airside Assets	3 Cargo
	4 Commercial Revenues
	5 Percentage of Flights on time

Table 3: Inputs and Outputs in the DEA models

Financial data, except depreciation, were extracted directly from the AENA's annual reports for 2013. This was the most recent data set available at the time when this study was carried out. On the outputs side, annual number of passengers (PAX), air traffic movements (ATM), cargo, and commercial revenues are desirable outputs. Aeronautical revenues have not been included as an output because they were found to be highly correlated with PAX, ATM, and Cargo. Rather than using the number of flights delayed −a negative output−, which is the usual measure of punctuality, we used as output the percentage of number of flights arriving on time −a positive output. An aircraft is considered to arrive on time if it arrives with a maximum delay of four minutes.

There were four missing values in the variable percentage of flights on time. Instead of removing these airports from the database, we used a nearest neighbour imputation routine. Given an airport with a missing value, such as Ceuta, we found the airport (airports) with most similar data structure in the remaining variables. The value of flights on time for this nearest neighbour was used as the percentage of flights on time for the airport with the missing value. When several airports were found to be nearest neighbours an average was used. This procedure is not ideal, but we preferred to work with a small amount of measurement error rather than lose observations in the subsequent analysis.

Turning now to inputs, staff cost (labour) excludes the cost of air traffic control services. Operating costs depend on the level of activity of the airport. Depreciation measures the use of capital assets. An overall concept that summarizes airport capacity is the infrastructure.

Airport assets can be classified as airside or landside (Gillen and Lall, 1997; and Pels et al., 2001). The literature does not converge in defining capital measures, leading to their exclusion in some benchmarking analyses (Parker, 1999). The difficulties in obtaining the acquisition costs of airport assets is overcome by using capital proxy measures such as rent expenses (Parker, 1999); depreciation of fixed assets (Murillo et al. 1999; Martin et al. 2001, 2009 and 2011); capital expenses (Martin-Cejas 2002); or net book value (Pestana et al. 2004; Coto-Millan et al. 2014 and 2016). Physical measures have been also used such as the length of runways (Martin et al. 2011), airport surface area, and number of gates (Tovar et al. 2009 and 2010). Also, more specific assets that can be classified into those that are linked to aircraft movements (boarding gates; apron capacity and runways areas) and those linked to loading processes such as checking counters and baggage belts (Lozano et al. 2013). In this paper, we capture airport infrastructure utilisation by means of its depreciation. The importance of considering depreciation as an input is based on the reflection that the use of the infrastructure defines the potential capacity of an airport in its main operational activity. We note that depreciation is a fixed cost since it is an expense incurred even if an airport does not have any traffic. Airports not earning enough revenue to cover their depreciation annual charge will be inefficient in the sense that they become a burden on financial resources of the system. For this reason, when calculating efficiencies we use an output oriented version of the DEA model.

AENA publishes aggregated depreciation figures for all the airports as a whole. The depreciation expenses provided by AENA show an extremely high correlation with operating costs (+0.9915) suggesting that published depreciation and operating costs may contain similar information. In meetings with airport managers it was found that the accounting policies applied by AENA do not match standard accounting estimation procedures. Consequently, there is a question on the validity of the data published by AENA. This suggests that AENA's financial statements may not be a faithful representation of reality in Spanish airports. For this reason, an alternative measure of depreciation was adopted in this study.

In this study, the value of airport assets and their depreciation are calculated according to international financial reporting standards (IFRSs). The historical cost of the assets −understood as the initial infrastructure− was estimated using the construction certification disclosures published by AENA from 2000 to 2012. The standard depreciation coefficients used in the air transport sector were used to estimate the depreciation of each asset. The useful life of the assets was estimated following the current regulation in the transportation sector for buildings and structures (1993 to 2005 and from 2006 to date). According to international financial reporting standards (IFRSs) for property, plant and equipment (PPE, IAS16), any improvement made from 2001 will increase the historical cost of the specific asset, and such asset will depreciate accordingly from the moment when it is ready to be used. Table 4 gives summary statistics for the inputs and outputs used in the model.

Variable	Observations	Mean	Standard Dev.	Minimum	Maximum
Commercial Revenues (€)	49	12,865.36	30,805.75	9.01	161,391.76
Passengers	49	3,824,594.47	8,189,925.23	273	39,735,618
Air Traffic Movements	49	36,549.96	64,745.84	476	333,056.00
Cargo (t)	49	13,039,859.43	51,900,442.76	0	346,602,597.00
Labour Costs (€)	49	6,113.92	9,176.74	108.12	48,934.72
Operating Costs (€)	49	19,035.00	49,592.68	333.38	299,582.10
Depreciation AENA (€)	49	15,025.25	37,457.04	342.39	226,544.94
Depreciation Airside (€)	48	4,052.17	9,923.97	26.53	66,174.99
Depreciation Landside (€)	48	1,168.52	2,283.18	0	11,863.57

Table 4: Summary Statistics (Source: AENA, 2013 except for depreciation airside and landside)

5. Analysis and results

The methodology implemented requires estimating efficiencies for each airport using an output-oriented variable returns to scale (VRS) model. The decision to use the VRS formulation was taken after extensive talks with airport managers. Previous research by Adler (2013) also supports this decision, since it was established that small airports tend to work under increasing returns to scale. Efficiencies were estimated for 124 DEA specifications, a specification being a particular combination of inputs and outputs. Inputs were identified by means of capital letters, and outputs by means of numbers, following the notation introduced in Table 3. For example, the model AC24 contains as inputs Labour (A) and Depreciation (C) and as outputs Air Traffic Movements (2) and Commercial Revenues (4). Not all possible combinations of inputs and outputs were considered, as some did not make operating sense. Appendix 1 shows the efficiency scores achieved by each airport under each model specification.

The estimation procedure generates a table of 124 columns (specifications) by 49 rows (airports). Although some relevant characteristics can be discovered through visual inspection of Appendix 1, it is better to use the tools of multivariate analysis in order to reveal the important features of the data and represent them in a graphical form. Following the procedure suggested by Serrano-Cinca and Mar-Molinero (2004; 2005), the specifications have been treated as variables and airports have been treated as observations. The factors were orthogonal and un-rotated. Other forms of the Factor Analysis procedure were entertained, but there was no improvement with respect to the results presented here.

The first step in the procedure consists on reducing the dimensionality of the data. With this aim in mind, we performed and unrotated principal component analysis on the data in Appendix 1. The results are shown in Table 5. Eight principal components were found to be associated with an eigenvalue greater than one, using the standard Kaiser criterion, and nine under the more restrictive Jolliffe criterion (Jolliffe, 1972)

We notice that the first two factors account for just over 71% of the variability of the data, whilst the addition of the third factor increases this figure to 81%. It is clear that it is important to attach meaning to the first and the second factor in the analysis.

Component	Eigenvalue	% of Variance	Cumulative %
PC1	72.244	58.261	58.261
PC2	16.525	13.327	71.588
PC3	11.043	8.905	80.493
PC4	9.421	7.598	88.091
PC5	5.889	4.749	92.841
PC6	3.563	2.874	95.714
PC7	1.495	1.206	96.920
PC8	1.405	1.133	98.053

Table 5: Factor Analysis. Variance explained by factors under Kaiser criterion.

We can see in Table 5 that Factor 1 explains 72% of the variability in the data, making it by far the most important factor. Factor 2 adds 16% to the explanation of the variability. Factor 3 contributes a further 11%, and Factor 4 contributes a further 9%. Put together, these four factors explain just over 88% of the variability in the data, a high percentage in most studies of this kind.

In order to attach meaning to the factors we need to consider factor score. These are reproduced in Table 6. In order to facilitate interpretation, factor scores that have a value lower than 0.4 are not shown. We see that, with a small number of exceptions, correlations between the first factor and the various specifications are positive and high. When this is the case, Factor 1 is interpreted as an overall measure of activity. Since we are modelling efficiency in airports, Factor 1 is to be interpreted as an overall measure of efficiency under a variety of ways of defining what an efficient airport is. But it is measure of efficiency that ignores punctuality (output 5) while including all the measures of output that generate income for AENA. This suggests that Factor 1 is to be understood as an overall measure of efficiency in generating income. The ordering of airports in terms of the score in Factor 1 provides a raking of airports in terms of efficiency in generating income. We can see in Figure 2 that the main destinations, such as Madrid, Barcelona and Palma rank high in terms of Factor 1, and small airports with low traffic are situated on the negative side of Factor 1. That small airports are loss-making was also observed by the European Court of Auditors (2014).

Efficiency in dealing with Punctuality appears to be well captured by Factor 2. All the specifications that include Punctuality are associated with positive loadings in Factor 2, whilst all the specifications that exclude Punctuality are associated with negative loadings in this factor. Punctuality (output 5) along with cargo (output 3) also achieves higher and positive loadings in Factor 2. The specifications that load into Factor 3 include outputs 1 (Passengers) and 5 (Punctuality). It appears that Factor 3 is associated with efficiency in dealing with passengers. The specifications that load high on Factor 4 include output 3 (Cargo), suggesting that efficiency in handling cargo is captured by Factor 4 (for example: Zaragoza is a clearly cargo oriented airport). There are no high factor loadings for Factors 5, 6, 7, and 8 and no interpretation is put forward here for their meaning.

Airline punctuality is essential, but it is not always easy to achieve. Airport punctuality depends on the air traffic control restrictions imposed to the airlines operating in a specific moment of time. There are different air traffic control restrictions that airlines must follow: there are airports with low-level of coordination; partially coordinated, and fully coordinated airports (slots). It is assumed that airports of the first type satisfy current and potential airline demand; they are usually small airports with surplus capacity due to low traffic. The second group contains some airports that operate under restrictions during the summer, and of airports that operate under schedules during the whole year. These are usually medium size airports with significant seasonal effects (peaks of demand) that have difficulties in satisfying current and potential demand during specific periods (for example, Ibiza in the Balearic Islands during the summer). Their capacity is usually close to their actual demand. Other airports located in the neighbourhood may be used during congestion periods. Finally, "slots" are large airports with high demand and with a significant lower capacity compared to their current and forecast demands. These are busy airports highly restricted in terms of landing and taking off. In general, airports with less traffic will have less air traffic control restrictions compared to busy airports, usually large airports. On this basis, airports with low level of traffic tend to be more punctual compared to large and medium airports. Figure 1 shows the location of airports together with their classification in terms of air traffic control.

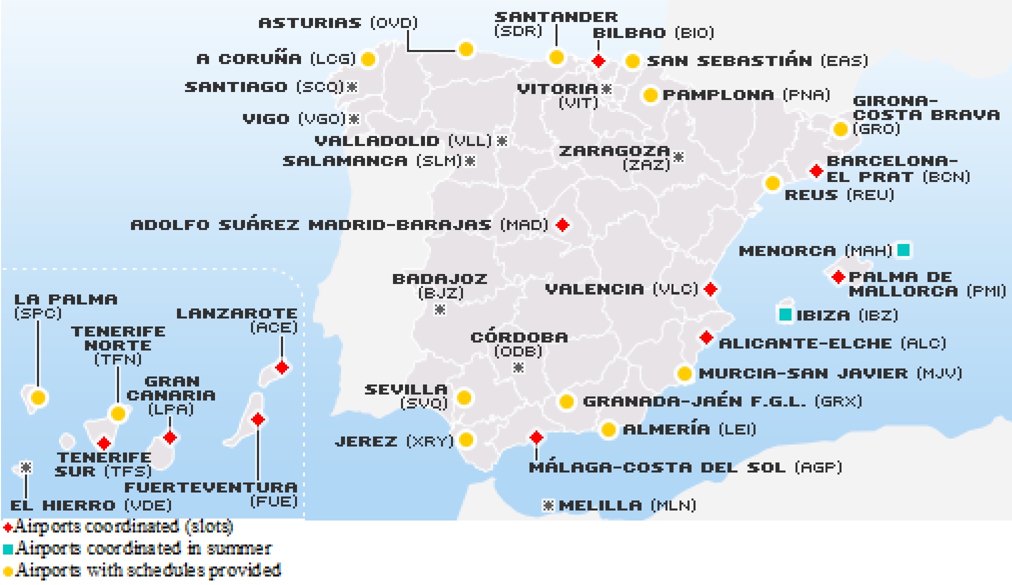

Figure 1: Air traffic control restrictions (Source AECFA, 2010)

Component Matrix[a]				
	PC1	PC2	PC3	PC4
ABC12345	.875			
A12345	.856			
AB12345	.874			
AC12345	.865			
A1234	.836			
AB1234	.798	-.441		
ABC1234	.789	-.410		
AC1234	.833			
A1235	.847			
AB1235	.856			
ABC1235	.856			
AC1235	.853			
A1245	.844			
AB1245	.841			-.419
ABC1245	.841			-.421
AC1245	.850			
A1345	.821			
AB1345	.779		.575	
ABC1345	.796		.551	
AC1345	.849			
A2345	.822			
AB2345	.875			
ABC2345	.887			
AC2345	.865			
A123	.828			
AB123	.787	-.421		
ABC123	.777			
AC123	.823			
A124	.822		-.413	
AB124	.758	-.522		
ABC124	.756	-.527		
AC124	.826			
A125	.831			
AB125	.813			-.441
ABC125	.812			-.442
AC125	.835			
A134	.820			
AB134	.724	-.478		
ABC134	.720	-.449		
AC134	.821			
A135	.747			
AB135	.706		.661	
ABC135	.727		.640	
AC135	.813			

Table 6: Factor loadings. Figures lower than 0.4 in absolute value have been removed. Factors 5; 6; 7 and 8 are not shown since factor loadings are lower than 0.4 or just marginally higher.

(continued)

Component Matrix[a]

	PC1	PC2	PC3	PC4
A145	.830			
AB145	.758		.541	
ABC145	.774		.514	
AC145	.848			
A234	.825		-.407	
AB234	.855			
ABC234	.851			
AC234	.852			
A235	.725	.520		
AB235	.710	.560		
ABC235	.715	.556		
AC235	.752	.525		
A245	.822			
AB245	.854			
ABC245	.864			
AC245	.858			
A345	.775			
AB345	.802		.419	
ABC345	.847			
AC345	.855			
A12	.811		-.421	
AB12	.737	-.509		
ABC12	.736	-.511		
AC12	.814			
A13	.747			
AB13	.665	-.474	.479	
ABC13	.671	-.424	.459	
AC13	.786			.409
A14	.827			
AB14	.697	-.565		
ABC14	.702	-.570		
AC14	.830			
A15	.751			
AB15	.681		.621	
ABC15	.696		.606	
AC15	.809			
A23	.752		-.503	
AB23	.753			
ABC23	.745			
AC23	.774		-.456	
A24	.823		-.462	
AB24	.827			
ABC24	.831			
AC24	.853			

(continued)

Component Matrix[a]				
	PC1	**PC2**	**PC3**	**PC4**
A25	.731	.425	-.406	
AB25	.697	.481		
ABC25	.701	.478		
AC25	.753	.438		
A34	.807			.456
AB34	.807			
ABC34	.817			
AC34	.847			
A35		.775		.401
AB35		.818		
ABC35		.805		
AC35		.791		
A45	.801			
AB45	.861			
ABC45	.835			
AC45	.861			
A1	.750	-.410		
AB1	.634	-.568	.437	
ABC1	.645	-.553	.425	
AC1	.793			
A2	.760		-.572	
AB2	.738		-.439	
ABC2	.742		-.436	
AC2	.789		-.534	
A3		.402		.697
AB3		.429		.589
ABC3		.422		.628
AC3	.443			.689
A4	.838			
AB4	.792			
ABC4	.812	-.421		
AC4	.865			
A5		.829		
AB5		.799		
ABC5		.786		
AC5		.817		

Figure 2 plots the airports in the space of Factor 1 and Factor 2, while Figure 3 plots the airports in the space of Factor 3 and Factor 4.

We need to remember that each airport is a point in a space with 124 dimensions− the number of specifications contemplated− although we have reduced the dimensionality of such a space to eight dimensions− the number of factors associated with a Kaiser value higher than unity− and we have only interpreted four factors. Only projections of the 124 dimensional spaces on two dimensions have been shown in Figure 2 and Figure 3. It is perfectly possible for two airports to appear located next to each other in Figure 2 and Figure 3 while being very far away in the space. For this reason, we have conducted a Cluster analysis of the table of airports by specifications. In order to conduct the cluster analysis we have not standardised the data, since efficiencies are naturally standardised between zero and one hundred. We have used the method proposed by Ward. This method is akin to the analysis of variance in that it attempts to simultaneously maximise homogeneity within clusters and heterogeneity between clusters. The dendogram for Ward's method is shown in Figure 4.

The number of clusters identified in Figure 4 is a decision to be taken by the analyst. Seven clusters have been identified in this case, and they are represented in Figures 2 and 3. There is a clear cluster of small and some medium airports from Granada to Melilla. This cluster is located on the left hand side of Figure 2, indicating that all the airports belonging to this cluster share the characteristic of being inefficient at generating income. Two clusters contain the airports with highest level of traffic, although these clusters differ in that one of them groups airports in touristic seaside areas, while the other one is dominated by Madrid, in the centre of the country. Both clusters are located on the right hand side of Figure 2, indicating high overall financial efficiency levels. Another cluster contains cargo oriented airports, such as Vitoria and Zaragoza (as previously discussed). Airports belonging to this cargo oriented cluster are located towards the top of Figure 2, indicating punctuality. Zaragoza and Vitoria can also be found towards the top of Figure 3, indicating efficiency in dealing with cargo. The cluster− formed by Madrid Cuatro Vientos, Sabadell, and Jerez− is mediocre from the point of view of overall efficiency, and from the point of view of punctuality, but becomes efficient when considering efficiency in dealing with passengers as its main objective. Madrid Cuatro Vientos and Sabadell are general aviation airports, whereas Jerez is a medium sized airport with air traffic control schedules for the whole year. No particular features can be discerned when examining the remaining clusters.

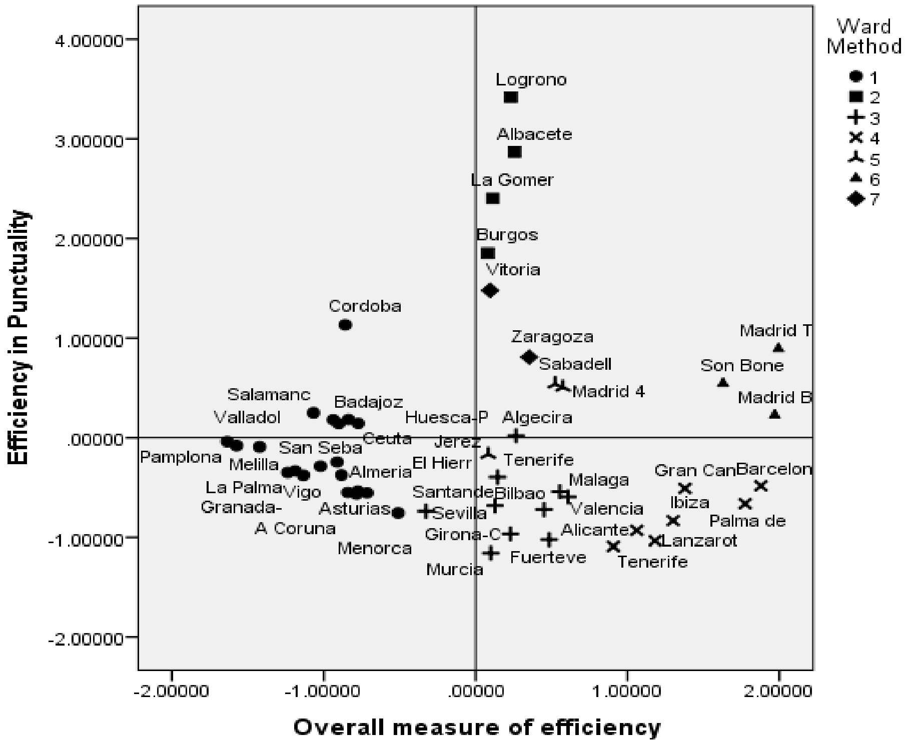

Figure 2: Plot of the airports in the space of the first and the second factors

Most large airports are located towards the South East of Figure 2, suggesting that although they are efficient from an overall point of view, they suffer from delay problems. Medium sized airports tend to be inefficient from an overall point of view, and many have few flights on time. The smallest airports tend to be inefficient from an overall point of view, but tend to have positive scores in the second factor indicating few delays. It appears that there is a trade-off between airport efficiency in generating income and punctuality. Large airports tend to make an efficient use of resources but they are inefficient when delays are included as an output. This is further confirmed by the observation that large touristic airports located in seaside areas, such as Barcelona, are located towards the lower part of the figure, indicating punctuality problems, while airports that are cargo oriented, such as Zaragoza and Vitoria, appear to be good from the punctuality point of view. In fact, Logroño is the airport with the highest proportion of flights arriving on time. This is clearly due to its low level of traffic that results in most aircraft landing or taking off on time. A similar comment can be made in the cases of airports with low traffic and very low or even no cargo, such as La Gomera, Albacete, and Burgos. The different clusters are clearly visualised: small airports (cluster 1); small airports with zero cargo and very low number of passengers (cluster 2); cargo oriented airports (cluster 7); medium airports in terms of passengers (cluster 3); large airports (cluster 4); general aviation airports (cluster 5); outliers (cluster 6).

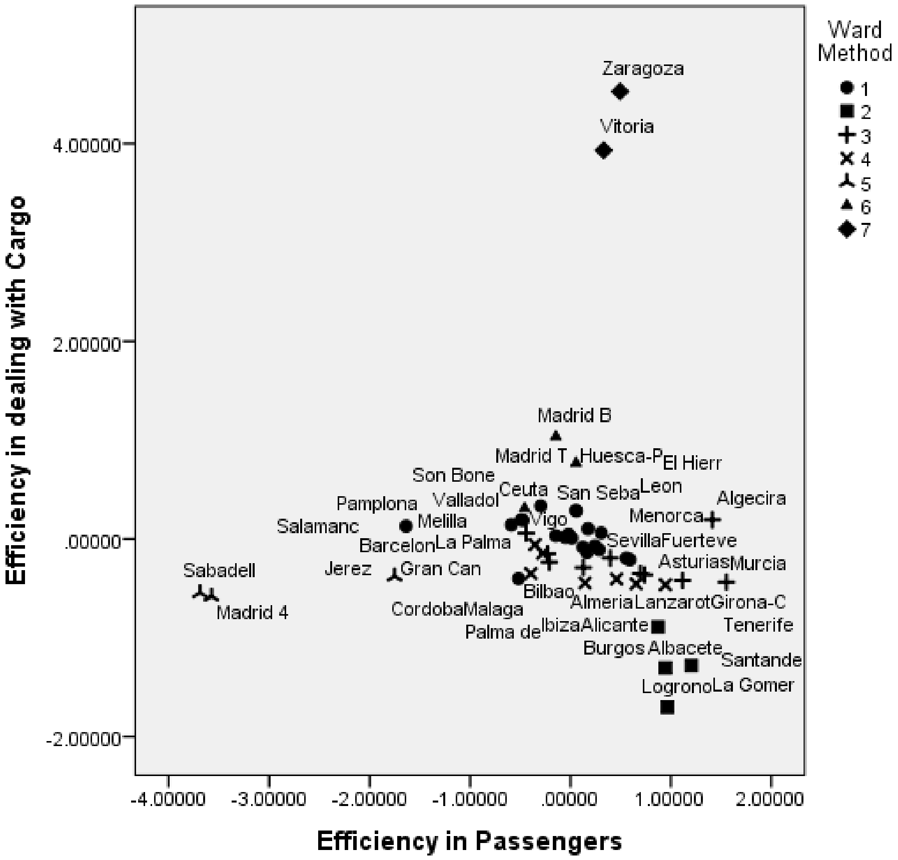

Figure 3: Plot of the airports in the space of the third and fourth factors

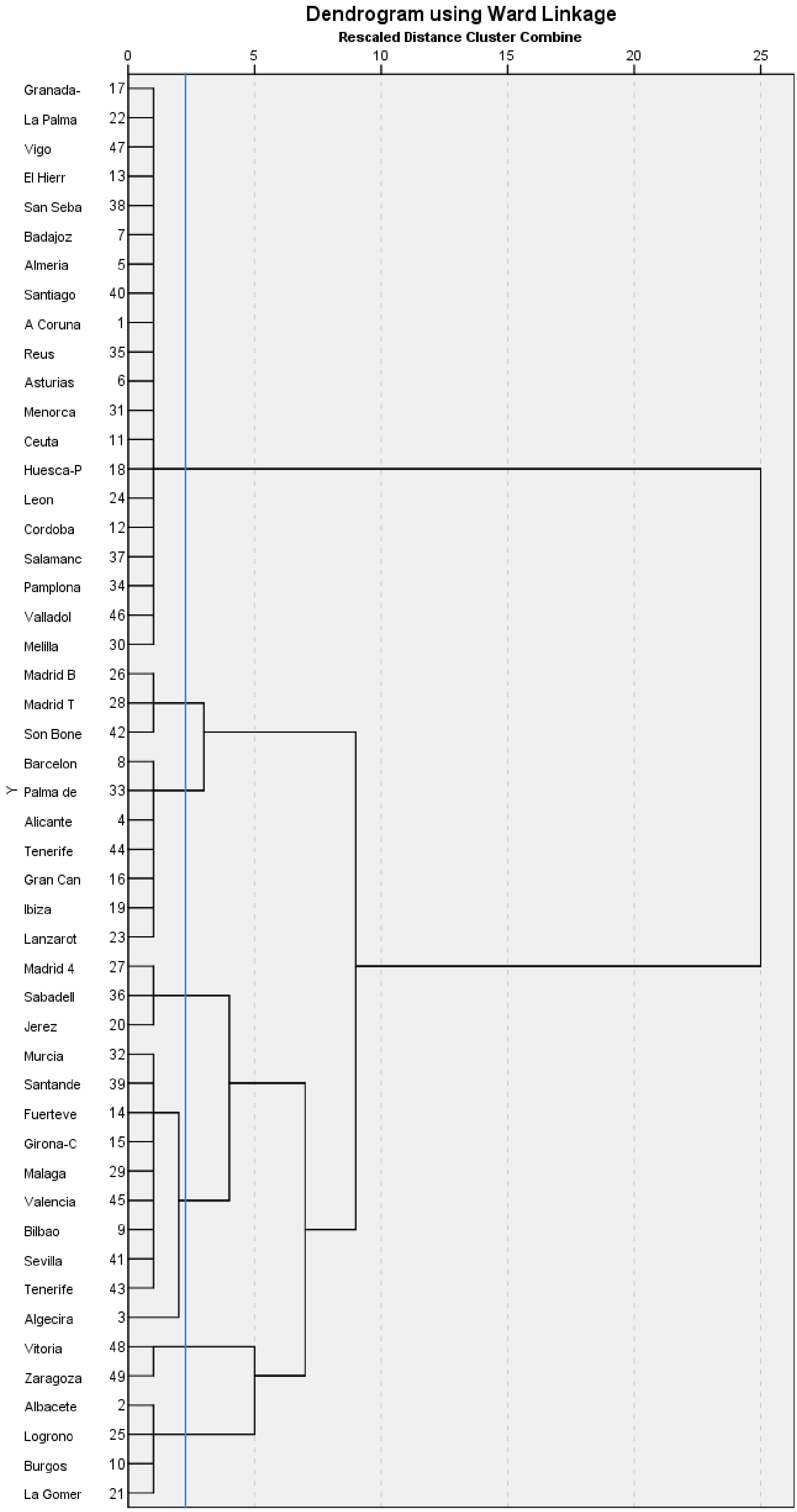

Figure 4: Dendogram of airport data using Ward's Agglomeration Method

It has been argued that the main strengths and weaknesses of an airport can be discerned by looking at Figures 2 and 3. Thus, Figures 2 and 3 summarise in a visual manner the results of a multivariate analysis. By representing the main features of the data in a graphical form we make the results of the analysis accessible to managers and decision makers, who are intelligent people but not necessarily well versed in multivariate statistics. Visualisation can be important when, for example, taking decisions about the future of an airport.

The use of multivariate analysis can be taken one step further. We can represent efficiencies under the various specifications in the same figure as airports. To do this we resort to Biplots (Gower and Hand, 1996), in particular to a technique known as Property Fitting (ProFit). A clear introduction to ProFit can be found in the book by Schiffman et al (1981). The mathematical method used to represent variables and specifications in the same space is described in Mar-Molinero and Mingers (2007).

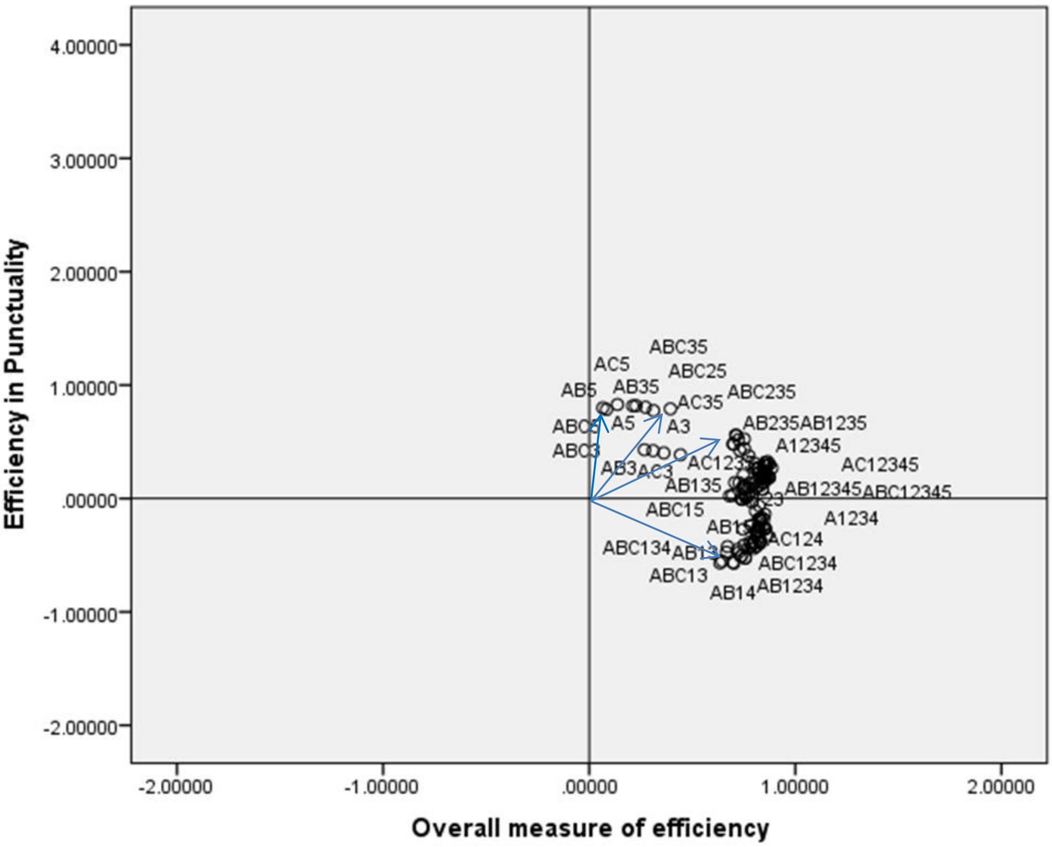

Figure 5: Property fitting vectors on the space of Factor 1 and Factor 2

Under the ProFit approach, each specification is represented by a vector starting at the origin of coordinates and pointing in the direction in which a particular feature of the data increases. The vectors are drawn in the space of the data; in this case an eight-dimensional space. Figure 5 shows only the projection of the end point of the vectors in the space of Factor 1 and Factor 2. Airport names have not been added to the figure in order not to clutter the representation, but interpretation only requires superimposing Figure 2 on Figure 5. Only a few vectors are represented in Figure 5. We can see, for example, that the vector associated with specification ABC3 points towards the top of the figure. This indicates that airports that use labour (A), operating costs (B) and depreciation (C) in an efficient way in order to deal with cargo (3) are located at the top of Figure 2. Figure 2 tells us that the most efficient airports from this point of view are Logroño, Albacete, La Gomera, Burgos, and Vitoria. It also tells us that the most inefficient airport under specification ABC3 is Murcia. This is reasonable since Logroño, Albacete, La Gomera, Burgos, and Vitoria have a low level of traffic. These airports have very low restrictions in terms of air traffic control and are unlikely to suffer from delays. On the other hand, Murcia is an airport with schedules provided during the whole year. Additionally, Vitoria and Zaragoza are air cargo-oriented airports, and this is reflected in Figure 3. Large airports may be more efficient in generating income, but it is difficult for them to achieve higher punctuality levels. The vector associated with the full model, ABC12345, points in the direction of the first principal component, confirming our interpretation of Factor 1 as an overall measure of efficiency.

Using the results in this way, it is possible to establish the strengths and weaknesses of each airport, as we have done with, for example, Logroño and Murcia, but discussing each individual airport in detail goes beyond the scope of this paper.

6. Discussion and Conclusions

Airports require large investment in infrastructure, and are expensive to run. For this reason, it is important to assess if the resources are used in the most efficient manner for the generation of revenue, the benefit of the local industry, and the satisfaction of users of the air services. But airports can be seen in many different lights, as satisfying tourist demand, or as support to main logistic centres. This is why the efficiency that we attach to an airport depends on how we see its role. In this paper we have estimated efficiencies under 124 different ways of contemplating the work of an airport, and we have used the term specification in order to refer to each combination of inputs and outputs. Since we had 49 airports in the data, the end result was a table with 49 rows and 124 columns. A data set like this one is difficult to comprehend, although some features may be evident by looking at the numbers. For example, no sophisticated analysis is required to discover that large airports, such as Madrid and Barcelona, are efficient from a global point of view, and that small and medium airports such as Burgos or Murcia are inefficient. This is clear in the results of the analysis, and it is also well known in the world of air transport. In fact, there has been much debate on whether all airports should be kept open or whether some of them should be closed and the system rationalised. This debate is highly political, as local communities would like to have the best infrastructures that are possible, and politicians are not always concerned about the opportunity cost of resources used. Take, for example, San Sebastian airport. This airport is not particularly efficient from the overall point of view, nor from the punctuality perspective, it does not appear to use resources efficiently for cargo purposes, and is not particularly efficient from the passenger perspective. Furthermore, it is not far from Bilbao, Santander, or Biarritz (within two hours driving distance). So, San Sebastian would be a clear target for rationalisation. In the same way, there are three airports within 150 kilometres from Valladolid (Burgos; Leon and Salamanca). The traffic from Valladolid (airport highly inefficient) could be transferred to Burgos. This might improve overall efficiency and punctuality with a minimum impact in connectivity. The efficiency of dealing with cargo would also improve since Burgos did not deal with any cargo in 2013. In the same way, Pamplona airport could be rationalised by transferring its traffic to either Logroño o Vitoria. Vitoria is efficient in dealing with cargo, and could become more efficient in terms of passengers after absorbing Pamplona's traffic.

These previous examples suggest that there is an excessive number of inefficient regional airports with less than 750,000 passengers per year located within a short distance of each other. The question is if the traffic of these airports could be transferred to larger airports to increase efficiency while, at the same time minimising the impact on connectivity.

Clearly, decisions about the future of an airport go beyond data discussion, there may other reasons to keep it open, but these must be stated clearly in the discussion. The European Commission (European Court of Auditors, December 2014) has identified an excess of investment in public infrastructures in Europe. This is at times due to some funded airports being located too close to each other. Infrastructures are sometimes built on the basis of forecasts that cannot be justified. This has resulted in some construction projects being excessive for the numbers of passengers and aircraft involved. Cordoba is one of the clear examples. It was forecasted to have 179,000 passengers per year, but got only 7,000 in 2013. Other examples are Badajoz; Burgos; La Palma and Vigo which will also struggle to remain open unless it receives additional and constant public funding. The recommendations of the European Court of Auditors are clearly based on actual needs and on forecasts for 2030. It recommends that investment should only take place in profitable airports or in airports with demonstrable requirements. It further recommends that during 2014-2020, the European Commission should grant European Union funding money to airports infrastructure only when the investment needed has been properly assessed and demonstrated. It estimated that airports with less than 100,000 passengers lose 130 € per passenger and year. These airports are not financially self-sustainable and will struggle to remain in operation without more public money. It raises the question of why the Spanish government is determined to maintain open all the airports even when they operate inefficiently due to low level of traffic. Additionally, the report also suggests that there is little evidence of additional socio-economic benefits, such as regional employment, from keeping the airports open.

This study confirms the view that many Spanish airports are not efficient in generating income due to the low-level of traffic and idle infrastructure. Airports' over-capacity implies excessive fixed costs not justified by actual operating activity. All the smallest and medium airports (except Girona) are cross-subsidised by the large airports that not only are profitable, but that use better their infrastructure. The question is how to make the system more efficient. A possibility would be to increase the number of passengers by increasing the number of airlines that operate in each airport. This could be achieved, for example, by means of appropriate price structures, but this cannot be done under the existing centralised decision process, which does not enhance flexibility or competition. It has been suggested (CNMC, 2014) that Spanish airports need to become more attractive in terms of fair prices and quality of the services provided and that airports managers should be awarded flexibility in deciding decide commercial policies. But this implies decentralisation, and it is unlikely to take place. The inexistence of an independent regulator does not help either. Unless individual airport managers are granted decision power among commercial variables, Spanish airports will be suffering from low traffic and over-capacity. In a word, the Spanish airport-system will continue to be largely inefficient.

References

Banker, R.D.; Charnes, A. & Cooper, W.W. (1984): 'Some models for estimating technical and scale efficiency in data envelopment analysis'. *Management Science* 30, 1078-1092

Charnes, A.; Cooper, W. W.; Rhodes, E. (1978): 'Measuring the efficiency of decision making units'. *European Journal of Operational Research* 2, 429-444

Charnes, A.; Cooper, W. W.; Golany, B.; Seiford, L. M. & Stutz, J. (1985): 'Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions'. *Journal of Econometrics* 30, 91-107

Charnes, A.; Cooper, W.W.; Lewin, A.Y. & Seiford, L.M. (1993): *'Data Envelopment Analysis: Theory, Methodology and Applications'.* Kluwer Academic Publishers, Norwell, MA.

Coelli, T.J.; Rao, D.S.P.; O'Donnell, C.J. & Battese, G.E. (2005): *'An Introduction to Efficiency and Productivity Analysis'.* Springer, New York

Cooper, W. W.; Kyung, S.P. & Pastor, J. T. (1999): 'RAM: a range adjusted measure of inefficiency for use with additive models, and relations to other models and measures in DEA'. *Journal of Productivity Analysis* 11, 5-42

Cooper, W. W.; Seiford, L.M. & Tone, K. (2000): *'Data Envelopment Analysis'.* Kluwer Academic Publishers, The Netherlands.

Cooper, W. W.; Seiford, L. M. & Thrall, R. M. & Zhu, J. (2001): 'Sensitivity and stability analysis in DEA: some recent developments'. *Journal of Productivity Analysis* 15, 217-246

Coto-Millan, P.; Carrera-Gómez, G.; Castanedo-Galán, J.; Inglada, V.; Núñez-Sánchez, R.; Pesquera, M.A.; Sainz, R. (2007): 'Efficiency Stochastic Frontiers: a Panel Data Analysis for Spanish Airports (1992–1994)' *Essays on Transport Economics* (chapter 121-126), Physica-Verlag HD

Coto-Millan, P.; Casares-Hontañón, P.; Inglada, V.; Agüeros, M.; Pesquera, M.A.; Badiola, A. (2014): 'Small is beautiful? The impact of economic crisis, low cost carriers, and size on efficiency in Spanish airports (2009–2011)' *Journal of Air Transport Management* 40, 34-41

Coto-Millan, P.; Inglada, V.; Fernandez, X.L.; Inglada-Perez, L. & Pesquera, M.A. (2016): 'The effect procargo on technical and scale efficiency at airports: The case of Spanish airports (2009–2011)' *Utilities Policy* 39, 29-35

Debreu, G. (1951): 'The coefficient of resource utilization'. *Econometrica* 19, 273-292

Fare, R. & Grosskopf, S. (2000): 'Theory and application of directional distance functions'. *Journal of Productivity Analysis* 13(2), 93-103

Farrell, M. J. (1957): 'The measurement of productive efficiency'. *Journal of the Royal Statistical Society-A* 120, 253-290

Fernandes, E. and Pacheco, R. R. (2002): 'Efficient use of airport capacity' *Transportation Research Part A* 36 (3), 225-38

Fung, M.K.Y.; Wan, K.K. H.; Hui, Y.V. and Law, J.S. (2008): 'Productivity Changes in Chinese Airports 1995-2004' *Transportation Research Part E* 44 (3), 521-542

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

Gower, J. C., & Hand, D. J. (1996): *'Biplots'*. Chapman & Hall, London

Gutiérrez-Nieto, B.; Serrano-Cinca, C. & Mar-Molinero, C. (2007): 'Microfinance institutions and efficiency'. *Omega, The International Journal of Management Science* 35, 131-142

Jolliffe, I. T. (1972): 'Discarding Variables in a Principal Component Analysis I: Artificial

Data' *Applied Statistics* 21, 160-173

Koopmans, T.C. (1951): *'Activity analysis of production and allocation'*. Willey, New York

Lozano S. & Gutierrez, E. (2011): **'**Slacks-based measure of efficiency of airports with airplanes delays as undesirable outputs'**.** *Journal Computers and Operations Research* 38(1), 131-139

Lozano S.; Gutierrez, E. & Moreno, P. (2013): 'Network DEA approach to airports performance assessment considering undesirable outputs'**.** *Applied Mathematical Modelling* 37, 1665-1676

Mar-Molinero, C. & J. Mingers (2007): 'Mapping MBA Programmes: An Alternative Analysis'. *Journal of the Operational Research Society* 58 (1), 874–886.

Martin J.C. & Roman, C. (2001): 'An application of DEA to measure the efficiency of Spanish airports prior to privatization'. *Journal of Air Transport Management* 7(3), 149-157

Martin, J. C. & Roman, C. (2006): 'A benchmarking analysis of Spanish commercial airports. A comparison between SMOP and DEA ranking methods' *Networks and Spatial Economics* 6(2), 111-134

Martin J.C.; Roman, C. & Voltes-Dorta, A. (2009): 'A stochastic frontier analysis to estimate the relative efficiency of the Spanish airports'. *Journal of Productivity Analysis* 31(3), 163-176

Martin J.C.; Roman, C. & Voltes-Dorta, A. (2011): 'Scale economies and marginal costs in Spanish airports'. *Transportation Research Part E* 47, 238-248

Martin-Cejas, R.R. (2002): 'An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier'. *Journal of Air Transport Management* 8 (4), 233–238

Murillo-Melchor, C. (1999): 'An Analysis of technical efficiency and productivity changes in Spanish Airports using the Malmquist Index'. *International Journal of Transport Economics 26(2), 271-292*

Norman, M. & Stoker, B. (1991): *'Data Envelopment Analysis, the assessment of performance'*. Wiley Chichester, United Kingdom

Nyshadham, E.A. & Rao, V.K. (2000): 'Assessing Efficiency of European Airports. A Total Factor Productivity Approach' *Public Works Management and Policy* 5(2), 106-114

Pastor, J.; Ruiz-Gomez, J.L. & Sirvent, I. (2002): 'A statistical test for nested radial DEA models'. *Operations Research* 50, 728-735

Parker, D. (1999): 'The performance of BAA before and after privatisation'. *Journal of Transport Economics and Policy* 33, *133-145*

Pedraja Chaparro, F.; Salinas Jimenez, J. & Smith, P. (1999): 'On the quality of the data envelopment analysis model'. *Journal of the Operational Research Society* 50, 636-645.

Pels, E.; Nijkamp, P. & Rietveld, P. (2001): 'Relative efficiency of European airports'. *Transport Policy* 8, 183-192

Pestana, B. C. & Sampaio, A. (2004): 'Technical and allocative efficency in airports' *International Journal of Transport Economics* 31, 355-377

Porter, M.E. (1979). 'How Competitive Forces Shape Strategy'. *Harvard Business Review*, March-April

Russell, R. R. (1985): 'Measures of technical efficiency'. *Journal of Economic Theory* 35, 109-126

Sagarra, M.; Mar-Molinero, C. & Garcia Cestona, M.A. (2013): 'Spanish savings banks in the credit crunch: could distress have been predicted before the crisis? A multivariate analysis' *European Journal of Finance* 21, 195-214

Sagarra, M.; Mar-Molinero, C. & Agasisti, T. (2016): 'Exploring the efficiency of Mexican universities: integrating Data Envelopment Analysis and Multidimensional Scaling'. *Omega* online (April)

Salazar de la Cruz, F. (1999): 'Technical, allocative and economic efficiency in transport'. *International Journal of Transport Economics 26(2), 255-270*

Schiffman, J.F.; Reynolds, M.L. & Young, F.W. (1981): *'Introduction to Multidimensional Scaling: Theory, Methods and Applications'*. Academic Press, London

Serrano-Cinca, C. & Mar-Molinero (2004): 'Selecting DEA specifications and ranking units via PCA'. *Journal of the Operational Research Society* 55, 521-528

Serrano-Cinca, C.; Mar-Molinero, C. & Chaparro F. (2004): 'Spanish saving banks: a view of intangibles'. *Knowledge Management Research and Practice* 2(2), 103-117

Serrano-Cinca, C.; Fuertes Callen, Y. & Mar-Molinero, C. (2005): 'Measuring DEA efficiency in internet companies'. *Decission Support Systems* 38(4), 557-573

Serrano-Cinca, C.; Mar-Molinero, C. & Fuertes Callen, Y. (2016): 'Input and output search in DEA: the case of financial institutions', 51-87 in Hwang, S.N.; Lee, H.S. & Zhu, J. (editors): *'Handbook of Operation Analytics using Data Envelopment Analysis'*. Springer, New York

Simar, L. & Wilson, P.W. (2000a): 'Statistical inference in non-parametric frontier models: the state of the art'. *Journal of Productivity Analysis* 13, 49-78

Simar, L. & Wilson, P.W. (2000b): 'A general methodology for bootstrapping in non-parametric frontier models'. *Journal of Applied Statistics* 27, 779-802

Simar, L. & Wilson, P.W. (1999): 'Of course we can bootstrap DEA scores! But does it mean anything? Logic trumps wishful thinking'. *Journal of Productivity Analysis* 11, 93-97

Simar, L. & Wilson, P.W. (2007): 'Estimation and inference in two stage, semi-parametric models of productive efficiency'. *Journal of Econometrics* 136, 31-64

Sirvent, I; Ruiz, J.L.; Borras, F. & Pastor, J. (2005): 'A Monte Carlo evaluation of several tests for the selection of variables in DEA models'. *International Journal of Information Technology and Decision Making* 4, 325-343

Tapiador, F.J.; Mateos, A. & Martí-Henneberg, J. (2008): 'The geographical efficiency of Spain's regional airports: a quantitative analysis'. *Journal of Air Transport Management* 14(4), 205-212

Tovar, B. & Martin-Cejas, R.R. (2009): 'Are outsourcing and non-aeronautical revenues important drivers in the efficiency of Spanish airports?' *Journal of Air Transport Management* 15(5), 217-220

Tovar, B. & Martin-Cejas, R.R. (2010): 'Technical efficiency and productivity changes in Spanish airports: A parametric distance functions approach'. *Transportation Research Part E* 46(5), 249-260

Reports

AECFA (2010): https://www.slotcoordination.es/csee/Satellite/Slots/en/Page/1237545152315/1237544440201/

European Commission: European Court of Auditors (2014): *'EU-funded airport infrastructures: poor value for money'* Special Report, 21 Publications Office of the European Union, Luxembourg. http://www.politico.eu/article/eu-wasted-money-on-new-airports-say-auditors/

Cambra de Comerç de Barcelona (November, 2010): '*El modelo de gestión aeroportuaria en Espana: marco institutional y juridico y lineas maestras para una propuesta de cambio'*

Comisión Nacional de los Mercados y la Competencia (CNMC, July 2014): *'El Sector Aeorportuario en España: Situación Actual y Recomendaciones de Liberización'*

ICAO: https://www.icao.int/

Airports	ABC12345	A12345	AB12345	AC12345	A1234	AB1234	ABC1234	AC1234	A1235	AB1235	ABC1235	AC1235	A1245	AB1245	ABC1245	AC1245	A1345
A Coruña	60%	32%	60%	32%	32%	60%	60%	32%	32%	60%	60%	32%	32%	60%	60%	32%	27%
Albacete	100%	87%	100%	87%	26%	28%	28%	26%	87%	100%	100%	87%	87%	100%	100%	87%	87%
Algeciras	100%	24%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%
Alicante	100%	76%	100%	82%	76%	100%	100%	82%	71%	86%	86%	71%	76%	100%	100%	82%	76%
Almeria	52%	31%	52%	35%	31%	50%	50%	33%	31%	51%	51%	32%	31%	52%	52%	35%	27%
Asturias	63%	31%	63%	31%	29%	60%	60%	30%	30%	63%	63%	30%	31%	63%	63%	31%	29%
Badajoz	44%	34%	44%	34%	34%	44%	44%	34%	34%	44%	44%	34%	34%	44%	44%	34%	31%
Barcelona	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Bilbao	84%	69%	82%	73%	69%	81%	83%	73%	68%	75%	75%	68%	69%	81%	84%	73%	63%
Burgos	100%	62%	100%	62%	30%	46%	46%	30%	62%	100%	100%	62%	62%	100%	100%	62%	56%
Ceuta	50%	21%	50%	21%	21%	50%	50%	21%	21%	50%	50%	21%	21%	50%	50%	21%	19%
Cordoba	59%	46%	59%	46%	28%	30%	30%	28%	46%	59%	59%	46%	46%	59%	59%	46%	34%
El Hierro	58%	25%	55%	42%	25%	55%	58%	42%	25%	55%	58%	42%	25%	55%	57%	39%	20%
Fuerteventura	86%	71%	86%	72%	71%	86%	86%	72%	70%	85%	85%	70%	71%	86%	86%	72%	70%
Girona-Costa Brava	84%	64%	84%	64%	64%	84%	84%	64%	64%	84%	84%	64%	64%	84%	84%	64%	60%
Gran Canaria	100%	69%	100%	100%	69%	100%	100%	100%	69%	100%	100%	100%	69%	100%	100%	100%	66%
Granada-Jaen	45%	26%	45%	26%	26%	45%	45%	26%	26%	45%	45%	26%	26%	45%	45%	26%	21%
Huesca-Pirineos	53%	26%	53%	26%	26%	53%	53%	26%	23%	53%	53%	23%	26%	53%	53%	26%	23%
Ibiza	100%	77%	100%	100%	77%	100%	100%	100%	77%	100%	100%	100%	77%	100%	100%	100%	72%
Jerez	89%	59%	89%	61%	59%	89%	89%	61%	59%	87%	87%	61%	59%	89%	89%	61%	30%
La Gomera	100%	49%	100%	100%	18%	40%	40%	18%	48%	100%	100%	100%	49%	100%	100%	100%	47%
La Palma	43%	29%	43%	29%	29%	43%	43%	29%	29%	43%	43%	29%	29%	43%	43%	29%	24%
Lanzarote	100%	76%	98%	100%	76%	98%	100%	100%	76%	98%	100%	100%	76%	98%	100%	100%	75%
Leon	58%	20%	58%	20%	18%	51%	51%	18%	20%	58%	58%	20%	20%	58%	58%	20%	17%
Logroño	100%	100%	100%	100%	20%	20%	20%	20%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Appendix 1: Efficiency scores based on 124 DEA specifications

(continued)

Airports	ABC12345	A12345	AB12345	AC12345	A1234	AB1234	ABC1234	AC1234	A1235	AB1235	ABC1235	AC1235	A1245	AB1245	ABC1245	AC1245	A1345
Madrid Barajas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Madrid 4 vientos	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	29%
Madrid Torrejon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Malaga	84%	68%	82%	74%	68%	81%	83%	74%	66%	66%	66%	66%	68%	82%	84%	74%	68%
Melilla	33%	29%	33%	29%	29%	33%	33%	29%	29%	33%	33%	29%	29%	33%	33%	29%	21%
Menorca	69%	39%	69%	39%	39%	68%	68%	39%	39%	69%	69%	39%	39%	69%	69%	39%	37%
Murcia	100%	41%	100%	41%	41%	100%	100%	41%	40%	100%	100%	40%	41%	100%	100%	41%	40%
Palma de Mallorca	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pamplona	27%	17%	27%	17%	17%	27%	27%	17%	17%	26%	26%	17%	17%	27%	27%	17%	12%
Reus	61%	38%	61%	38%	38%	61%	61%	38%	38%	61%	61%	38%	38%	61%	61%	38%	31%
Sabadell	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	30%
Salamanca	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	19%
San Sebastian	49%	23%	47%	42%	23%	47%	49%	42%	23%	47%	48%	42%	23%	47%	49%	42%	18%
Santander	91%	40%	91%	40%	38%	86%	86%	38%	40%	91%	91%	40%	40%	91%	91%	40%	36%
Santiago	54%	35%	54%	35%	35%	54%	54%	35%	35%	54%	54%	35%	35%	54%	54%	35%	34%
Sevilla	82%	48%	80%	60%	48%	79%	80%	60%	48%	78%	78%	60%	48%	79%	81%	60%	44%
Son Bonet	100%	100%	100%	100%	100%	100%	100%	100%	86%	100%	100%	100%	100%	100%	100%	100%	59%
Tenerife North	78%	64%	78%	65%	64%	78%	78%	65%	64%	78%	78%	65%	61%	73%	73%	61%	56%
Tenerife South	100%	66%	100%	72%	66%	100%	100%	72%	64%	100%	100%	64%	66%	100%	100%	72%	66%
Valencia	92%	63%	92%	67%	63%	92%	92%	67%	63%	80%	80%	64%	63%	89%	89%	67%	56%
Valladolid	27%	21%	27%	21%	21%	27%	27%	21%	21%	27%	27%	21%	21%	27%	27%	21%	18%
Vigo	46%	26%	46%	27%	26%	46%	46%	27%	26%	46%	46%	26%	26%	46%	46%	27%	22%
Vitoria	100%	91%	100%	100%	74%	74%	100%	100%	91%	100%	100%	100%	25%	42%	42%	30%	91%
Zaragoza	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	19%	45%	45%	19%	100%

(continued)

Airports	AB1345	ABC1345	AC1345	A2345	AB2345	ABC2345	AC2345	A123	AB123	ABC123	AC123	A124	AB124	ABC124	AC124	A125	AB125
A Coruña	59%	59%	27%	25%	38%	38%	26%	32%	60%	60%	32%	32%	60%	60%	32%	32%	60%
Albacete	100%	100%	87%	87%	100%	100%	87%	25%	28%	28%	25%	26%	28%	28%	26%	87%	100%
Algeciras	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%
Alicante	100%	100%	82%	76%	100%	100%	81%	71%	85%	85%	71%	76%	100%	100%	82%	71%	86%
Almeria	51%	52%	35%	29%	43%	44%	35%	30%	49%	49%	30%	31%	50%	50%	33%	31%	51%
Asturias	63%	63%	30%	25%	47%	47%	28%	29%	60%	60%	29%	29%	60%	60%	30%	30%	63%
Badajoz	44%	44%	31%	31%	37%	37%	31%	34%	44%	44%	34%	34%	44%	44%	34%	34%	44%
Barcelona	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Bilbao	78%	82%	68%	62%	79%	84%	67%	68%	73%	73%	68%	69%	80%	83%	73%	68%	75%
Burgos	98%	98%	56%	60%	100%	100%	60%	30%	46%	46%	30%	30%	46%	46%	30%	62%	100%
Ceuta	50%	50%	19%	21%	49%	49%	21%	21%	50%	50%	21%	21%	50%	50%	21%	21%	50%
Cordoba	49%	49%	34%	46%	58%	58%	46%	28%	30%	30%	28%	28%	30%	30%	28%	46%	59%
El Hierro	54%	58%	42%	18%	30%	30%	18%	25%	55%	58%	42%	25%	55%	57%	39%	25%	55%
Fuerteventura	86%	86%	71%	58%	76%	80%	63%	70%	85%	85%	70%	71%	86%	86%	72%	70%	85%
Girona-Costa Brava	84%	84%	60%	49%	68%	68%	52%	64%	84%	84%	64%	64%	84%	84%	64%	64%	84%
Gran Canaria	89%	100%	100%	65%	100%	100%	100%	69%	100%	100%	100%	69%	100%	100%	100%	69%	97%
Granada-Jaen	44%	44%	21%	19%	25%	25%	20%	26%	45%	45%	26%	26%	45%	45%	26%	26%	45%
Huesca-Pirineos	53%	53%	23%	26%	53%	53%	26%	23%	53%	53%	23%	26%	53%	53%	26%	23%	53%
Ibiza	100%	100%	95%	57%	92%	98%	98%	77%	100%	100%	100%	77%	100%	100%	100%	77%	100%
Jerez	47%	49%	34%	59%	89%	89%	61%	59%	87%	87%	61%	59%	89%	89%	61%	59%	87%
La Gomera	100%	100%	100%	49%	100%	100%	100%	17%	40%	40%	17%	18%	40%	40%	18%	48%	100%
La Palma	43%	43%	24%	22%	26%	26%	22%	29%	43%	43%	29%	29%	43%	43%	29%	29%	43%
Lanzarote	98%	100%	100%	56%	79%	100%	100%	76%	98%	100%	100%	76%	98%	100%	100%	76%	98%
Leon	57%	57%	17%	19%	51%	51%	19%	17%	51%	51%	17%	18%	51%	51%	18%	20%	58%
Logroño	100%	100%	100%	100%	100%	100%	100%	19%	19%	19%	19%	20%	20%	20%	20%	100%	100%

(continued)

Airports	AB1345	ABC1345	AC1345	A2345	AB2345	ABC2345	AC2345	A123	AB123	ABC123	AC123	A124	AB124	ABC124	AC124	A125	AB125
Madrid Barajas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Madrid 4 vientos	39%	45%	45%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Madrid Torrejon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Malaga	81%	84%	74%	68%	82%	84%	72%	66%	66%	66%	66%	68%	81%	83%	74%	66%	66%
Melilla	32%	32%	21%	18%	19%	19%	18%	29%	33%	33%	29%	29%	33%	33%	29%	29%	33%
Menorca	69%	69%	37%	30%	54%	54%	31%	39%	68%	68%	39%	39%	68%	68%	39%	39%	69%
Murcia	100%	100%	41%	34%	75%	75%	36%	40%	100%	100%	40%	41%	100%	100%	41%	40%	100%
Palma de Mallorca	100%	100%	100%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pamplona	26%	26%	13%	16%	19%	19%	16%	17%	26%	26%	17%	17%	27%	27%	17%	17%	26%
Reus	60%	60%	31%	29%	43%	43%	30%	38%	61%	61%	38%	38%	61%	61%	38%	38%	61%
Sabadell	36%	38%	32%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Salamanca	20%	20%	19%	40%	40%	40%	40%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%
San Sebastian	46%	49%	42%	21%	28%	29%	27%	23%	47%	48%	42%	23%	47%	49%	42%	23%	47%
Santander	91%	91%	36%	27%	50%	50%	27%	38%	86%	86%	38%	38%	86%	86%	38%	40%	91%
Santiago	54%	54%	34%	30%	45%	45%	31%	35%	54%	54%	35%	35%	54%	54%	35%	35%	53%
Sevilla	76%	79%	60%	41%	73%	79%	60%	48%	75%	75%	59%	48%	78%	79%	59%	48%	77%
Son Bonet	100%	100%	100%	100%	100%	100%	100%	86%	100%	100%	100%	100%	100%	100%	100%	86%	100%
Tenerife North	69%	69%	56%	47%	72%	72%	49%	64%	78%	78%	65%	61%	73%	73%	61%	61%	73%
Tenerife South	100%	100%	72%	59%	100%	100%	71%	64%	100%	100%	64%	66%	100%	100%	72%	64%	100%
Valencia	80%	82%	61%	60%	92%	92%	64%	63%	80%	80%	64%	63%	89%	89%	67%	61%	76%
Valladolid	27%	27%	18%	16%	17%	17%	16%	21%	27%	27%	21%	21%	27%	27%	21%	21%	27%
Vigo	46%	46%	23%	22%	33%	33%	23%	26%	46%	46%	26%	26%	46%	46%	27%	26%	46%
Vitoria	100%	100%	100%	25%	100%	100%	100%	73%	73%	100%	100%	15%	19%	19%	16%	19%	32%
Zaragoza	100%	100%	100%	17%	100%	100%	100%	100%	100%	100%	100%	19%	45%	45%	19%	19%	45%

(continued)

Airports	ABC125	AC125	A134	AB134	ABC134	AC134	A135	AB135	ABC135	AC135	A145	AB145	ABC145	AC145	A234	AB234	ABC234	AC234	A235	AB235	ABC235
A Coruña	60%	32%	27%	59%	59%	27%	27%	59%	59%	27%	27%	59%	59%	27%	25%	38%	38%	26%	14%	16%	16%
Albacete	100%	87%	26%	28%	28%	26%	87%	100%	100%	87%	87%	100%	100%	87%	26%	28%	28%	26%	87%	100%	100%
Algeciras	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%
Alicante	86%	71%	76%	100%	100%	82%	71%	86%	86%	71%	76%	100%	100%	82%	76%	100%	100%	81%	44%	56%	56%
Almeria	51%	32%	27%	49%	50%	33%	27%	51%	51%	28%	27%	51%	52%	35%	28%	40%	41%	32%	13%	15%	15%
Asturias	63%	30%	28%	60%	60%	29%	29%	63%	63%	29%	29%	63%	63%	30%	24%	43%	43%	26%	10%	13%	13%
Badajoz	44%	34%	31%	44%	44%	31%	31%	44%	44%	31%	31%	44%	44%	31%	31%	37%	37%	31%	29%	37%	37%
Barcelona	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Bilbao	75%	68%	63%	77%	81%	68%	62%	72%	72%	62%	63%	78%	82%	68%	62%	78%	83%	67%	36%	40%	40%
Burgos	100%	62%	23%	44%	44%	23%	56%	98%	98%	56%	56%	98%	98%	56%	28%	41%	41%	28%	60%	100%	100%
Ceuta	50%	21%	19%	50%	50%	19%	19%	50%	50%	19%	19%	50%	50%	19%	21%	49%	49%	21%	21%	49%	49%
Cordoba	59%	46%	15%	20%	20%	15%	32%	48%	48%	32%	34%	49%	49%	34%	28%	30%	30%	28%	46%	58%	58%
El Hierro	57%	39%	20%	54%	58%	42%	20%	54%	58%	42%	20%	54%	57%	39%	18%	30%	30%	18%	17%	30%	30%
Fuerteventura	85%	70%	70%	86%	86%	71%	69%	85%	85%	69%	70%	86%	86%	71%	58%	76%	80%	63%	20%	20%	20%
Girona-Costa Brava	84%	64%	60%	84%	84%	60%	60%	84%	84%	60%	60%	84%	84%	60%	49%	68%	68%	52%	19%	21%	21%
Gran Canaria	97%	95%	66%	89%	100%	100%	66%	89%	100%	100%	65%	87%	100%	100%	65%	100%	100%	100%	65%	100%	100%
Granada-Jaen	45%	26%	21%	44%	44%	21%	21%	44%	44%	21%	21%	44%	44%	21%	19%	25%	25%	20%	12%	13%	13%
Huesca-Pirineos	53%	23%	23%	53%	53%	23%	18%	51%	51%	18%	23%	53%	53%	23%	26%	53%	53%	26%	23%	53%	53%
Ibiza	100%	100%	72%	100%	100%	94%	72%	100%	100%	95%	72%	100%	100%	95%	57%	92%	98%	98%	53%	77%	78%
Jerez	87%	61%	30%	47%	49%	34%	25%	39%	39%	25%	30%	47%	49%	34%	59%	89%	89%	61%	59%	87%	87%
La Gomera	100%	100%	16%	40%	40%	17%	46%	100%	100%	100%	47%	100%	100%	100%	18%	36%	36%	18%	47%	100%	100%
La Palma	43%	29%	24%	43%	43%	24%	24%	43%	43%	24%	24%	43%	43%	24%	22%	26%	26%	22%	13%	15%	15%
Lanzarote	100%	100%	75%	98%	100%	100%	75%	98%	100%	100%	75%	98%	100%	100%	56%	79%	100%	100%	35%	44%	50%
Leon	58%	20%	15%	50%	50%	15%	17%	57%	57%	17%	17%	57%	57%	17%	17%	43%	43%	17%	18%	51%	51%
Logroño	100%	100%	19%	19%	19%	19%	100%	100%	100%	100%	100%	100%	100%	100%	20%	20%	20%	20%	100%	100%	100%

(continued)

Airports	ABC125	AC125	A134	AB134	ABC134	AC134	A135	AB135	ABC135	AC135	A145	AB145	ABC145	AC145	A234	AB234	ABC234	AC234	A235	AB235	ABC235
Madrid Barajas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Madrid 4 vientos	100%	100%	23%	31%	33%	29%	15%	23%	24%	24%	29%	39%	45%	45%	100%	100%	100%	100%	100%	100%	100%
Madrid Torrejon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Malaga	66%	66%	68%	80%	83%	74%	65%	65%	65%	65%	68%	81%	84%	74%	67%	81%	83%	72%	56%	59%	59%
Melilla	33%	29%	21%	32%	32%	21%	21%	32%	32%	21%	21%	32%	32%	21%	18%	19%	19%	18%	18%	19%	19%
Menorca	69%	39%	37%	68%	68%	37%	37%	69%	69%	37%	37%	69%	69%	37%	30%	54%	54%	31%	12%	15%	15%
Murcia	100%	40%	40%	100%	100%	41%	40%	100%	100%	40%	40%	100%	100%	41%	34%	75%	75%	36%	12%	14%	14%
Palma de Mallorca	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	93%	100%	100%	100%	93%	100%	100%
Pamplona	26%	17%	12%	26%	26%	13%	12%	25%	25%	12%	12%	26%	26%	13%	16%	19%	19%	16%	11%	14%	14%
Reus	61%	38%	31%	60%	60%	31%	31%	60%	60%	31%	31%	60%	60%	31%	29%	43%	43%	30%	17%	19%	19%
Sabadell	100%	100%	23%	26%	27%	24%	20%	24%	24%	22%	30%	36%	38%	32%	100%	100%	100%	100%	100%	100%	100%
Salamanca	41%	41%	19%	20%	20%	19%	17%	17%	17%	17%	19%	20%	20%	19%	40%	40%	40%	40%	40%	40%	40%
San Sebastian	48%	42%	18%	46%	49%	42%	18%	45%	48%	42%	18%	46%	49%	42%	21%	28%	29%	27%	14%	19%	19%
Santander	91%	40%	34%	85%	85%	34%	36%	91%	91%	36%	36%	91%	91%	36%	25%	40%	40%	25%	15%	23%	23%
Santiago	53%	35%	34%	54%	54%	34%	34%	54%	54%	34%	34%	54%	54%	34%	30%	45%	45%	31%	11%	12%	12%
Sevilla	77%	55%	44%	75%	78%	59%	44%	75%	75%	58%	44%	75%	77%	59%	41%	73%	79%	60%	25%	43%	43%
Son Bonet	100%	100%	58%	100%	100%	100%	22%	81%	100%	100%	59%	100%	100%	100%	100%	100%	100%	100%	86%	100%	100%
Tenerife North	73%	61%	56%	69%	69%	56%	56%	69%	69%	56%	51%	66%	66%	51%	49%	72%	72%	49%	48%	72%	72%
Tenerife South	100%	64%	66%	100%	100%	72%	64%	100%	100%	64%	66%	100%	100%	72%	59%	100%	100%	71%	31%	50%	50%
Valencia	76%	61%	56%	80%	82%	61%	56%	72%	72%	57%	56%	77%	78%	61%	60%	92%	92%	64%	51%	75%	75%
Valladolid	27%	21%	18%	27%	27%	18%	18%	27%	27%	18%	18%	27%	27%	18%	16%	17%	17%	16%	11%	12%	12%
Vigo	46%	26%	22%	46%	46%	23%	22%	45%	45%	22%	22%	46%	46%	23%	22%	33%	33%	23%	12%	13%	13%
Vitoria	32%	25%	73%	73%	100%	100%	91%	100%	100%	100%	23%	39%	39%	30%	74%	74%	100%	100%	91%	100%	100%
Zaragoza	45%	19%	100%	100%	100%	100%	100%	100%	100%	100%	16%	45%	45%	17%	100%	100%	100%	100%	100%	100%	100%

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Airports	AC235	A245	AB245	ABC245	AC245	A345	AB345	ABC345	AC345	A12	AB12	ABC12	AC12	A13	AB13	ABC13	AC13	A14	AB14	ABC14	AC14	A15
A Coruña	14%	25%	38%	38%	26%	20%	38%	38%	22%	32%	60%	60%	32%	27%	59%	59%	27%	27%	59%	59%	27%	27%
Albacete	87%	87%	100%	100%	87%	87%	100%	100%	87%	25%	28%	28%	25%	25%	28%	28%	25%	26%	28%	28%	26%	87%
Algeciras	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%
Alicante	46%	76%	100%	100%	81%	76%	100%	100%	81%	71%	85%	85%	71%	71%	85%	85%	71%	76%	100%	100%	82%	71%
Almeria	14%	29%	43%	44%	35%	25%	43%	44%	35%	30%	49%	49%	30%	26%	49%	49%	26%	27%	49%	50%	33%	27%
Asturias	11%	25%	47%	47%	28%	23%	47%	47%	28%	29%	60%	60%	29%	28%	60%	60%	28%	28%	60%	60%	29%	29%
Badajoz	29%	31%	37%	37%	31%	28%	37%	37%	28%	34%	44%	44%	34%	31%	44%	44%	31%	31%	44%	44%	31%	31%
Barcelona	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Bilbao	37%	62%	78%	84%	67%	56%	73%	82%	62%	68%	73%	73%	68%	61%	70%	70%	61%	63%	77%	81%	68%	62%
Burgos	60%	60%	100%	100%	60%	54%	96%	96%	54%	30%	46%	46%	30%	23%	44%	44%	23%	23%	44%	44%	23%	56%
Ceuta	21%	21%	49%	49%	21%	19%	49%	49%	19%	21%	50%	50%	21%	19%	50%	50%	19%	19%	50%	50%	19%	19%
Cordoba	46%	46%	58%	58%	46%	34%	49%	49%	34%	28%	30%	30%	28%	12%	19%	19%	12%	15%	20%	20%	15%	32%
El Hierro	18%	18%	29%	29%	18%	13%	29%	29%	15%	25%	55%	57%	39%	20%	54%	58%	42%	20%	54%	57%	39%	20%
Fuerteventura	20%	58%	76%	80%	63%	54%	72%	79%	59%	70%	85%	85%	70%	69%	85%	85%	69%	70%	86%	86%	71%	69%
Girona-Costa Brava	19%	49%	68%	68%	52%	43%	63%	64%	47%	64%	84%	84%	64%	60%	84%	84%	60%	60%	84%	84%	60%	60%
Gran Canaria	100%	65%	100%	100%	100%	52%	80%	100%	100%	69%	97%	97%	95%	66%	89%	100%	100%	65%	87%	100%	100%	64%
Granada-Jaen	12%	19%	25%	25%	20%	15%	25%	25%	16%	26%	45%	45%	26%	21%	44%	44%	21%	21%	44%	44%	21%	21%
Huesca-Pirineos	23%	26%	53%	53%	26%	23%	53%	53%	23%	23%	53%	53%	23%	18%	51%	51%	18%	23%	53%	53%	23%	18%
Ibiza	78%	57%	92%	98%	98%	48%	72%	94%	92%	77%	100%	100%	100%	72%	100%	100%	94%	72%	100%	100%	94%	72%
Jerez	61%	59%	89%	89%	61%	30%	47%	49%	34%	59%	87%	87%	61%	25%	39%	39%	25%	30%	47%	49%	34%	25%
La Gomera	100%	49%	100%	100%	100%	47%	100%	100%	100%	17%	40%	40%	17%	15%	40%	40%	15%	16%	40%	40%	17%	46%
La Palma	13%	22%	25%	25%	22%	17%	26%	26%	18%	29%	43%	43%	29%	24%	43%	43%	24%	24%	43%	43%	24%	24%
Lanzarote	50%	56%	79%	100%	100%	50%	71%	100%	100%	76%	98%	100%	100%	75%	98%	100%	100%	75%	98%	100%	100%	75%
Leon	18%	19%	51%	51%	19%	17%	51%	51%	17%	17%	51%	51%	17%	14%	50%	50%	14%	15%	50%	50%	15%	17%
Logroño	100%	100%	100%	100%	100%	100%	100%	100%	100%	19%	19%	19%	19%	17%	17%	17%	17%	19%	19%	19%	19%	100%

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Airports	AC235	A245	AB245	ABC245	AC245	A345	AB345	ABC345	AC345	A12	AB12	ABC12	AC12	A13	AB13	ABC13	AC13	A14	AB14	ABC14	AC14	A15
Madrid Barajas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Madrid 4 vientos	100%	100%	100%	100%	100%	29%	39%	45%	45%	100%	100%	100%	100%	9%	15%	15%	9%	23%	31%	33%	29%	15%
Madrid Torrejon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Malaga	58%	68%	82%	84%	72%	67%	80%	84%	72%	66%	66%	66%	66%	65%	65%	65%	65%	68%	80%	83%	74%	65%
Melilla	18%	18%	19%	19%	18%	8%	11%	11%	8%	29%	33%	33%	29%	21%	32%	32%	21%	21%	32%	32%	21%	21%
Menorca	12%	30%	53%	53%	31%	26%	50%	50%	28%	39%	68%	68%	39%	37%	68%	68%	37%	37%	68%	68%	37%	37%
Murcia	12%	34%	75%	75%	36%	32%	75%	75%	35%	40%	100%	100%	40%	40%	100%	100%	40%	40%	100%	100%	41%	40%
Palma de Mallorca	100%	93%	100%	100%	100%	68%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pamplona	11%	16%	19%	19%	16%	12%	19%	19%	13%	17%	26%	26%	17%	12%	25%	25%	12%	12%	26%	26%	13%	12%
Reus	17%	29%	43%	43%	30%	21%	37%	37%	23%	38%	61%	61%	38%	31%	60%	60%	31%	31%	60%	60%	31%	31%
Sabadell	100%	100%	100%	100%	100%	30%	36%	38%	32%	100%	100%	100%	100%	12%	15%	15%	12%	23%	26%	27%	24%	20%
Salamanca	40%	40%	40%	40%	40%	19%	20%	20%	19%	41%	41%	41%	41%	17%	17%	17%	17%	19%	20%	20%	19%	17%
San Sebastian	15%	21%	28%	29%	27%	17%	28%	29%	27%	23%	47%	48%	42%	18%	45%	48%	42%	18%	46%	49%	42%	18%
Santander	15%	27%	50%	50%	27%	21%	48%	48%	23%	38%	86%	86%	38%	34%	85%	85%	34%	34%	85%	85%	34%	36%
Santiago	11%	30%	45%	45%	31%	28%	45%	45%	30%	35%	53%	53%	35%	34%	54%	54%	34%	34%	54%	54%	34%	34%
Sevilla	33%	41%	72%	79%	60%	35%	64%	76%	60%	48%	74%	74%	54%	44%	74%	74%	56%	44%	74%	77%	58%	43%
Son Bonet	100%	100%	100%	100%	100%	59%	100%	100%	100%	86%	100%	100%	100%	22%	81%	100%	100%	58%	100%	100%	100%	22%
Tenerife North	48%	47%	66%	66%	49%	37%	52%	54%	37%	61%	73%	73%	61%	56%	69%	69%	56%	51%	66%	66%	51%	51%
Tenerife South	33%	59%	100%	100%	71%	59%	100%	100%	71%	64%	100%	100%	64%	64%	100%	100%	64%	66%	100%	100%	72%	64%
Valencia	53%	60%	89%	89%	64%	53%	77%	82%	58%	61%	76%	76%	61%	56%	72%	72%	57%	56%	77%	78%	61%	54%
Valladolid	11%	16%	17%	17%	16%	13%	17%	17%	13%	21%	27%	27%	21%	18%	27%	27%	18%	18%	27%	27%	18%	18%
Vigo	12%	22%	33%	33%	23%	19%	33%	33%	20%	26%	46%	46%	26%	22%	45%	45%	22%	22%	46%	46%	23%	22%
Vitoria	100%	25%	42%	42%	30%	91%	100%	100%	100%	10%	11%	11%	10%	72%	72%	100%	100%	13%	19%	19%	14%	15%
Zaragoza	100%	17%	31%	31%	17%	100%	100%	100%	100%	19%	45%	45%	19%	100%	100%	100%	100%	16%	45%	45%	17%	16%

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Airports	AB15	ABC15	AC15	A23	AB23	ABC23	AC23	A24	AB24	ABC24	AC24	A25	AB25	ABC25	AC25	A34	AB34	ABC34	AC34	A35	AB35	ABC35	AC35
A Coruña	59%	59%	27%	14%	16%	16%	14%	25%	38%	38%	26%	14%	16%	16%	14%	20%	38%	38%	22%	3%	8%	8%	3%
Albacete	100%	100%	87%	25%	28%	28%	25%	26%	28%	28%	26%	87%	100%	100%	87%	26%	28%	28%	26%	87%	100%	100%	87%
Algeciras	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%
Alicante	86%	86%	71%	44%	56%	56%	46%	76%	100%	100%	81%	44%	56%	56%	46%	76%	100%	100%	81%	2%	2%	2%	2%
Almeria	51%	51%	28%	13%	14%	14%	13%	28%	40%	41%	32%	13%	15%	15%	14%	24%	40%	41%	32%	4%	10%	10%	5%
Asturias	63%	63%	29%	10%	11%	11%	10%	24%	43%	43%	26%	10%	13%	13%	11%	22%	43%	43%	25%	4%	10%	10%	5%
Badajoz	44%	44%	31%	29%	37%	37%	29%	31%	37%	37%	31%	29%	37%	37%	29%	28%	37%	37%	28%	25%	37%	37%	25%
Barcelona	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	23%	23%	23%	23%
Bilbao	71%	71%	62%	36%	40%	40%	37%	62%	78%	83%	67%	36%	37%	37%	37%	55%	72%	81%	61%	4%	4%	5%	4%
Burgos	98%	98%	56%	28%	41%	41%	28%	28%	41%	41%	28%	60%	100%	100%	60%	21%	40%	40%	21%	54%	96%	96%	54%
Ceuta	50%	50%	19%	21%	49%	49%	21%	21%	49%	49%	21%	21%	49%	49%	21%	19%	49%	49%	19%	18%	49%	49%	18%
Cordoba	48%	48%	32%	28%	30%	30%	28%	28%	30%	30%	28%	46%	58%	58%	46%	15%	19%	19%	15%	32%	48%	48%	32%
El Hierro	54%	57%	39%	17%	30%	30%	18%	18%	29%	29%	18%	16%	29%	29%	17%	13%	29%	29%	15%	9%	28%	28%	9%
Fuerteventura	85%	85%	69%	20%	20%	20%	20%	58%	76%	80%	63%	20%	20%	20%	20%	54%	72%	79%	59%	3%	3%	3%	3%
Girona-Costa Brava	84%	84%	60%	19%	21%	21%	19%	49%	68%	68%	52%	19%	21%	21%	19%	43%	63%	64%	47%	2%	4%	4%	2%
Gran Canaria	87%	88%	84%	65%	100%	100%	100%	65%	100%	100%	100%	65%	97%	97%	95%	52%	80%	100%	100%	6%	6%	27%	27%
Granada-Jaen	44%	44%	21%	12%	13%	13%	12%	19%	25%	25%	20%	12%	13%	13%	12%	15%	25%	25%	16%	3%	8%	8%	3%
Huesca-Pirineos	51%	51%	18%	23%	53%	53%	23%	26%	53%	53%	26%	23%	53%	53%	23%	23%	53%	53%	23%	18%	51%	51%	18%
Ibiza	100%	100%	95%	53%	77%	78%	78%	57%	92%	98%	98%	53%	77%	78%	78%	48%	72%	94%	92%	3%	3%	7%	7%
Jerez	39%	39%	25%	59%	87%	87%	61%	59%	89%	89%	61%	59%	87%	87%	61%	30%	47%	49%	34%	3%	6%	6%	3%
La Gomera	100%	100%	100%	16%	35%	35%	16%	18%	36%	36%	18%	47%	100%	100%	100%	16%	36%	36%	17%	44%	100%	100%	100%
La Palma	43%	43%	24%	13%	15%	15%	13%	22%	25%	25%	22%	13%	14%	14%	13%	17%	26%	26%	18%	4%	7%	7%	4%
Lanzarote	98%	100%	100%	35%	44%	50%	50%	56%	79%	100%	100%	35%	43%	49%	49%	50%	71%	100%	100%	3%	3%	7%	7%
Leon	57%	57%	17%	15%	43%	43%	15%	17%	43%	43%	17%	18%	51%	51%	18%	15%	43%	43%	15%	14%	49%	49%	14%
Logroño	100%	100%	100%	18%	18%	18%	18%	20%	20%	20%	20%	100%	100%	100%	100%	19%	19%	19%	19%	100%	100%	100%	100%

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Airports	AB15	ABC15	AC15	A23	AB23	ABC23	AC23	A24	AB24	ABC24	AC24	A25	AB25	ABC25	AC25	A34	AB34	ABC34	AC34	A35	AB35	ABC35	AC35
Madrid Barajas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Madrid 4 vientos	23%	24%	24%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	23%	31%	33%	29%	15%	23%	24%	24%
Madrid Torrejon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Malaga	65%	65%	65%	56%	59%	59%	58%	67%	81%	83%	72%	56%	59%	59%	58%	67%	80%	83%	72%	1%	1%	1%	1%
Melilla	32%	32%	21%	18%	19%	19%	18%	18%	19%	19%	18%	17%	19%	19%	17%	8%	11%	11%	8%	6%	11%	11%	6%
Menorca	69%	69%	37%	12%	15%	15%	12%	30%	53%	53%	31%	11%	15%	15%	11%	26%	50%	50%	28%	3%	4%	4%	3%
Murcia	100%	100%	40%	12%	14%	14%	12%	34%	75%	75%	36%	12%	14%	14%	12%	32%	75%	75%	35%	4%	11%	11%	4%
Palma de Mallorca	100%	100%	100%	93%	100%	100%	100%	93%	100%	100%	100%	93%	100%	100%	100%	68%	93%	100%	100%	3%	3%	9%	9%
Pamplona	25%	25%	12%	11%	14%	14%	11%	16%	19%	19%	16%	11%	14%	14%	11%	12%	19%	19%	13%	5%	12%	12%	5%
Reus	60%	60%	31%	17%	19%	19%	17%	29%	43%	43%	30%	17%	19%	19%	17%	21%	37%	37%	23%	3%	8%	8%	3%
Sabadell	24%	24%	22%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	23%	26%	27%	24%	20%	24%	24%	22%
Salamanca	17%	17%	17%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	19%	20%	20%	19%	15%	15%	15%	15%
San Sebastian	45%	48%	42%	14%	19%	19%	15%	21%	28%	29%	27%	14%	19%	19%	15%	17%	28%	29%	27%	6%	16%	16%	6%
Santander	91%	91%	36%	14%	16%	16%	14%	25%	40%	40%	25%	15%	23%	23%	15%	19%	40%	40%	21%	5%	15%	15%	6%
Santiago	53%	53%	34%	11%	12%	12%	11%	30%	45%	45%	31%	10%	11%	11%	10%	28%	45%	45%	30%	3%	4%	4%	3%
Sevilla	75%	75%	52%	25%	43%	43%	33%	41%	72%	78%	59%	24%	38%	38%	26%	35%	64%	75%	59%	4%	4%	12%	12%
Son Bonet	81%	100%	100%	86%	100%	100%	100%	100%	100%	100%	100%	86%	100%	100%	100%	58%	100%	100%	100%	22%	80%	100%	100%
Tenerife North	66%	66%	51%	48%	72%	72%	48%	47%	66%	66%	49%	46%	59%	59%	48%	37%	52%	54%	37%	11%	11%	11%	11%
Tenerife South	100%	100%	64%	31%	50%	50%	33%	59%	100%	100%	71%	31%	50%	50%	33%	59%	100%	100%	71%	2%	2%	3%	3%
Valencia	71%	71%	54%	51%	75%	75%	53%	60%	89%	89%	64%	50%	68%	68%	53%	53%	77%	82%	58%	8%	8%	9%	9%
Valladolid	27%	27%	18%	11%	12%	12%	11%	16%	17%	17%	16%	11%	12%	12%	11%	13%	17%	17%	13%	6%	10%	10%	6%
Vigo	45%	45%	22%	12%	13%	13%	12%	22%	33%	33%	23%	11%	13%	13%	11%	19%	33%	33%	20%	4%	8%	8%	4%
Vitoria	27%	27%	22%	73%	73%	100%	100%	15%	19%	19%	16%	19%	32%	32%	25%	73%	73%	100%	100%	91%	100%	100%	100%
Zaragoza	44%	44%	16%	100%	100%	100%	100%	17%	31%	31%	17%	9%	12%	12%	9%	100%	100%	100%	100%	100%	100%	100%	100%

(continued)

Airports	A45	AB45	ABC45	AC45	A1	AB1	ABC1	AC1	A2	AB2	ABC2	AC2	A3	AB3	ABC3	AC3	A4	AB4	ABC4	AC4	A5	AB5	ABC5	AC5
A Coruña	20%	22%	38%	22%	27%	59%	59%	27%	14%	16%	16%	14%	3%	8%	8%	3%	20%	38%	38%	22%	3%	8%	8%	3%
Albacete	87%	87%	100%	87%	25%	28%	28%	25%	25%	28%	28%	25%	25%	28%	28%	25%	26%	28%	28%	26%	87%	100%	100%	87%
Algeciras	24%	24%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%	24%	100%	100%	24%
Alicante	76%	81%	100%	81%	71%	85%	85%	71%	44%	56%	56%	46%	2%	2%	2%	2%	76%	100%	100%	81%	1%	1%	1%	1%
Almeria	25%	35%	44%	35%	26%	49%	49%	26%	13%	14%	14%	13%	4%	8%	8%	4%	24%	40%	41%	32%	4%	9%	9%	5%
Asturias	23%	28%	47%	28%	28%	60%	60%	28%	10%	11%	11%	10%	3%	7%	7%	3%	22%	43%	43%	25%	4%	9%	9%	5%
Badajoz	28%	28%	37%	28%	31%	44%	44%	31%	29%	37%	37%	29%	25%	37%	37%	25%	28%	37%	37%	28%	25%	37%	37%	25%
Barcelona	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	23%	23%	23%	23%	100%	100%	100%	100%	0%	0%	0%	0%
Bilbao	56%	62%	82%	62%	61%	70%	70%	61%	36%	37%	37%	37%	4%	4%	4%	4%	55%	71%	81%	61%	2%	3%	3%	2%
Burgos	54%	54%	96%	54%	23%	44%	44%	23%	28%	41%	41%	28%	20%	40%	40%	20%	21%	40%	40%	21%	54%	96%	96%	54%
Ceuta	19%	19%	49%	19%	19%	50%	50%	19%	21%	49%	49%	21%	18%	49%	49%	18%	19%	49%	49%	19%	18%	49%	49%	18%
Cordoba	34%	34%	49%	34%	12%	19%	19%	12%	28%	30%	30%	28%	12%	19%	19%	12%	15%	19%	19%	15%	32%	48%	48%	32%
El Hierro	13%	15%	29%	15%	20%	54%	57%	39%	16%	29%	29%	17%	9%	28%	28%	9%	13%	29%	29%	15%	9%	27%	27%	9%
Fuerteventura	54%	59%	79%	59%	69%	85%	85%	69%	20%	20%	20%	20%	3%	3%	3%	3%	54%	72%	79%	59%	2%	3%	3%	2%
Girona-Costa Brava	43%	47%	64%	47%	60%	84%	84%	60%	19%	21%	21%	19%	2%	4%	4%	2%	43%	63%	64%	47%	2%	4%	4%	2%
Gran Canaria	52%	100%	100%	100%	64%	87%	87%	83%	65%	97%	97%	95%	6%	6%	27%	27%	52%	77%	100%	100%	1%	1%	1%	1%
Granada-Jaen	15%	16%	25%	16%	21%	44%	44%	21%	12%	13%	13%	12%	3%	8%	8%	3%	15%	25%	25%	16%	3%	8%	8%	3%
Huesca-Pirineos	23%	23%	53%	23%	18%	51%	51%	18%	23%	53%	53%	23%	18%	51%	51%	18%	23%	53%	53%	23%	18%	51%	51%	18%
Ibiza	48%	92%	94%	92%	72%	100%	100%	94%	53%	77%	78%	78%	3%	3%	7%	7%	48%	72%	94%	92%	1%	2%	2%	1%
Jerez	30%	34%	49%	34%	25%	39%	39%	25%	59%	87%	87%	61%	3%	6%	6%	3%	30%	47%	49%	34%	3%	6%	6%	3%
La Gomera	47%	100%	100%	100%	15%	40%	40%	15%	16%	35%	35%	16%	12%	34%	34%	12%	16%	36%	36%	17%	44%	100%	100%	100%
La Palma	17%	18%	25%	18%	24%	43%	43%	24%	13%	14%	14%	13%	4%	7%	7%	4%	17%	25%	25%	18%	3%	6%	6%	3%
Lanzarote	50%	100%	100%	100%	75%	98%	100%	100%	35%	43%	49%	49%	3%	3%	7%	7%	50%	71%	100%	100%	2%	3%	3%	2%
Leon	17%	17%	51%	17%	14%	50%	50%	14%	15%	43%	43%	15%	11%	42%	42%	11%	15%	43%	43%	15%	14%	49%	49%	14%
Logroño	100%	100%	100%	100%	17%	17%	17%	17%	18%	18%	18%	18%	16%	16%	16%	16%	19%	19%	19%	19%	100%	100%	100%	100%

(continued)

Airports	A45	AB45	ABC45	AC45	A1	AB1	ABC1	AC1	A2	AB2	ABC2	AC2	A3	AB3	ABC3	AC3	A4	AB4	ABC4	AC4	A5	AB5	ABC5	AC5
Madrid Barajas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%
Madrid 4 vientos	29%	45%	45%	45%	9%	15%	15%	9%	100%	100%	100%	100%	9%	15%	15%	9%	23%	31%	33%	29%	15%	23%	24%	24%
Madrid Torrejon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Malaga	67%	72%	84%	72%	65%	65%	65%	65%	56%	59%	59%	58%	1%	1%	1%	1%	67%	80%	83%	72%	1%	1%	1%	1%
Melilla	8%	8%	11%	8%	21%	32%	32%	21%	17%	19%	19%	17%	6%	11%	11%	6%	8%	11%	11%	8%	6%	11%	11%	6%
Menorca	26%	28%	50%	28%	37%	68%	68%	37%	11%	15%	15%	11%	3%	4%	4%	3%	26%	50%	50%	28%	2%	4%	4%	2%
Murcia	32%	35%	75%	35%	40%	100%	100%	40%	12%	14%	14%	12%	4%	11%	11%	4%	32%	75%	75%	35%	4%	11%	11%	4%
Palma de Mallorca	68%	100%	100%	100%	100%	100%	100%	100%	93%	100%	100%	100%	3%	3%	9%	9%	68%	93%	100%	100%	0%	1%	1%	0%
Pamplona	12%	13%	19%	13%	12%	25%	25%	12%	11%	14%	14%	11%	5%	12%	12%	5%	12%	19%	19%	13%	5%	12%	12%	5%
Reus	21%	23%	37%	23%	31%	60%	60%	31%	17%	19%	19%	17%	3%	8%	8%	3%	21%	37%	37%	23%	3%	8%	8%	3%
Sabadell	30%	32%	38%	32%	12%	15%	15%	12%	100%	100%	100%	100%	12%	15%	15%	12%	23%	26%	27%	24%	20%	24%	24%	22%
Salamanca	19%	19%	20%	19%	17%	17%	17%	17%	40%	40%	40%	40%	15%	15%	15%	15%	19%	20%	20%	19%	15%	15%	15%	15%
San Sebastian	17%	27%	29%	27%	18%	45%	48%	42%	14%	19%	19%	15%	6%	16%	16%	6%	17%	28%	29%	27%	6%	16%	16%	6%
Santander	21%	23%	48%	23%	34%	85%	85%	34%	14%	16%	16%	14%	3%	10%	10%	3%	19%	40%	40%	21%	5%	15%	15%	6%
Santiago	28%	30%	45%	30%	34%	53%	53%	34%	10%	11%	11%	10%	3%	4%	4%	3%	28%	45%	45%	30%	2%	3%	3%	2%
Sevilla	35%	59%	76%	59%	43%	73%	73%	50%	24%	38%	38%	26%	4%	4%	12%	12%	35%	63%	75%	58%	1%	3%	3%	1%
Son Bonet	59%	100%	100%	100%	22%	81%	100%	100%	86%	100%	100%	100%	22%	80%	100%	100%	58%	100%	100%	100%	22%	80%	100%	100%
Tenerife North	34%	37%	48%	37%	51%	66%	66%	51%	46%	59%	59%	48%	11%	11%	11%	11%	34%	47%	48%	37%	2%	3%	3%	2%
Tenerife South	59%	71%	100%	71%	64%	100%	100%	64%	31%	50%	50%	33%	2%	2%	3%	3%	59%	100%	100%	71%	1%	2%	2%	1%
Valencia	53%	58%	78%	58%	54%	70%	70%	54%	50%	68%	68%	53%	8%	8%	9%	9%	53%	75%	78%	58%	1%	2%	2%	1%
Valladolid	13%	13%	17%	13%	18%	27%	27%	18%	11%	12%	12%	11%	6%	10%	10%	6%	13%	17%	17%	13%	5%	10%	10%	5%
Vigo	19%	20%	33%	20%	22%	45%	45%	22%	11%	13%	13%	11%	4%	8%	8%	4%	19%	33%	33%	20%	3%	8%	8%	3%
Vitoria	23%	30%	39%	30%	4%	9%	9%	4%	9%	11%	11%	9%	72%	72%	100%	100%	13%	19%	19%	14%	15%	27%	27%	22%
Zaragoza	14%	15%	31%	15%	16%	44%	44%	16%	9%	12%	12%	9%	100%	100%	100%	100%	14%	31%	31%	15%	3%	10%	10%	3%

Chapter three

The impact of the Economic Crisis on the efficiency of Spanish airports: a DEA Visualisation Analysis

Ripoll-Zarraga, A.E.; Portillo, F. & Mar-Molinero, C. (2017): ‘The impact of the Economic Crisis on the efficiency of Spanish airports: a DEA Visualisation Analysis' *Transportation Science* (second round, under review)

List of Tables

List of Figures

The impact of the Economic Crisis on the efficiency of Spanish airports: A DEA Visualisation Analysis

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Abstract

We study DEA efficiencies of 47 Spanish airports over the period 2009-2013 under 186 input/output specifications obtained by combining 6 inputs and 5 outputs. Given the large differences in size between the airports, we use the Variable Returns to Scale approach. Since it is a characteristic of economic crisis that some capacity remains idle, we use the output oriented version of DEA. The results are visualised using the tools of multivariate statistical analysis. The analysis reveals six independent aspects of efficiency that can be assessed for an airport, and how their relative importance evolved during the economic crisis. Important changes in efficiency between 2009 and 2010 are revealed. They were followed by a period of slow return to the pre-crisis situation. The methodology presented here makes it possible to assess the strengths and weaknesses of each airport in terms of efficiency.

Keywords: *Data Envelopment Analysis (DEA); Multivariate Statistical Analysis; Airport Efficiency; Spanish Airport-System; Panel-data.*

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1. Introduction

Airports are public resources that require a large amount of investment, and there has been substantial interest in exploring whether such resources have been effectively and efficiently used. Spain has not been an exception. The European Court of Auditors (2014) investigated if investment expenditure in Spanish airports had been justified. Authors who explored efficiency in airports, in an international context, are Gillen and Lall (1997; 2001) , Sarkis (2000) , Bazargan and Vasigh (2003), Parker (1999), Sarkis and Talluri (2004) , Wang *et al.* (2004), Yu (2004; 2010), Barros *et al.* (2007), Barros (2008a; 2008b; 2009), Pathomsiri *et al.* (2008), Yu *et al.* (2008) , Assaf *et al.* (2012). In Spain we can mention Murillo-Melchor (1999), Salazar de la Cruz (1999), Martin and Roman (2001; 2006), Martin-Cejas (2002) , Coto-Millan *et al.* (2007; 2014; 2016), Tapiador *et al.* (2008), Martin *et al.* (2009; 2011), Tovar and Martin-Cejas (2009; 2010), Lozano and Gutierrez (2011), Lozano *et al.* (2013).

A popular technique for efficiency assessment is Data Envelopment Analysis (DEA). DEA takes a particular unit to be assessed as the focus of analysis and asks if the inputs used by such unit would have been better employed elsewhere. The question is basically: imagine that we close the unit under observation and distribute its inputs amongst other similar units, the units that have received extra inputs will generate extra outputs; will these extra outputs be at least as large as the outputs that were generated by the unit we consider closing? If the answer to this question is “yes”, then the unit under observation is deemed to be inefficient.

There are many possible input/output combinations (specifications) that can enter into a DEA study, and calculated efficiencies depend on the specification chosen. In fact, two different analysts working on the same data can come up with different results just because they have chosen different specifications. It is difficult to justify how two different results can arise from the same data when the analysis is performed by two perfectly competent people. A solution proposed by Serrano-Cinca *et al.* (2016) is to estimate a variety of specifications for each unit under observation and to analyse the results using Factor Analysis. This approach has been revealed to be very effective in various studies Gutierrez-Nieto *et al.*, (2007); Serrano-Cinca *et al.*, (2016); and Sagarra *et al.*, (2017). Ripoll-Zarraga and Mar-Molinero (2017) applied this approach to study the efficiency of Spanish airports.

Extreme values are a problem in DEA since they may have considerable influence on the results. But an extreme efficiency value may just be consequence of the choice of inputs and outputs. Serrano Cinca *et al.* (2016) demonstrated that whether a particular unit of assessment appears to be an extreme value depends on the particular choice of inputs and outputs that are incorporated in the specification. Units of assessment that are associated with extreme efficiency values under a particular specification may not appear to present discordant behaviour under other specifications. For this reason, we have decided not to start the modelling by looking for extreme values. By estimating a variety of specifications, we will be able to reveal the reasons why some units of assessment present extreme behaviour, if any such units exist. This will, in fact, disclose the strengths and weaknesses in the efficiencies of the various airports.

Airport efficiency studies tend to be static, in the sense that data on inputs and outputs are collected for a particular year, and the model is estimated. Here we take the analysis a step further by adding the time dimension to the analysis.

The standard way to incorporate time changes in DEA is by means of the Malmquist index approach (Thanassoulis, 2001). But the Malmquist index approach suffers from the same limitations as the standard DEA approach in that a particular specification has to be selected, and no alternatives are considered.

Our data consists in four inputs and five outputs for 47 Spanish airports over a five-year period. DEA efficiency was calculated for each airport under an output-oriented variable returns to scale model (VRS). VRS is justified given the large difference in size between the various airports. Output orientation was selected as an approach because we considered that the 2008 economic crisis had left capacity under-utilised, and we wanted to see how this had developed. As for the specifications, many can be contemplated, but we were selective in the sense that some of them did not make much managerial sense and these were excluded from the analysis. The final data set was a three-way table of airports by specifications by years. The cells in the table contained efficiencies.

The approach followed to analyse the results was based on the Individual Differences Scaling (INDSCAL) model of Carroll and Chang (1970). This model reveals what has remained constant over the time period, and any time effects that may exist. This is done by means of a "common map" and a set of weights.

The common map represents airports over the time period in a consensus map that, in this case, is represented in a nine dimensional space, although only six dimensions are interpreted. The interpretation of the dimensions is done using the technique of Property Fitting (ProFit) (Schiffman *et al.*, 1981).

To study time effects we need to analyse the weights produced by the INDSCAL model. This we do in a graphical way using a representation suggested by Young (Coxon, 1982). The weights reveal that the economic crisis had a large impact in the data after 2009, followed by a period of slow recovery.

After this section, we describe the data in Section 2. Section 3 describes the methodology and the results. The paper ends with a discussion section that contains the conclusions.

2. The Data

Spanish airports are government owned and managed by a public company named AENA (Aeropuertos Españoles y Navegación Aérea). AENA manages 49 civilian aviation airports including four general aviation airports and two heliports. One of the consequences of this centralised management is that airports do not compete. There has been much debate about the adequacy of a centralised system versus local decision making (Cambra de Comerç de Barcelona, 2010; CNMC-The National Board for Markets and Competition, 2014; Word Finance, 2016).

Our data set includes 47 of the 49 airports over a period of five years (2009-2013). There is no financial data information on individual airports prior to 2009. The list of airports can be seen in Table 1. Two airports were excluded from the analysis due to lack of data: Son Bonet (in Majorca island) and Algeciras.

In terms of passengers, the network contains 14 large airports (i.e. more than 3.5 million of passengers per year). The remaining 43 airports can be described as medium or small sized, and have a high variability in terms of passengers and cargo. The data have been extracted from the annual reports of AENA from 2009 to 2013 where individual data per airports was published except for the depreciation of assets and runway length.

Despite being government owned, AENA does not receive public subsidies. To obtain extra funds, Spanish airports have engaged in commercial activities alongside with their aeronautical mission. Amongst these commercial activities we can list duty-free shops; car rental; food services; shops; advertising; VIP lounges; banking; travel agencies; and vending machines. Diversification towards commercial activities is normally associated with privatisation processes (Humphreys, 1999). In the Spanish case, commercial revenues are as important as aeronautical revenues (ICAO, 2013).

DEA requires specifying what are the inputs and the outputs of an airport. The inputs considered are:

Labour costs excluding air traffic control services (A)

Operating costs (B)

Depreciation of airside assets (C)

Runway length (D)

All the inputs are in euros except for runway length. The letters in brackets indicate the symbol that has been used in the analysis.

The outputs generated by an airport are considered to be:

Passengers (1)

Air traffic movements (ATM) (2)

Cargo (3)

Commercial revenues (4)

Percentage flights on time (5)

Cargo is measured in tons and commercial revenues are measured in euros. The numbers in brackets indicate the symbol that has been used in the analysis.

These variables used have been frequently used in airports' efficiency studies; see Tovar and Martin-Cejas (2010). The choice of inputs and outputs has been guided by data availability as published by AENA. Labour and operating costs; the number of passengers; movements; cargo and commercial revenues have been extracted from AENA's annual reports.

Cargo has increased its importance over the years. It requires different handling methods compared to passengers (Tovar and Martin-Cejas, 2009; Chi-Lok and Zhang, 2009). Aircraft movements are treated as an output of airside operations. They generate revenues in the form of landing and aircraft parking charges (Coto-Millan *et al.*, 2014). The percentage of flights on time has been used as an indicator of congestion.

Turning our attention to inputs, airports' resources are normally related to infrastructure. Infrastructure includes the number of runways; terminal buildings; boarding gates; number of checking desks; terminal size; parking capacity; and number of full-time employees. Nevertheless, infrastructure is difficult to define or quantify. Indeed, one of the main challenges of airport benchmarking analysis is the inclusion of capital measures (Parker, 1999). Various capital proxies have been used in airport industry research: rent expenses (Parker, 1999);

depreciation of fixed assets (Murillo and Melchor, 1999; Martin and Roman 2001; Martin *et al.*, 2009; 2011); capital expenses (Martin-Cejas, 2002); book value (Barros and Sampaio, 2004; Coto-Millan *et al.*, 2014; 2016); length of runways (Martin *et al.*, 2011); and airport surface area or number of gates (Tovar *et al*., 2009; 2010). It is also possible to take into account if assets are linked to aircraft movements (boarding gates; apron capacity and runways areas), or to loading processes such as checking counters and baggage belts (Lozano *et al.*, 2013).

In this study, we have employed as a proxy for capital usage, the depreciation of airside assets. From an accounting perspective depreciation reflects the consumption of airport assets that takes place in the process of generating revenues. Following Ashford *et al.* (1996) airport infrastructure was classified into airside and landside. In this study, only the depreciation of airside assets is considered. The split between airside and landside assets has been discussed by Gillen and Lall (1997), and Pels *et al.* (2001; 2003). Airside assets are considered to be essential to develop aeronautical activities. The depreciation of airside assets refers to aviation terminals; aprons; taxiway and air traffic control and visualisation systems (beacon), excluding runway depreciation. Depreciation was calculated using established depreciation rules while taking into account the historical cost of non-current assets. The calculation required knowing the initial cost of assets and of the subsequent work performed on them. The historical cost of non-current assets was obtained from the construction certifications of works performed in airports. It was not possible to find individual airport infrastructure expenditure information before 2000, and calculations were made as if airports had started their activity in the year 2000. Airports' initial investments for 2000 were estimated from depreciation charges for 2004 (accidentally released by the Spanish Government). These depreciation expenses were available per airport within individual income statements. The useful life of the assets conforms to current regulation in the transportation sector for buildings and structures as required by international financial reporting standards (IFRS) for property, plant and equipment (IAS 16).

There was no information regarding the type of labour cost (full or part-time; permanent or fixed term). In a few instances, there was missing data. We preferred making a small estimation error rather than removing an airport from the data set because a particular item was not available, and we inputted an estimate using the nearest neighbour approach. We estimated some items in the cases of Ceuta, Cordoba, Huesca, La Gomera, and Madrid-4Vientos.

Runway length is a non-discretionary input in the sense that runway length cannot be changed in the short term in order to improve efficiency. Non-discretionary inputs in DEA have been studied, amongst others, by Banker and Morey (1986), Ruggiero (1988), and Cordero-Ferrara *et al.*, (2008). In our case, the DEA models estimated are output oriented, and the standard model does not need to be modified.

All the data measured in monetary units was deflated by the Spanish gross domestic product deflator (base Spain, 2010).

Table 1 Descriptive Statistics.

Variable	Mean	Std. Dev.	Min	Max
Passengers	4,094,892	8,656,221	0	49,866,113
Air Traffic Movements	42,736.41	72,758.36	476	435,187
Cargo (t)	13,472,972	53,369,951	0	394,154,078
Aeronautical Revenues (mill €)	35.45	97.33	0.03	703.93
Commercial Revenues (mill €)	13.40	31.16	0	186.82
Labour Costs (mill €)	8.25	11.36	0.12	81.83
Operating Costs (mill €)	21.75	55.88	0.45	350.82
Depreciation Airside (€)	2,208.97	5,498.38	0	31,100.24
Runway Length (m^2)	177,574.20	161,175.30	10,626	927,000

Descriptive statistics for inputs and outputs are given in Table 1 (Source: AENA 2009-2013 except for depreciation and runway length. Data deflated by the GDP deflator base Spain, 2010).

3. Analysis and Results

Efficiencies were estimated under 186 DEA specifications for each airport and for each of the five years. This makes a total of 43,710 estimations. Inputs were identified by means of capital letters, and outputs by means of numbers, in line with the notation introduced in the previous section. For example, model AC32 contains as inputs labour (A) and depreciation (C) and as outputs cargo (3) and ATM (2). The specifications estimated are not all the possible combinations between the five outputs and the four inputs since some were excluded on the grounds that they did not make operational sense.

3.1. *Factor analysis of efficiencies for individual years*

The data to be analysed is a three-way matrix of 186 specifications, by 47 airports, and by 5 years. Although some relevant information can be obtained through visual inspection of the data, it is clearly necessary to use a data reduction technique in order to deal with such a large set of figures.

In the first instance, the data set was treated as a set of five matrices of airports by specifications, one such matrix for each year, the cells of the matrices containing estimated efficiencies. Specifications were treated as variables, and airports were treated as cases. Each matrix was analysed using Unrotated Orthogonal Factor Analysis. This was done in order to assess the dimensionality of the data.

There was little variation between the five years. In general, either 9 or 8 factors were associated with eigenvalues greater that unity, the standard Kaiser's criterion. The 9 factors always accounting for more than 95% of the variability in the data. The first factor was clearly an overall measure of efficiency, and accounted for more than 60% of the variability in the information. Similar patterns were observed by Gutierrez-Nieto *et al.*, (2007), Serrano-Cinca *et al.*, (2016), and Sagarra *et al.*, (2017).

It was also observed that factorial weights associated with dimensions 7, 8, and 9 were low (less than 0.3). Considering that the statistical package employed, SPSS, orders factors in terms of their eigenvalues, it can be conjectured that factors 7, 8, and 9 are of lesser importance in the analysis.

Following this— matrix by matrix— factor analysis study, it was decided to model the data as nine-dimensional, although we did not expect to obtain interesting findings for dimensions higher than six.

3.2. The individual differences scaling model

Given the amount of data we had, we decided to use a statistical technique that reveals its main characteristics in a graphical form. There are several such approaches that can be used to model three-way data. We preferred to employ the Individual Differences Scaling (INDSCAL) model of Carroll and Chang (1970). Estimations were performed with the PROXSCAL routine of the package SPSS.

Scaling models are estimated using numerical hill-climbing methods and can suffer from local minima problems. To be sure that it was not the case in this instance, several approximation methods were used. Another problem with hill-climbing approaches is that iterations can finish before the optimal value is found. To avoid this problem as far as possible, the default level of precision in SPSS was increased by a factor of one thousand. The results reported here were found to be robust to the estimation method used and to the level of precision in the calculations.

The INDSCAL model is proximity based. First, proximities between airports are calculated for every year. There are various ways in which proximities can be calculated. We used Euclidean metric between airports using as variables standardised efficiency values. This method is equivalent to Factor Analysis when certain restrictive conditions apply; Coxon (1982). In other words, each airport is a point in a space of 186 dimensions (one dimension for each specification). The proximity (dissimilarity) between any two airports is taken to be the distance between the points in the 186-dimensional space. Since there are 47 airports in the data set, this results in the calculation of 1081 proximity values for each year. In mathematical terms, the proximity between airport i and airport j in year t is given by:

$$\delta_{ij}^{t} = \left(\sum_{k=1}^{186}\left(e_{ik}^{t} - e_{jk}^{t}\right)^{2}\right)^{\frac{1}{2}} \qquad (1)$$

where e_{ik}^{t} is the standardised efficiency of airport i under specification k for year t.

INDSCAL models the airports as a set of points in a d-dimensional space. Following the findings of the year by year factor analysis, d was set to 9. INDSCAL is not rotation invariant, as is the case with factor analysis or with Multidimensional Scaling. It has been found that the dimensions in an INDSCAL study often have a meaning. Attaching a meaning to the dimensions is important in order to interpret the results of the analysis. This is done below.

It is assumed that the relative position of the airports with respect to each other, in this 9 dimensional space, remains invariable over time, but that the relative importance (salience) of the dimensions changes over time. This assumption is appropriate for the Spanish airport data set since it is reasonable to assume that the airports that are similar in a particular year will continue to be similar over the time period. For example, if Vitoria and Zaragoza airports are similar during the first year, they will continue to be similar during the following four years. This does not mean that things do not change; the relative importance of the dimensions in the space may change over time as a result of, for example, the economic cycle.

INDSCAL returns as output both a common map that represents what has remained invariant over time, and a set of weights that reveals time-related effects. The set of weights, one for each dimension and for each year, are used to “distort” the common map. The distortion is a simple change of scale that is used to emphasise the importance (salience) of each dimension in each particular year. The importance of each dimension of the common map will increase in a particular year if the weight associated for that year for that dimension is higher than average, and will decrease if the weight associated with that dimension is lower than average.

Mathematically, INDSCAL performs a non-linear regression where the dependent variables are the δ_{ij}^t and the unknowns are of two types: the coordinates of the airports in the common space, c_{id}, and the set of weights w_d^t. Where c_{id} is the coordinate d of airport i in the common space, and w_d^t is the weight attached to dimension d in the specific year t.

We can write:

$$\delta_{ij}^t = \left(\sum_{d=1}^{9}(c_{id} - c_{jd})^2 w_d^t\right)^{\frac{1}{2}} + \varepsilon_{ij}^t = d_{ij}^t + \varepsilon_{ij}^t \,, \qquad (2)$$

where the d_{ij}^t are the distances between airports as calculated from the common map.

Being regression based, model fit can be assessed using the correlation between the dissimilarities, δ_{ij}^t, and the distances d_{ij}^t. This is done for each year.

$$R_t = Correlation\ (\delta_{ij}^t, d_{ij}^t) \qquad (3)$$

The model contains an ambiguity: if we multiply the coordinates of the common space by a constant and divide the weights by the square of this figure, the value under the square root remains unchanged. To avoid this, the weights for each year are normalised so that

$$R_t^2 = \sum_{d=1}^{9}(w_d^t)^2 \qquad (4)$$

In other words, the sum of the square of the weights for each year adds up to the square of the correlations between dissimilarities and distances for that particular year.

The weights for each dimension and each year can be seen in Table 2. This table also contains the sum of squares of the weights for each particular year.

Table 2 INSCAL Weights (w_t) and Goodness of Fit measure for each year.

Year	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	R_t^2
2009	0.24	0.58	0.10	0.00	0.13	0.00	0.22	0.02	0.02	0.48
2010	0.21	0.17	0.16	0.15	0.23	0.09	0.18	0.13	0.49	0.48
2011	0.26	0.14	0.24	0.50	0.21	0.12	0.14	0.04	0.05	0.48
2012	0.30	0.17	0.27	0.16	0.16	0.10	0.09	0.46	0.00	0.48
2013	0.28	0.14	0.24	0.11	0.19	0.50	0.10	0.00	0.07	0.48

It can be seen in Table 2 that correlations between dissimilarities and distances for each year are in the region of 0.7 (the square root of the figure under the R_t^2 column). It can also be seen that the relative salience of the dimensions, as measured by the weights, changes over time. This is something we will further explore below.

Another way of assessing the goodness of fit of the model is known as "stress". Stress is a measure of lack of fit. As such, we would like stress to be near to zero. There are various measures of stress, depending on the way the result is normalised, the most common measure is known as Stress1; Kruskal (1964). In this case Stress1 was found to be 0.0610, which ranks as "very good" in Kruskal's (1964) verbal classification.

INDSCAL also generates a common map. The common map is a consensus map over time, which plots each airport in the 9-dimensional space. Each airport is then, a point in a 9-dimensional space. The coordinates of each airport in the common map are given in Appendix A.

Clearly, a mathematical map in nine dimensions is difficult to comprehend. It needs to be projected into pairs of dimensions. The projection of the common map into dimensions 1 and 2 can be seen in Figure 1. The projection of the common map into dimensions 3 and 4 can be seen in Figure 2, and the projection of the common map into dimensions 5 and 6 can be seen in Figure 3. Airports are identified by means of their codes.

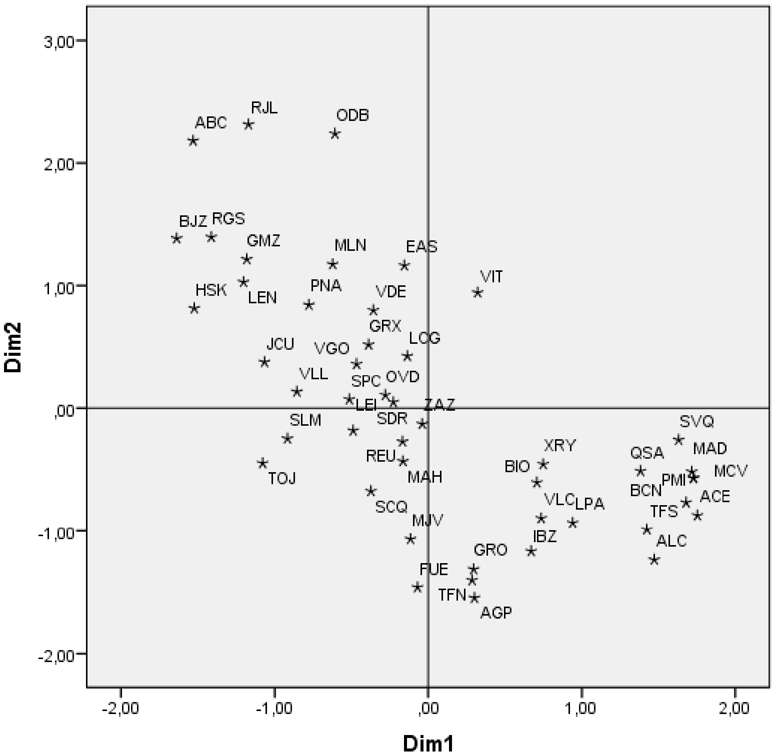

Fig. 1. Common Map. Projection into Dimension 1 and Dimension 2. Airports identified by means of their codes.

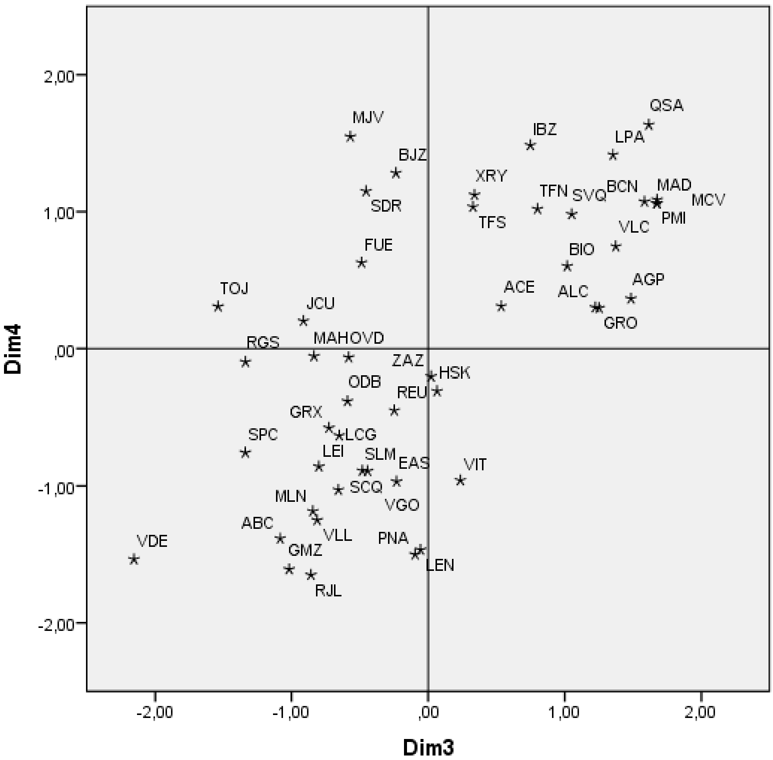

Fig. 2. Common Map. Projection into Dimension 3 and Dimension 4. Airports identified by means of their codes.

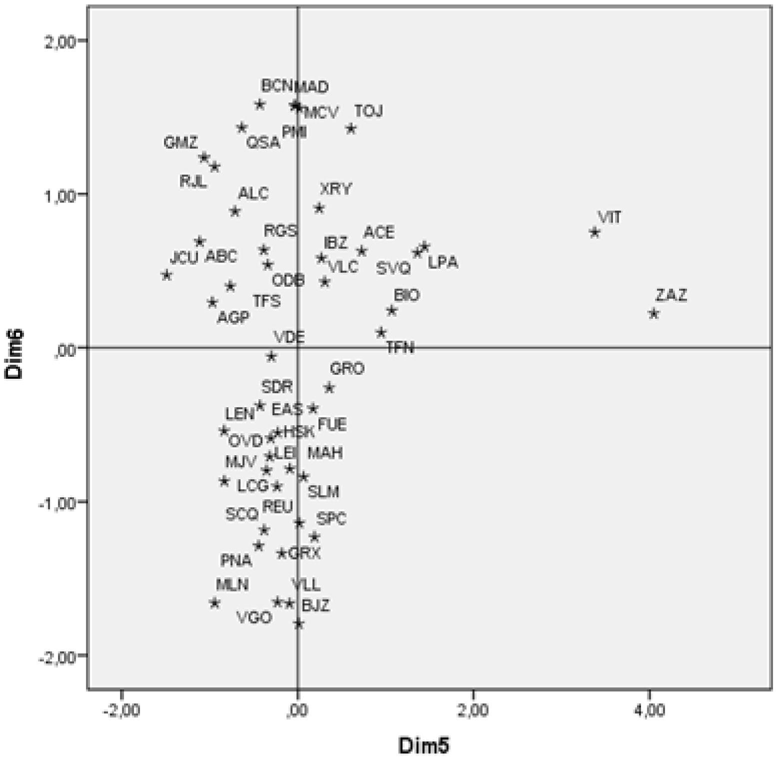

Fig. 3. Common Map. Projection into Dimension 5 and Dimension 6. Airports identified by means of their codes.

3.3. *Interpreting the common map. Property Fitting*

In order to better understand the results of the analysis, it is important that dimensions in the common map be attached a meaning. This can be done in a more formal way using the Property Fitting approach (ProFit). ProFit is a form of biplot; see Gower and Hand (1996). It attempts to establish if there are directions in the common space that are related to the way in which efficiency under a particular specification changes. For example, if efficiency in dealing with cargo grows in the direction of Dimension 5, we plot a vector in the direction of Dimension 5 to make this explicit. To draw the vectors, we need to perform a regression in which the independent variables are the coordinates of the airports in the common space, and the dependent variable is the efficiency under the specification of interest. For a mathematical justification of this procedure see Mar-Molinero and Mingers (2006).

ProFit vectors were normalised to unit length,

$$\beta_i^* = \frac{\beta_i}{\sqrt[2]{\sum_{i=1}^{9} \beta_i^2}} , i = 1 \dots .9 , \qquad (5)$$

where β_i is the i −th regression coefficient. The β_i^* values can be seen in Appendix B. Appendix B also shows the R^2, that measures Goodness of Fit in the regression.

Normalisation is important for the interpretation of the dimensions. All ProFit vectors have their origin in the centre of co-ordinates and, after normalization, have unit length. If, in a two-dimensional projection, the end point of the ProFit vector associated with a particular specification is close to the centre of coordinates, it is concluded that the dimensions on which the vector is plotted are unrelated to efficiency under that particular specification. If, on the other hand, the vector appears to have unit length in a particular projection, one can conclude that the dimensions of the figure are the relevant ones for the interpretation.

3.4. *Interpreting the common map. Hierarchical Cluster Analysis*

Figures 4, 5, and 6 have to be seen together with Figures 1, 2, and 3. Ideally, one would project both the end points of the profit vectors and the airports on the same pair of dimensions, but this would have resulted in too much information within each figure.

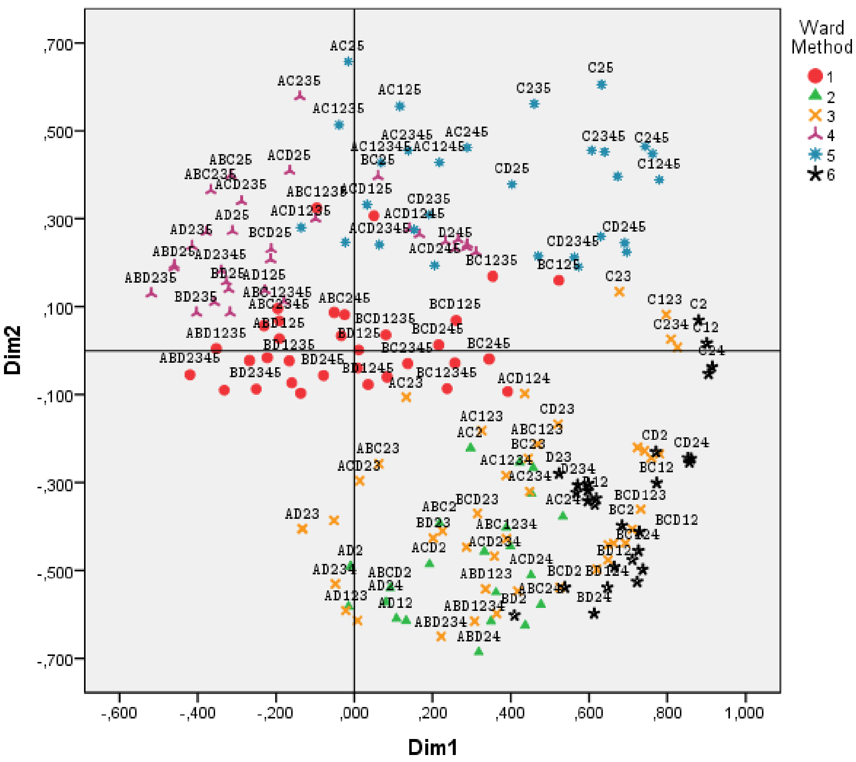

Fig. 4. DEA Specifications projection into Dimension 1 and Dimension 2 with indication of Ward clustering method.

Before we proceed to interpretation, we need to realise that the end points of the ProFit vectors are located in a 9-dimensional space, and it is possible for two such end points to appear near to each other in the projection while being far away in the space. In order to address this issue we have conducted a Hierarchical Cluster Analysis of the end points of the ProFit vectors. The β_i^* values were treated as variables, and the specifications as observations. Ward´s agglomeration method was chosen, since it maximises homogeneity within clusters and heterogeneity between clusters. After observing the dendrogram, it was decided that six would be an appropriate number of clusters. The specifications that belong to the same cluster have been identified in Figures 5, 6, and 7.

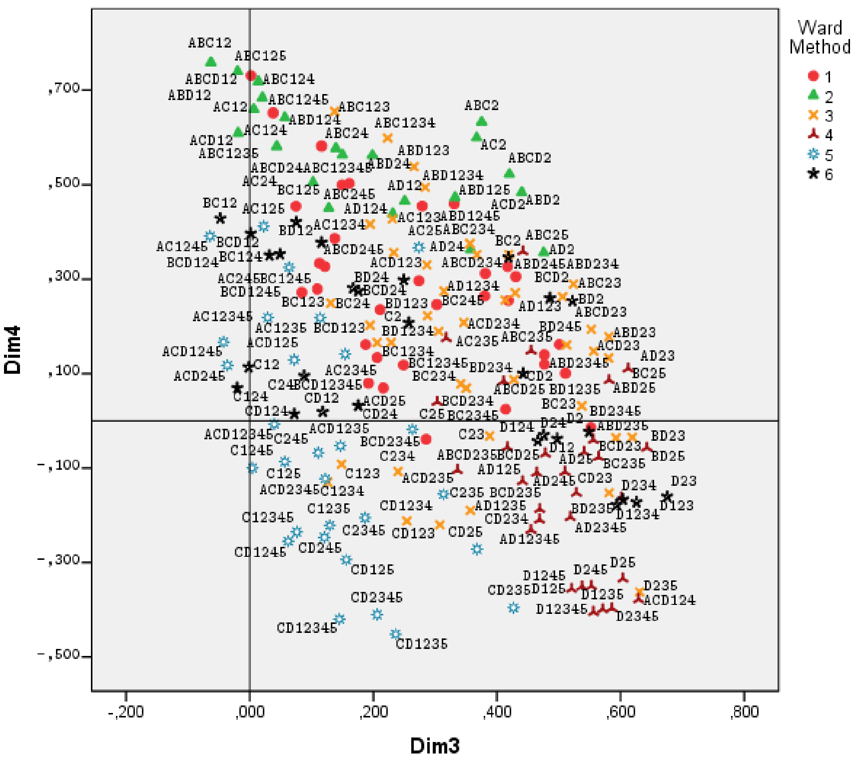

Fig. 5. DEA Specifications projection into Dimension 3 and Dimension 4 with indication of Ward clustering method.

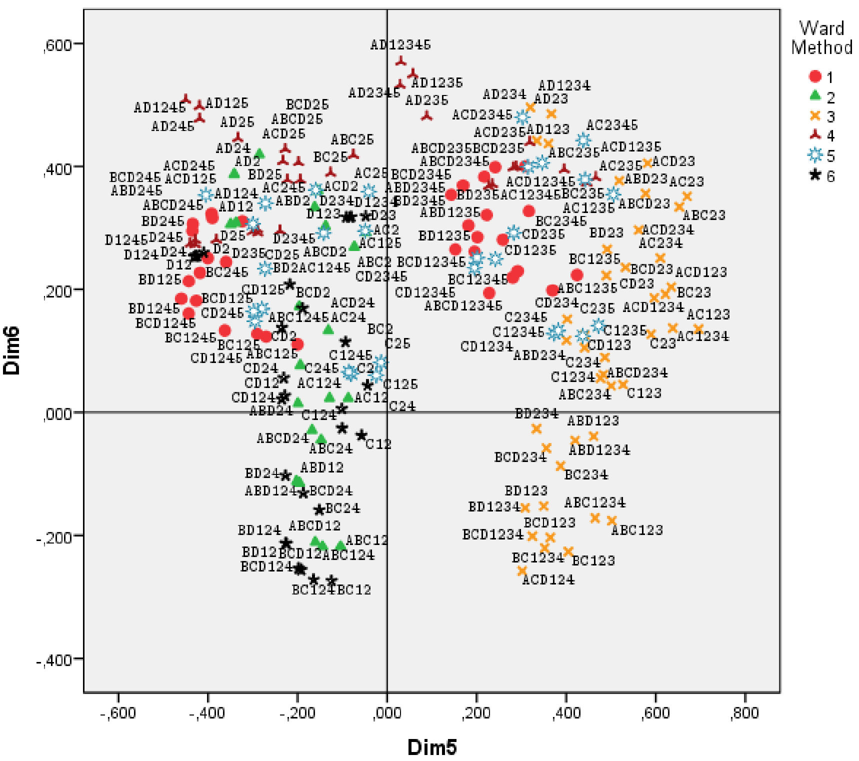

Fig. 6. DEA Specifications projection into Dimension 5 and Dimension 6 with indication of Ward clustering method.

3.5. *Interpreting the common map. Exploring the meaning of the dimensions*

In this section we interpret the common map, as projected in Figures 1, 2, and 3 taking into account the results of ProFit and Cluster analysis.

We observe in Figure 1 that airports concentrate in the lower right-hand-side quadrant and in the upper left-hand-side quadrant. Airports located in the lower right side of the figure are, on the whole, large or medium-sized (Madrid Barajas, Barcelona El Prat, Palma, Alicante). Airports located on the top left hand side quadrant are small airports (Albacete, Logroño, Badajoz). It is clear that the north-west, south-east diagonal is related to the size of the airport. To understand how the efficiency of large airports differs from the efficiency of small airports, we turn our attention to Figure 4.

In Figure 4 we observe that the end points of ProFit vectors that are most distant from the centre of coordinates in the direction south-east belong to Cluster 6 and, to a smaller amount, to cluster 3. Furthermore, the distance from the origin of coordinates to points that belong to Cluster 6 is almost unity, indicating that this cluster is important for interpretation purposes. Members of Cluster 6 have as inputs Operating Costs (B), Depreciation (C), and Runway Length (D) and as outputs Passengers (1), ATM (2), and Commercial Revenues (4). This indicates that large airports are efficient at generating aeronautical activity and revenues given the use they make of the infrastructure, while the same cannot be said of small airports. Almost half of the airports in the EU can be described as being “small”, but these account for just 0.75% of air traffic.

Using a similar way of proceeding we turn our attention to Dimension 1 in Figure 4. ProFit vectors that point towards the right hand side contain Depreciation (C) and Runway Length (D) as inputs; as outputs they contain Passengers (1) and ATM (2). We can then suggest that Dimension 1 is related to the efficient use of investment in order to generate air traffic movements (passengers and/or cargo).

If we now look at Dimension 2 in Figure 4 we see that the ProFit vectors that point towards the top contain as inputs Labour Cost (A) and Depreciation (C), and as outputs ATM (2), Cargo (3), and Flights on Time (5). We have already observed that the airports that are located towards the top of Figure 1 are small ones. This suggests that small airports have high punctuality records, and deal with aircraft traffic in a cheap way, both from the point of view of labour and the point of view of investment in infrastructures. We can label this dimension as cost efficiency with respect to aeronautical activity in terms of punctuality.

Dimension 3 is associated with a variety of specifications combining a variety of inputs and outputs, but all of them include ATM (output 2). This suggests that dimension 3 is related to the efficiency in obtaining financial resources in relation with Air Traffic Movements (airport charges in relation to approach and landing taxes). Dimension 3 shows the trade-off between the length of runways and cargo activities, taking into account punctuality. Large airports handle large aircraft, which may take longer times for cargo operations and affecting punctuality.

It can be seen in Figure 5 that the ProFit vectors most associated with Dimension 4 contain Labour Costs (A) and Operating Costs (B) as inputs, and Passengers and (1) ATM (2) as outputs. This dimension could be interpreted as cost efficiency in dealing with passengers.

Dimension 5 is clearly associated with the efficiency in dealing with cargo.

Finally, Dimension 6 captures efficiency effects associated with runway length. Clearly, longer runways make it possible for larger aircraft to land, and this impacts on efficiency. But, at the same time technical efficiency will depend on the existence of traffic and its impact on punctuality.

3.6. *Time evolution*

Time related effects are captured by the weights in Equation 2. For a given year and a given dimension, the absolute value of the weight is not important, since this depends on the normalisation performed in Equation 4. What is important for a given year, t, is whether the value of the weight associated with a particular dimension is greater or smaller than the value of the weight associated with another dimension. If both weights are of equal value, the common map is a good representation of the efficiency situation for the airports. If the weight for dimension i is higher than the weight for dimension j, the common map has to be elongated along dimension i and shrunk along dimension j. This is to say, if weight, w_{ti}, is higher than weight, w_{tj}, dimension i takes more importance than dimension j during year t.

This is best explored graphically, but because there are 6 weights, 15 such graphs are necessary to give full details. We have decided to only reproduce here the most informative graphs.

There are various ways in which the relative importance of the weights can be revealed. Here we have opted for Young's plots; Coxon (1982, p.199). Four such plots can be seen in Figure 7.

It can be seen in section (a) of Figure 7 that there was a large change in the relative importance of Dimension 2 with respect to Dimension 1 after 2009. This can be directly attributed to the impact of the economic crisis. In 2009 Dimension 2 was clearly more important than Dimension 1, a situation that was reversed in the following years. Dimension 2 has been interpreted as cost and investment efficiency, and Dimension 1 was interpreted as efficiency in the use of investment in order to generate passenger activity. From this we deduce that in the year 2009, when passenger activity was high, the emphasis was on cost reduction and good use of infrastructures. After 2009 the emphasis appears to have shifted to generating passenger activity given the investment available in each airport.

The next plot of interest corresponds to section (b) of Figure 7. Here we concentrate on cost efficiency in dealing with passengers, which was associated with Dimension 4. This efficiency appears to have taken more importance during the worst years of the economic crisis (2010 and 2011). In years 2012 and 2013 the relative importance of Dimension 4 with respect to Dimension 1 decreased, indicating a return to the pre-crisis situation.

The relative importance of Dimension 4 with respect to Dimension 2 is explored in section (c) of Figure 7. We see that cost efficiency in relation to passengers appears to have had relatively low emphasis in 2009, before the economic crisis hit Spanish airports, but that the situation was reversed during the crisis.

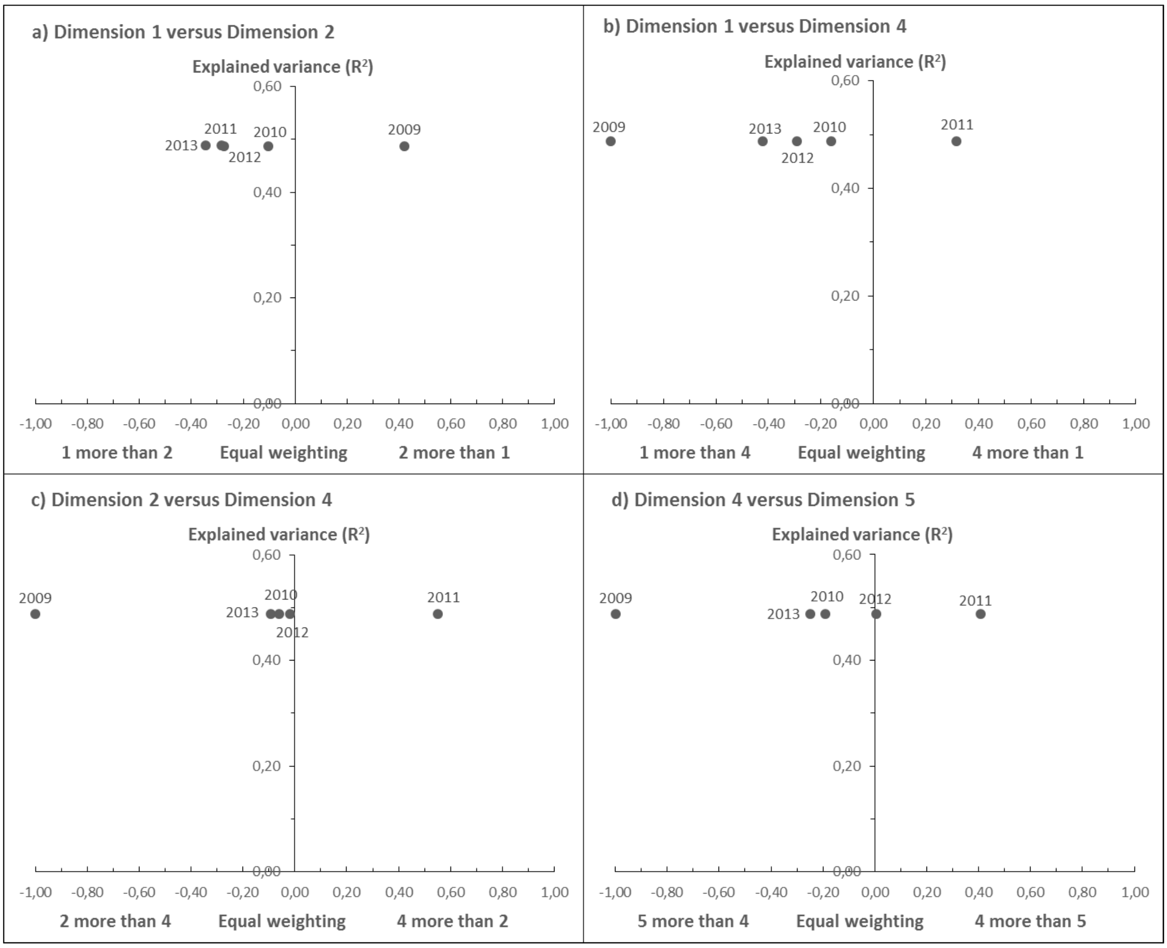

Fig. 7. INDSCAL weights, Young's plots.

Finally, the relative salience of efficiency in dealing with passengers or cargo is explored in section (d) of Figure 7. We can see that efficiency in cargo took more importance before the crisis and that, as the crisis developed, efficiency in dealing with passengers took more importance. This can be due to a fall in cargo activity as a consequence of the economic crisis.

4. Discussion and conclusions

Airports are important infrastructures that command many resources. In Spain, airports are nationally owned and managed through a state company: AENA. There has been substantial interest in establishing if the resources have been efficiently managed in the aeronautical industry.

From 2004 to 2007, the vast majority of small and medium sized airports increased their number of passengers. The financial crisis that started in 2008 impacted on small and medium sized airports that suffered a significant reduction in air traffic compared to large airports. In fact, the reduction in traffic that took place between 2007 and 2013 was so drastic that only two airports reported increases in the number of passengers (27.86% Santander and 1.12% Santiago). However, efficiency depends on inputs and on outputs. This begs the question of how the crisis affected the efficiency of the airport system. The research reported in this paper addresses such question using the technique of Data Envelopment Analysis combined with the tools of Multivariate Statistical Analysis.

The first issue explored is: what is airport DEA efficiency? Is there just one form of DEA efficiency or can several efficiencies be identified? In standard studies data is collected on the values of inputs and outputs and calculations take place. But the results of the analysis depend on the choice of inputs and outputs. This is no trivial matter, as inputs (and outputs) tend to be correlated and there are no modelling rules equivalent to the ones that are available in statistical analysis.

Our approach has been to estimate a variety of input/output combinations that we have named specifications. We have used four inputs and five outputs that are standard in the airport efficiency literature.

The treatment of capital assets has been particularly complex, since appropriate data could not be had from AENA's financial statements. Capital usage had to be estimated from investment expenditure (tangible assets) whilst taking into account established depreciation rules.

In total, efficiencies were estimated under 186 combinations of inputs and outputs. The calculations were performed for each of the five years for which we had data. Since we had data for 47 airports, this represents the calculation of 43,710 efficiency values.

To analyse such a large number of results we resorted to the tools of multivariate statistical analysis, in particular to scaling techniques because these permit the graphical presentation of the main features of the data.

The particular statistical approach chosen was the Individual Differences Scaling model of Carrol and Chang (INDSCAL). INDSCAL produces a "common map", that shows what has remained constant over time, and a set of weights that contain information about time-related changes.

The study of the common map revealed that six efficiency definitions can be identified: (1) efficient use of investment in order to generate passenger activity; (2) cost efficiency in relation to aeronautical activity; (3) efficiency in obtaining revenues in relation to Air Traffic Movements; (4) cost efficiency in dealing with passengers; (5) efficiency in dealing with cargo; and (6) efficiency effects associated with runway length.

Having interpreted the meaning of the dimensions, it is possible to assess the strengths and weaknesses of each airport in terms of efficiency. For example, Vitoria airport is located near the centre of the representation in Figure 1 suggesting that it is slightly better than average in terms of efficient use of investment in order to generate passenger activity, and that it is slightly better than average in terms of cost efficiency as related to aeronautical activity; from Figure 2 we deduce that Vitoria airport is slightly better than average in terms of cost efficiency in relation to ATM, and that it is below average in cost efficiency when dealing with passengers; however, in Figure 3 we see that the real strength of Vitoria is in cargo efficiency. We conclude that in Vitoria airport there is room for improvement in terms of use of investment, cost reduction, and generation of passenger activity, but that it stands as an example of good practice in relation to cargo. Similar analyses can be easily done with any other airport, since this only requires the observation of the airport in the different dimensions of the common map. In fact, it has been shown that operational knowledge can be derived from appropriate processing of the data and that this knowledge can be represented in a graphical way for easy understanding.

The relative importance of these approaches to efficiency has varied over time, and this is revealed in the weights generated by the INDSCAL model. We see in Figure 7 (a) that in 2009 cost efficiency took priority over efficient use of investment in the generation of passenger activity, but that the situation was reversed as a consequence of the economic crisis. In Figure 7

(b) we see that after 2009, cost efficiency in relation to passengers took priority over efficient use of investment. From Figure 7 (c) we observe that, before the crisis, cost efficiency in relation to passengers also took priority over cost efficiency in relation to aeronautical activity. Figure 7 (d) shows how cost efficiency in dealing with cargo lost importance during the period, and this was gained by cost efficiency in relation to passengers. These changes can be related to the loss of outputs as a consequence of the crisis, whilst inputs were slow to adapt to change. What is more, the slow return that is observed to the pre-crisis situation has probably more to do with increases in the outputs than with decreases in the inputs.

We conclude that the combination of multivariate statistical analysis with DEA efficiency evaluation can produce important insights in time related effects in efficiency. However, in this analysis we have not taken into account shifts in the production frontier. This may not be a great loss, since five years is a short period, and the situation is dominated by the impact of the economic crisis.

Appendix A

See Table A1.

Table Al
Coordinates of Spanish airports in the common space.

Code	Airport	Dim1	Dim2	Dim3	Dim4	Dim5	Dim6	Dim7	Dim8	Dim9
LCG	A Coruña	-0,14	0,43	-0,65	-0,63	-0,24	-0,90	0,71	0,93	-0,57
ABC	Albacete	-1,53	2,18	-1,08	-1,38	-1,11	0,69	0,14	0,64	0,64
ALC	Alicante-Elche	1,47	-1,24	1,22	0,30	-0,72	0,89	-1,02	-0,50	0,67
LEI	Almeria	-0,49	-0,18	-0,80	-0,86	-0,36	-0,80	1,46	0,76	-1,02
OVD	Asturias	-0,28	0,11	-0,58	-0,07	-0,32	-0,71	0,19	0,44	-0,55
BJZ	Badajoz	-1,64	1,38	-0,24	1,28	0,01	-1,79	-0,22	-0,82	0,08
BCN	Barcelona-El Prat	1,68	-0,77	1,59	1,07	-0,43	1,58	-1,31	-1,46	1,41
BIO	Bilbao	0,71	-0,61	1,02	0,60	1,07	0,24	-1,23	-0,74	0,82
RGS	Burgos	-1,41	1,39	-1,34	-0,10	-0,39	0,64	0,45	-0,20	0,34
JCU	Ceuta	-1,07	0,38	-0,91	0,20	-1,49	0,47	1,22	-0,94	0,33
ODB	Cordoba	-0,61	2,24	-0,59	-0,38	-0,34	0,54	0,03	-0,29	0,97
VDE	El Hierro	-0,36	0,80	-2,16	-1,54	-0,30	-0,06	0,47	-0,25	-0,30
FUE	Fuerteventura	-0,07	-1,46	-0,49	0,63	0,17	-0,39	1,04	0,38	0,01
GRO	Girona	0,30	-1,31	1,25	0,30	0,36	-0,26	-0,94	0,64	-0,24
LPA	Las Palmas GC	0,94	-0,93	1,35	1,42	1,44	0,66	-1,19	-1,23	1,25
GRX	Granada-Jaen	-0,39	0,52	-0,73	-0,58	-0,18	-1,34	0,30	1,45	-0,92
HSK	Huesca	-1,52	0,82	0,07	-0,31	-0,23	-0,55	-0,99	-0,45	-1,59
IBZ	Ibiza	0,67	-1,17	0,75	1,49	0,27	0,58	-0,33	-0,35	0,45
XRY	Jerez	0,75	-0,46	0,34	1,12	0,24	0,91	0,79	-0,29	0,23
GMZ	La Gomera	-1,18	1,21	-1,02	-1,61	-1,07	1,24	1,14	2,97	-3,16
SPC	La Palma	-0,51	0,07	-1,34	-0,76	0,19	-1,23	1,59	1,59	-1,27
ACE	Lanzarote	1,75	-0,87	0,54	0,31	0,73	0,63	-0,40	-0,72	0,51
LEN	Leon	-1,20	1,03	-0,06	-1,47	-0,84	-0,54	0,76	1,10	-0,55
RJL	Logroño-Agoncillo	-1,17	2,31	-0,86	-1,65	-0,95	1,18	-0,63	0,49	-0,20
MAD	Madrid-Barajas	1,73	-0,57	1,68	1,06	-0,04	1,58	-1,57	-1,52	1,55
MCV	Madrid-Cuatro Vientos	1,72	-0,52	1,68	1,09	0,02	1,56	-1,54	-1,51	1,50
TOJ	Madrid-Torrejon	-1,08	-0,45	-1,54	0,31	0,60	1,43	2,26	0,75	-1,66
AGP	Malaga	0,30	-1,55	1,49	0,36	-0,97	0,29	-1,15	-0,34	1,32
MLN	Melilla	-0,62	1,17	-0,84	-1,19	-0,95	-1,66	-0,03	-1,12	-0,92
MAH	Menorca	-0,16	-0,43	-0,84	-0,06	-0,09	-0,79	1,54	0,72	-1,00
MJV	Murcia	-0,11	-1,07	-0,57	1,55	-0,84	-0,87	1,20	0,88	-0,35
PMI	Palma de Mallorca	1,73	-0,57	1,68	1,06	-0,04	1,58	-1,57	-1,52	1,53
PNA	Pamplona	-0,78	0,84	-0,10	-1,50	-0,45	-1,29	0,72	-0,11	-0,29
REU	Reus	-0,17	-0,27	-0,25	-0,45	0,02	-1,14	0,96	1,72	-0,60
QSA	Sabadell	1,38	-0,51	1,62	1,63	-0,64	1,43	-1,45	-1,20	1,44
SLM	Salamanca	-0,92	-0,25	-0,48	-0,89	0,06	-0,84	-0,97	1,98	-0,83
EAS	San Sebastian	-0,15	1,16	-0,23	-0,97	-0,31	-0,59	-0,66	-1,16	0,41
SDR	Santander	-0,23	0,05	-0,46	1,15	-0,43	-0,38	0,85	0,06	-0,24
SCQ	Santiago Compost	-0,37	-0,68	-0,45	-0,89	-0,39	-1,19	0,55	0,86	-0,83
SVQ	Sevilla	1,63	-0,26	1,05	0,98	1,36	0,62	-1,15	-0,96	0,98
TFN	Tenerife Norte	0,29	-1,40	0,80	1,02	0,95	0,10	-0,21	-0,53	0,56
TFS	Tenerife Sur	1,42	-0,99	0,33	1,04	-0,77	0,40	-0,23	-0,06	0,44
VLC	Valencia	0,74	-0,90	1,38	0,75	0,31	0,43	-1,33	-0,23	0,94
VLL	Valladolid	-0,85	0,13	-0,81	-1,25	-0,10	-1,66	0,55	0,08	-0,97
VGO	Vigo	-0,47	0,36	-0,66	-1,03	-0,23	-1,65	1,03	0,62	-1,28
VIT	Vitoria	0,32	0,94	0,24	-0,96	3,38	0,75	0,07	-0,45	0,80
ZAZ	Zaragoza	-0,04	-0,13	0,02	-0,20	4,05	0,22	0,08	-0,12	0,14

Appendix B

See Table B1.

Table Bl
End points of normalised ProFit vectors.

Model	$\boldsymbol{\beta}_1^*$	$\boldsymbol{\beta}_2^*$	$\boldsymbol{\beta}_3^*$	$\boldsymbol{\beta}_4^*$	$\boldsymbol{\beta}_5^*$	$\boldsymbol{\beta}_6^*$	$\boldsymbol{\beta}_7^*$	$\boldsymbol{\beta}_8^*$	$\boldsymbol{\beta}_9^*$	R^2
ABCD12345	-0,230	0,057	0,137	0,386	0,228	0,194	-0,301	-0,155	0,756	0,519
ABCD12	0,388	-0,403	-0,020	0,740	-0,161	-0,211	-0,241	-0,070	-0,078	0,820
ABCD2	0,092	-0,540	0,420	0,522	-0,138	0,303	-0,278	-0,223	-0,115	0,800
ABCD2345	-0,222	-0,016	0,206	0,134	0,241	0,399	-0,307	-0,212	0,731	0,544
ABCD234	0,364	-0,598	0,367	0,352	0,483	0,062	0,013	-0,044	0,109	0,863
ABCD235	-0,460	0,195	0,417	-0,056	0,288	0,400	-0,134	-0,329	0,453	0,586
ABCD245	-0,033	0,034	0,113	0,333	-0,391	0,316	-0,447	-0,183	0,623	0,537
ABCD23	-0,052	-0,386	0,552	0,193	0,577	0,356	-0,010	-0,200	0,078	0,856
ABCD24	0,437	-0,625	0,150	0,563	-0,168	-0,029	-0,214	-0,028	-0,061	0,859
ABCD25	-0,378	0,270	0,411	0,083	-0,198	0,407	-0,264	-0,379	0,436	0,539
ABC12345	-0,196	0,096	0,149	0,499	0,280	0,219	-0,321	0,043	0,670	0,548
ABC1234	0,389	-0,428	0,223	0,599	0,464	-0,172	-0,020	-0,064	0,090	0,833
ABC1235	-0,096	0,324	0,116	0,582	0,369	0,198	-0,308	0,007	0,513	0,523
ABC1245	-0,051	0,087	0,038	0,652	-0,290	0,128	-0,441	0,059	0,515	0,545
ABC123	0,468	-0,213	0,137	0,655	0,502	-0,176	-0,039	-0,059	0,001	0,820
ABC124	0,399	-0,445	0,014	0,718	-0,145	-0,218	-0,226	-0,048	-0,069	0,840
ABC125	0,050	0,307	0,002	0,731	-0,201	0,111	-0,426	0,020	0,367	0,498
ABC12	0,457	-0,267	-0,063	0,758	-0,104	-0,218	-0,243	-0,046	-0,146	0,809
ABC2	0,218	-0,393	0,375	0,632	-0,073	0,269	-0,305	-0,199	-0,217	0,786
ABC2345	-0,192	0,068	0,274	0,296	0,308	0,400	-0,328	-0,011	0,658	0,565
ABC234	0,418	-0,547	0,356	0,375	0,500	0,043	-0,012	-0,014	0,077	0,862
ABC235	-0,367	0,365	0,455	0,148	0,395	0,395	-0,146	-0,179	0,371	0,591
ABC245	-0,025	0,082	0,161	0,503	-0,324	0,311	-0,483	0,015	0,529	0,553
ABC23	0,063	-0,258	0,524	0,289	0,652	0,334	-0,030	-0,183	-0,010	0,859
ABC24	0,477	-0,578	0,140	0,577	-0,148	-0,045	-0,235	-0,003	-0,087	0,855
ABC25	-0,315	0,399	0,442	0,358	-0,076	0,418	-0,254	-0,053	0,412	0,523
ABD12345	-0,332	-0,090	0,380	0,264	0,181	0,304	-0,145	-0,091	0,716	0,497
ABD1234	0,308	-0,615	0,284	0,494	0,420	-0,046	0,055	-0,060	0,131	0,828
ABD1235	-0,352	0,004	0,419	0,255	0,222	0,321	-0,134	-0,135	0,669	0,478
ABD1245	-0,160	-0,073	0,279	0,455	-0,418	0,227	-0,283	-0,072	0,611	0,510
ABD123	0,336	-0,542	0,266	0,538	0,461	-0,039	0,045	-0,058	0,118	0,809
ABD124	0,349	-0,615	0,057	0,642	-0,196	-0,115	-0,169	-0,048	-0,040	0,851
ABD125	-0,192	0,028	0,331	0,459	-0,401	0,251	-0,273	-0,125	0,573	0,480
ABD12	0,362	-0,550	0,020	0,684	-0,203	-0,112	-0,195	-0,049	-0,068	0,828
ABD2	-0,014	-0,582	0,440	0,484	-0,162	0,333	-0,223	-0,198	-0,086	0,796
ABD2345	-0,420	-0,055	0,477	0,140	0,169	0,369	-0,120	-0,125	0,616	0,533
ABD234	0,222	-0,650	0,419	0,352	0,441	0,105	0,048	-0,020	0,141	0,842
ABD235	-0,519	0,130	0,556	-0,040	0,235	0,371	-0,019	-0,253	0,382	0,572
ABD245	-0,268	-0,022	0,417	0,326	-0,392	0,323	-0,258	-0,112	0,557	0,542
ABD23	-0,133	-0,406	0,581	0,178	0,518	0,377	0,023	-0,177	0,077	0,830
ABD24	0,318	-0,686	0,198	0,562	-0,199	0,015	-0,180	-0,010	-0,030	0,855
ABD25	-0,461	0,189	0,581	0,086	-0,194	0,378	-0,116	-0,288	0,360	0,534
ACD12345	-0,023	0,247	0,040	-0,007	0,314	0,399	-0,545	-0,398	0,473	0,569
ACD1234	0,287	-0,447	0,233	0,356	0,597	0,186	-0,246	-0,293	-0,002	0,829
ACD1235	-0,136	0,280	0,147	-0,053	0,346	0,406	-0,440	-0,446	0,449	0,571
ACD1245	0,154	0,275	-0,043	0,167	-0,300	0,306	-0,651	-0,371	0,354	0,544
ACD123	0,226	-0,410	0,287	0,330	0,634	0,204	-0,189	-0,331	0,015	0,825
ACD124	0,435	-0,098	0,631	-0,362	0,301	-0,258	0,304	-0,142	0,047	0,053
ACD125	0,033	0,332	0,072	0,129	-0,272	0,340	-0,586	-0,453	0,360	0,534
ACD12	0,333	-0,457	0,043	0,581	-0,194	0,077	-0,426	-0,291	-0,178	0,784
ACD2	0,192	-0,486	0,332	0,473	-0,155	0,360	-0,328	-0,314	-0,182	0,818
ACD2345	0,064	0,241	0,122	-0,122	0,302	0,480	-0,493	-0,373	0,451	0,572
ACD234	0,358	-0,468	0,346	0,208	0,562	0,297	-0,181	-0,226	-0,047	0,872
ACD235	-0,289	0,340	0,336	-0,104	0,318	0,440	-0,237	-0,390	0,419	0,583
ACD245	0,206	0,194	-0,036	0,117	-0,405	0,354	-0,655	-0,336	0,271	0,525
ACD23	0,014	-0,296	0,557	0,147	0,581	0,405	-0,023	-0,278	0,004	0,866

Model	β_1^*	β_2^*	β_3^*	β_4^*	β_5^*	β_6^*	β_7^*	β_8^*	β_9^*	R^2
ACD24	0,452	-0,510	0,128	0,450	-0,196	0,172	-0,400	-0,201	-0,219	0,846
ACD25	-0,165	0,409	0,303	0,040	-0,228	0,428	-0,380	-0,438	0,375	0,540
AC12345	0,069	0,428	0,029	0,218	0,442	0,379	-0,548	-0,186	0,300	0,591
AC1234	0,388	-0,284	0,195	0,416	0,638	0,137	-0,254	-0,244	-0,088	0,846
AC1235	-0,039	0,514	0,114	0,218	0,505	0,355	-0,429	-0,225	0,243	0,582
AC1245	0,218	0,428	-0,064	0,391	-0,142	0,292	-0,667	-0,167	0,183	0,537
AC123	0,326	-0,182	0,231	0,427	0,695	0,136	-0,191	-0,274	-0,106	0,837
AC124	0,453	-0,325	-0,019	0,609	-0,129	0,023	-0,446	-0,204	-0,244	0,799
AC125	0,117	0,556	0,022	0,412	-0,049	0,295	-0,588	-0,226	0,142	0,499
AC12	0,423	-0,254	0,007	0,659	-0,087	0,023	-0,419	-0,245	-0,279	0,762
AC2	0,297	-0,222	0,367	0,600	-0,047	0,292	-0,306	-0,279	-0,330	0,789
AC2345	0,138	0,455	0,154	0,141	0,438	0,443	-0,490	-0,154	0,279	0,594
AC234	0,448	-0,321	0,314	0,275	0,610	0,251	-0,192	-0,187	-0,125	0,887
AC235	-0,139	0,578	0,318	0,175	0,466	0,382	-0,247	-0,180	0,241	0,589
AC245	0,289	0,462	0,064	0,325	-0,160	0,362	-0,625	-0,139	0,166	0,543
AC23	0,133	-0,106	0,506	0,263	0,670	0,351	-0,036	-0,246	-0,110	0,878
AC24	0,533	-0,377	0,102	0,505	-0,132	0,133	-0,405	-0,166	-0,285	0,844
AC25	-0,015	0,658	0,274	0,367	-0,041	0,359	-0,402	-0,196	0,164	0,505
AD12345	-0,317	0,087	0,455	-0,231	0,030	0,570	-0,177	-0,412	0,323	0,450
AD1234	0,008	-0,614	0,413	0,256	0,334	0,442	-0,072	-0,271	-0,033	0,776
AD1235	-0,357	0,110	0,469	-0,209	0,057	0,550	-0,154	-0,402	0,326	0,450
AD1245	-0,179	0,112	0,441	-0,128	-0,450	0,508	-0,221	-0,404	0,267	0,493
AD123	-0,022	-0,591	0,430	0,271	0,360	0,437	-0,049	-0,261	-0,006	0,778
AD124	0,132	-0,615	0,231	0,439	-0,350	0,306	-0,240	-0,240	-0,166	0,819
AD125	-0,228	0,137	0,464	-0,110	-0,420	0,498	-0,201	-0,402	0,275	0,487
AD12	0,108	-0,609	0,251	0,465	-0,338	0,308	-0,226	-0,236	-0,146	0,814
AD2	-0,009	-0,491	0,475	0,356	-0,286	0,419	-0,146	-0,317	-0,165	0,795
AD2345	-0,340	0,182	0,518	-0,204	0,029	0,533	-0,120	-0,393	0,296	0,460
AD234	-0,048	-0,531	0,512	0,161	0,320	0,496	-0,031	-0,276	-0,041	0,788
AD235	-0,414	0,238	0,529	-0,153	0,088	0,481	-0,064	-0,380	0,285	0,464
AD245	-0,214	0,208	0,510	-0,108	-0,419	0,478	-0,160	-0,386	0,246	0,505
AD23	-0,133	-0,405	0,581	0,133	0,367	0,486	0,030	-0,303	-0,024	0,782
AD24	0,081	-0,572	0,358	0,362	-0,342	0,387	-0,202	-0,262	-0,174	0,828
AD25	-0,311	0,272	0,541	-0,066	-0,334	0,446	-0,104	-0,387	0,247	0,493
BCD12345	0,084	-0,060	0,192	0,080	0,195	0,262	-0,173	-0,141	0,889	0,508
BCD1234	0,693	-0,437	0,229	0,166	0,324	-0,201	0,087	0,080	0,298	0,871
BCD1235	0,081	0,036	0,216	0,070	0,258	0,281	-0,184	-0,197	0,850	0,492
BCD1245	0,257	-0,028	0,084	0,272	-0,444	0,161	-0,300	-0,106	0,727	0,514
BCD123	0,732	-0,361	0,195	0,202	0,364	-0,203	0,056	0,078	0,269	0,856
BCD124	0,711	-0,476	0,049	0,353	-0,198	-0,254	-0,113	0,079	0,137	0,885
BCD125	0,260	0,069	0,109	0,279	-0,427	0,182	-0,319	-0,170	0,701	0,486
BCD12	0,729	-0,412	0,002	0,397	-0,192	-0,256	-0,156	0,073	0,096	0,860
BCD2	0,539	-0,539	0,486	0,260	-0,189	0,169	-0,200	-0,043	0,100	0,866
BCD2345	0,009	-0,040	0,285	-0,039	0,217	0,383	-0,200	-0,198	0,802	0,549
BCD234	0,649	-0,476	0,350	0,069	0,356	-0,058	0,087	0,110	0,275	0,909
BCD235	-0,327	0,157	0,469	-0,187	0,282	0,398	-0,065	-0,329	0,513	0,580
BCD245	0,215	0,013	0,187	0,161	-0,436	0,295	-0,341	-0,167	0,687	0,547
BCD23	0,315	-0,371	0,592	-0,036	0,532	0,236	0,061	-0,045	0,258	0,905
BCD24	0,723	-0,526	0,176	0,275	-0,188	-0,131	-0,113	0,116	0,125	0,916
BCD25	-0,213	0,231	0,478	-0,070	-0,233	0,409	-0,189	-0,385	0,512	0,536
BC12345	0,237	-0,086	0,249	0,118	0,291	0,230	-0,144	0,086	0,834	0,524
BC1234	0,710	-0,407	0,206	0,166	0,352	-0,221	0,066	0,103	0,270	0,865
BC1235	0,354	0,169	0,211	0,235	0,424	0,223	-0,151	0,043	0,701	0,493
BC1245	0,392	-0,093	0,121	0,327	-0,363	0,133	-0,302	0,103	0,682	0,520
BC123	0,781	-0,235	0,131	0,249	0,405	-0,226	0,037	0,095	0,176	0,849
BC124	0,726	-0,455	0,032	0,350	-0,164	-0,272	-0,131	0,101	0,116	0,873
BC125	0,523	0,160	0,075	0,454	-0,271	0,123	-0,317	0,059	0,545	0,465
BC12	0,773	-0,301	-0,048	0,428	-0,124	-0,274	-0,165	0,090	0,023	0,839
BC2	0,684	-0,398	0,419	0,346	-0,093	0,115	-0,238	-0,005	-0,007	0,846
BC2345	0,137	-0,029	0,414	0,024	0,316	0,327	-0,166	0,037	0,757	0,553
BC234	0,663	-0,438	0,341	0,078	0,387	-0,087	0,059	0,148	0,252	0,903
BC235	-0,099	0,300	0,564	-0,077	0,446	0,373	-0,035	-0,175	0,454	0,561
BC245	0,344	-0,019	0,303	0,246	-0,360	0,245	-0,343	0,063	0,646	0,542
BC23	0,445	-0,245	0,537	0,032	0,621	0,192	0,034	-0,014	0,168	0,911
BC24	0,737	-0,498	0,167	0,281	-0,152	-0,159	-0,140	0,151	0,105	0,903

Model	β_1^*	β_2^*	β_3^*	β_4^*	β_5^*	β_6^*	β_7^*	β_8^*	β_9^*	R^2
BC25	0,061	0,397	0,612	0,110	-0,126	0,389	-0,202	-0,210	0,446	0,486
BD12345	-0,137	-0,097	0,477	0,120	0,152	0,265	-0,024	-0,073	0,795	0,508
BD1234	0,620	-0,497	0,305	0,189	0,308	-0,155	0,125	0,112	0,304	0,864
BD1235	-0,166	-0,023	0,511	0,101	0,201	0,285	-0,024	-0,122	0,751	0,491
BD1245	0,035	-0,077	0,381	0,312	-0,460	0,185	-0,161	-0,049	0,690	0,527
BD123	0,649	-0,442	0,288	0,223	0,350	-0,152	0,106	0,110	0,287	0,845
BD124	0,647	-0,539	0,116	0,377	-0,225	-0,213	-0,081	0,108	0,144	0,894
BD125	0,012	0,001	0,430	0,305	-0,444	0,213	-0,162	-0,112	0,664	0,497
BD12	0,665	-0,492	0,075	0,421	-0,227	-0,213	-0,119	0,100	0,108	0,871
BD2	0,410	-0,602	0,522	0,254	-0,218	0,208	-0,160	-0,026	0,123	0,861
BD2345	-0,250	-0,087	0,552	-0,014	0,143	0,354	-0,022	-0,105	0,684	0,544
BD234	0,526	-0,539	0,427	0,087	0,333	-0,027	0,121	0,138	0,312	0,883
BD235	-0,403	0,086	0,601	-0,162	0,226	0,368	0,046	-0,249	0,438	0,577
BD245	-0,078	-0,057	0,501	0,162	-0,435	0,306	-0,154	-0,090	0,632	0,559
BD23	0,202	-0,426	0,619	-0,035	0,491	0,265	0,089	-0,030	0,271	0,882
BD24	0,613	-0,598	0,249	0,298	-0,227	-0,103	-0,083	0,144	0,161	0,907
BD25	-0,321	0,140	0,642	-0,057	-0,223	0,378	-0,042	-0,286	0,430	0,544
CD12345	0,573	0,191	0,145	-0,420	0,195	0,235	-0,324	-0,312	0,378	0,613
CD1234	0,759	-0,244	0,254	-0,212	0,401	0,117	-0,196	-0,110	0,171	0,890
CD1235	0,470	0,215	0,236	-0,452	0,242	0,249	-0,279	-0,360	0,381	0,610
CD1245	0,696	0,224	0,062	-0,255	-0,296	0,148	-0,387	-0,269	0,255	0,608
CD123	0,724	-0,220	0,307	-0,220	0,441	0,126	-0,169	-0,139	0,163	0,890
CD124	0,856	-0,254	0,072	0,015	-0,235	0,022	-0,364	-0,092	0,004	0,878
CD125	0,630	0,260	0,156	-0,294	-0,280	0,168	-0,369	-0,328	0,273	0,592
CD12	0,853	-0,244	0,118	0,019	-0,229	0,027	-0,362	-0,120	-0,009	0,865
CD2	0,771	-0,230	0,442	0,100	-0,235	0,138	-0,257	-0,077	0,034	0,906
CD2345	0,562	0,212	0,206	-0,410	0,201	0,251	-0,302	-0,299	0,380	0,618
CD234	0,742	-0,228	0,357	-0,190	0,402	0,152	-0,149	-0,073	0,148	0,925
CD235	0,191	0,309	0,427	-0,396	0,283	0,292	-0,162	-0,365	0,453	0,598
CD245	0,691	0,245	0,121	-0,246	-0,299	0,164	-0,370	-0,258	0,259	0,613
CD23	0,521	-0,167	0,581	-0,152	0,489	0,223	-0,021	-0,080	0,210	0,925
CD24	0,861	-0,246	0,175	0,032	-0,231	0,056	-0,326	-0,060	-0,016	0,919
CD25	0,403	0,378	0,368	-0,272	-0,273	0,234	-0,279	-0,371	0,375	0,573
C12345	0,673	0,397	0,076	-0,235	0,373	0,128	-0,355	-0,115	0,185	0,606
C1234	0,826	0,008	0,126	-0,130	0,477	0,056	-0,211	-0,096	0,024	0,880
C1235	0,606	0,456	0,129	-0,221	0,437	0,125	-0,329	-0,136	0,161	0,594
C1245	0,780	0,389	0,004	-0,100	-0,080	0,063	-0,448	-0,102	0,097	0,552
C123	0,797	0,082	0,148	-0,092	0,527	0,045	-0,189	-0,109	-0,014	0,871
C124	0,905	-0,053	-0,020	0,070	-0,101	-0,026	-0,377	-0,088	-0,110	0,825
C125	0,744	0,464	0,057	-0,086	-0,025	0,060	-0,441	-0,128	0,074	0,518
C12	0,901	0,017	-0,002	0,113	-0,058	-0,037	-0,370	-0,103	-0,153	0,787
C2	0,880	0,069	0,257	0,208	-0,044	0,044	-0,287	-0,055	-0,148	0,846
C2345	0,640	0,452	0,187	-0,205	0,382	0,133	-0,314	-0,092	0,198	0,607
C234	0,809	0,026	0,240	-0,107	0,486	0,090	-0,162	-0,065	0,014	0,922
C235	0,460	0,562	0,313	-0,155	0,472	0,141	-0,228	-0,108	0,211	0,581
C245	0,762	0,448	0,111	-0,067	-0,086	0,066	-0,415	-0,081	0,106	0,556
C23	0,678	0,134	0,388	-0,032	0,589	0,127	-0,066	-0,055	0,017	0,924
C24	0,915	-0,037	0,088	0,095	-0,102	0,006	-0,340	-0,060	-0,125	0,876
C25	0,632	0,605	0,263	-0,018	-0,014	0,081	-0,360	-0,107	0,130	0,498
D12345	0,289	0,242	0,556	-0,405	-0,302	0,294	0,037	-0,328	0,313	0,534
D1234	0,597	-0,318	0,593	-0,178	-0,092	0,317	0,087	-0,181	0,095	0,892
D1235	0,265	0,253	0,571	-0,399	-0,289	0,292	0,045	-0,332	0,316	0,530
D1245	0,311	0,224	0,521	-0,356	-0,440	0,274	-0,007	-0,327	0,281	0,553
D123	0,598	-0,303	0,604	-0,166	-0,080	0,318	0,094	-0,185	0,089	0,892
D124	0,615	-0,350	0,466	-0,043	-0,431	0,253	-0,034	-0,171	0,002	0,923
D125	0,287	0,236	0,538	-0,351	-0,429	0,273	0,001	-0,332	0,284	0,549
D12	0,618	-0,336	0,476	-0,030	-0,425	0,254	-0,029	-0,176	-0,005	0,922
D2	0,567	-0,323	0,549	-0,023	-0,410	0,260	-0,005	-0,190	-0,001	0,910
D2345	0,233	0,248	0,586	-0,397	-0,290	0,298	0,050	-0,324	0,320	0,532
D234	0,571	-0,306	0,626	-0,172	-0,084	0,317	0,099	-0,179	0,099	0,889
D235	0,141	0,278	0,629	-0,378	-0,239	0,295	0,076	-0,338	0,316	0,519
D245	0,258	0,232	0,553	-0,350	-0,429	0,280	0,007	-0,324	0,290	0,551
D23	0,523	-0,280	0,675	-0,160	-0,048	0,319	0,123	-0,195	0,095	0,884
D24	0,597	-0,342	0,497	-0,038	-0,428	0,255	-0,024	-0,172	0,005	0,920
D25	0,167	0,264	0,604	-0,334	-0,382	0,281	0,035	-0,342	0,288	0,534

References

Ahn, Y.H.; and Min. H. (2014): 'Evaluating the multi-period operating efficiency of international airports using data envelopment analysis and the Malmquist productivity index'. *Journal of Air Transport Management* 39, 12-22

Ashford, N.; Stanton, H. and Moore, C. (1996): *'Airport Operations'* NewYork, McGraw-Hill Education (second edition)

Assaf, A.G.; Gillen, D. and Barros, C. (2012): 'Performance assessment of UK airports: evidence from a Bayesian dynamic frontier model'. *Transportation Research Part E* 48, 603–615

Banker, R.D. and Morey, R.C. (1986): 'Efficiency analysis for exogenously fixed inputs and outputs'. *Operations Research* 34 (4), 513-521

Barros, C. and Dieke, P.U.C. (2007): 'Performance evaluation of Italian airports: A data envelopment analysis' *Journal of Air Transport Management* 13, 184–191

Barros, C. (2008a): 'Airports in Argentina: Technical efficiency in the context of an economic crisis' *Journal of Air Transport Management* 14, 315–319

Barros, C. (2008b): 'Technical efficiency of UK airports' *Journal of Air Transport Management* 14, 175–178

Barros, C. (2009): 'The measurement of efficiency of UK airports, using a Stochastic Latent Class Frontier Model'. *Transport Reviews* 29, 479–498

Barros, C. and Sampaio, A. (2004): 'Technical and allocative efficiency in airports' *International Journal of Transport Economics* 31, 355-377

Bazargan, M. and Vasigh, B. (2003): 'Size versus efficiency: A case study of US commercial airports'. *Journal of Air Transport Management* 9, 187–193

Bezerra, G.C.L.; and Gomes, C.F. (2016) Performance measurement in airport settings: a systematic literature review. *Benchmarking: an International Journal* 23, 1027-1050.

Cambra de Comerç de Barcelona (November 2010): *'El modelo de gestión aeroportuaria en España: marco institucional y jurídico y líneas maestras para una propuesta de cambio'.*

Carroll, J.D. and Chang, J.J. (1970): 'Analysis of individual differences in multidimensional scaling via an N-way generalization of "Eckart-Young" decomposition' *Psychometrika* 35, 283–319

Chi-Lok, A.Y. and Zhang, A. (2009): 'Effects of competition and policy changes on Chinese airport productivity: an empirical investigation' *Journal of Air Transport Management* 15, 166-174.

Comisión Nacional de los Mercados y la Competencia (CNMC, July 2014): *'El Sector Aeorportuario en España: Situación Actual y Recomendaciones de Liberización'*

Cordero-Ferrara, J.M.; Pedraja-Chaparro, F. and Salinas-Jimenez, J. (2008): 'Measuring efficiency in education: an analysis of different approaches for incorporating non-discretionary inputs'. *Applied Economics* 40, 1323-1339

Coto-Millan, P.; Carrera-Gomez, G.; Castanedo-Galan, J.; Inglada, V.; Nuñez-Sanchez, R.; Pesquera, M.A.; Sainz, R. (2007): 'Efficiency Stochastic Frontiers: a Panel Data Analysis for Spanish Airports (1992–1994)' in *Essays on Transport Economics* (chapter 121-126), Physica-Verlag HD

Coto-Millan, P.; Casares-Hontañón, P.; Inglada, V.; Agüeros, M.; Pesquera, M.A.; Badiola, A. (2014): 'Small is beautiful? The impact of economic crisis, low cost carriers, and size on efficiency in Spanish airports (2009–2011)' *Journal of Air Transport Management* 40, 34-41

Coto-Millan, P.; Inglada, V.; Fernandez, X.L.; Inglada-Perez, L. and Pesquera, M.A. (2016): 'The *effect procargo* on technical and scale efficiency at airports: The case of Spanish airports (2009–2011)' *Utilities Policy* 39, 29-35

Coxon, A.P.M. (1982): '*The user's guide to Multidimensional Scaling'* Heinemann Educational Books, London, UK.

European Commission European Court of Auditors (2014): *'EU-funded airport infrastructures: poor value for money'* Special Report, 21 http://www.politico.eu/article/eu-wasted-money-on-new-airports-say-auditors/

Fasone, V.; Kofler, L.; and Scuderi, R. (2016): 'Business performance in airports: non-aviation revenues and their determinants'. *Journal of Air Transport Management* 53, 35-45.

Fragoudaki, A.; Giokas, D.; and Glyptou, K. (2016): 'Efficiency and productivity changes in Greek airports during the crisis years 2010-2014'. *Journal of Air Transport Management* 57, 306-315

Gillen, D., and A. Lall (1997): 'Developing Measures of airport productivity and performance: an application of Data Envelopment Analysis'. *Transportation Research Part B* 33 (4), 261-73

Gower, J. C. and Hand, D. J. (1996): *'Biplots'* Chapman and Hall, London

Gutiérrez-Nieto, B.; Serrano-Cinca, C. and Mar-Molinero, C. (2007): 'Microfinance institutions and efficiency' *Omega, the international journal of Management Science* 35, 131-142

Humphreys, I. (1999): 'Privatisation and commercialisation Changes in UK airport ownerships patterns' *Journal of Transport Geography* 7, 121-134

International Civil Aviation Organization (ICAO) (March 2013): '*Worldwide Air Transport Conference (ATCONF) Sixth meeting: Airport Competition'* https://www.google.com/maps/d/viewer?mid=zylWTnxRlUJE.kU5cVv1m27wk&hl=en_US

Kao, C.; Hwang, S.N. (2014): 'Multi-period efficiency and Malmquist productivity index in two-stage production systems'. *European Journal of Operational Research* 232, 512-521

Kruskal, J.B. (1964): 'Multidimensional scaling by optimizing goodness of fit to a non-metric hypothesis' *Psychometrika* 29, 1-27

Liu, D. (2017): 'Evaluating the multi-period efficiency of East Asia airport companies'. *Journal of Air Transport Management* 59, 71-82

Lozano S. and Gutiérrez, E. (2011): **'**Slacks-based measure of efficiency of airports with airplanes delays as undesirable outputs'**.** *Journal Computers and Operations Research* 38(1), 131-139

Lozano S.; Gutierrez, E. and Moreno, P. (2013): 'Network DEA approach to airports performance assessment considering undesirable outputs'. *Applied Mathematical Modelling* 37, 1665-1676

Mar-Molinero, C. and Mingers, J. (2006): 'An evaluation of the limitations of, and alternatives to, the Co-Plot Methodology' *Journal of the Operational Research Society* 58, 874-886

Martin J.C. and Roman, C. (2001): 'An application of DEA to measure the efficiency of Spanish airports prior to privatization' *Journal of Air Transport Management* 7(3), 149-157

Martin J.C. and Roman, C. (2006): ‘A benchmarking analysis of Spanish commercial airports. A comparison between SMOP and DEA ranking methods’ *Networks and Spatial Economics* 6(2), 111–134

Martin J.C.; Roman, C. and Voltes-Dorta, A. (2009): ‘A stochastic frontier analysis to estimate the relative efficiency of the Spanish airports’ *Journal of Productivity Analysis* 31(3), 163-176

Martin J.C.; Roman, C. and Voltes-Dorta, A. (2011): ‘Scale economies and marginal costs in Spanish airports’ *Transportation Research Part E* 47, 238-248

Martin-Cejas, R.R. (2002): ‘An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier’ *Journal of Air Transport Management* 8 (4), 233–238

Murillo-Melchor, C. (1999): ‘An Analysis of technical efficiency and productivity changes in Spanish Airports using the Malmquist Index’ *International Journal of Transport Economics 26(2), 271-292*

Parker, D. (1999): ‘The Performance of BAA Before and After Privatisation: A DEA Study’ *Journal of Transport Economics and Policy* 33 (2), 133-146

Pathomsiri S.; Haghani, A.; Dresner, M. and Windle, R.J. (2008): ‘Impact of undesirable outputs on the productivity of US airports’ *Transportation Research Part E* 44, 235–259

Pels, E.; Nijkamp, P. and Rietveld, P. (2001): ‘Relative Efficiency of European Airports’. *Transport Policy* 8 (3), 183-92

Pels, E.; Nijkamp, P. and Rietveld, P. (2003): ‘Inefficiencies and scale economies of European airport operations’ *Transportation Research Part E* 39, 341-361

Ripoll-Zarraga A.E. and Mar-Molinero, C. (2017): ‘Spanish airports: a visual study of management efficiency’ Funcas *Working Papers* September, 791

Ruggiero, J. (1998): ‘Non-discretionary inputs in Data Envelopment Analysis’. *European Journal of Operational Research* 111, 461-469

Sagarra, M.; Mar-Molinero, C. and Agasisti, T. (2017): ‘Exploring the efficiency of Mexican universities: integrating Data Envelopment Analysis and Multidimensional Scaling’. *Omega, the international journal of Management Science* 67, 123-133

Salazar de la Cruz, F. (1999): 'Technical, allocative and economic efficiency in transport' *International Journal of Transport Economics 26(2), 255-270*

Sarkis, J. (2000): 'An Analysis of the Operational Efficiency of Major Airports in the United States'. *Journal of Operations Management* 18 (3), 335-51

Sarkis, J. and Talluri, S. (2004): 'Performance based clustering for benchmarking of US airports' *Transportation Research Part A* 38, 329–346

Schiffman, J.F.; Reynolds, M.L. and Young, F.W. (1981): *'Introduction to Multidimensional Scaling: Theory, Methods, and Applications'* Academic Press, London.

Serrano-Cinca, C.; Mar-Molinero, C. and Fuertes, Y. (2016): 'Input and output search in DEA: the case of financial institutions'. Chapter 3 in *'Handbook of operations analytics using Data Envelopment Analysis'* Hwang, S.N.; Lee, H.S. and Zhu, J. Editors, Springer. New York.

Tapiador, F.J.; Mateos, A. and Marti-Henneberg, J. (2008): 'The geographical efficiency of Spain's regional airports: a quantitative analysis' *Journal of Air Transport Management* 14(4), 205-212

Thanassoulis, E. (2001): *'Introduction to the theory and application of Data Envelopment Analysis: a foundation text with integrated software'* Springer, USA.

Tovar, B. and Martin-Cejas, R.R. (2009): 'Are outsourcing and non-aeronautical revenues important drivers in the efficiency of Spanish airports?' *Journal of Air Transport Management* 15(5), 217-220

Tovar, B. and Martin-Cejas, R.R. (2010): 'Technical efficiency and productivity changes in Spanish airports: A parametric distance functions approach' *Transportation Research Part E* 46(5), 249-260

Wang R.T.; Ho, C.T.; Feng, C.M. and Yang, Y.K.(2004): 'A comparative analysis of the operational performance of Taiwan's major airports' *Journal of Air Transport Management* 10, 353–360.

Word Finance (March, 2016): *'Spain's infrastructure woes are more serious than they appear'* http://www.worldfinance.com/infrastructure-investment/government-policy/spains-infrastructure-woes-are-more-serious-than-they-appear

Yu, M.M.; Hsu, S.H.; Chang, C.C. and Lee, D.H. (2008): 'Productivity growth of Taiwan's major domestic airports in the presence of aircraft noise' *Transportation Research Part E* 44, 543–554

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Chapter four

A centralised DEA approach to resource reallocation in Spanish airports

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List of Tables

List of Figures

A centralised DEA approach to resource reallocation in Spanish airports

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Abstract

A centralized data envelopment analysis (DEA) approach optimises the resource usage for all the different units in an organization rather than for each unit separately (conventional DEA). This is particularly relevant for the Spanish airports since the inputs and outputs are controlled centrally by a government-owned company rather than by individual airport managers. In this study a non-oriented Slack-based inefficiency (SBI) DEA model is used in order to reallocate two transferrable inputs (namely, labour costs and operating costs) between the different airports managed by the Spanish Airport Authority (AENA). First, we apply a conventional (i.e. non-centralized) non-oriented SBI model to identify the inefficient airports. Then, we apply the corresponding centralised DEA model to the inefficient units to maximise the potential improvements (slacks) obtained by reducing the total consumption of the inputs (allowing resource reallocation) and increasing total outputs. The efficient airports are left as they are, i.e. they are not subject to resource reallocation. All the inputs are discretionary and transferrable except the depreciation of assets which cannot be changed in the short-term. The results show how it is feasible to increase the total amount of passengers and cargo as well as the number of aircraft movements without increasing the total amount of inputs, just by reallocating them in an efficient way. Actually, for the total labour costs input a small reduction is even possible.

Keywords: *centralised DEA; Spanish airports; AENA; centralised management; Slack-based inefficiency (SBI)*

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1. Introduction

Data Envelopment Analysis a non-parametric methodology commonly used to estimate the efficiency of a set of homogenous decision making units (DMUs). The development of a DEA model requires making decisions about several questions such as the orientation, the returns to scale or the appropriate selection of inputs and outputs (Cook et al. 2014). Resource allocation using DEA has been addressed from several perspectives (e.g. Wei et al. 2000; Hadi-Vencheh et al. 2008; Lozano et al. 2004, 2009; Du et al. 2010; Hosseinzadeh et al. 2010; Amirteimoori and Emrouznejad 2012; Fang and Li 2015, etc.). From an empirical perspective it is important to take into account who is controlling the resources or the production levels. Traditional DEA models optimise separately the resource allocation for each DMU. But this individual optimisation does not correspond to units organised under the same management (Boussofiane et al. 1991; Thanassoulis, 2001; Bogetoft, 2013) or with a budget (Kao, 2000).

Resource allocation is a relevant matter in management. It is the process of allocating limited number of resources (inputs) to different units (departments, divisions, chain, branches, etc.) of one organisation to facilitate reaching the overall corporate goals. Strong centralised management perspective confronts the flexibility of DMUs' managers to decide freely resources allocation and production transfers. Korhonen and Syrjänen (2004) propose a resource-allocation approach to be used in organizations with a centralized decision-making process. With this same aim further DEA models have been proposed to analyse units under some form of central management (for example, Lozano and Villa 2004; Varmaz et al. 2013). Lozano and Villa (2004, 2005) proposed the centralised resource allocation BCC model (CRA-BCC). In situations where the units of assessment are controlled by one central authority (parent company, head office, council, regional authority, etc.), certain inputs used are in fact non-discretionary at the DMU level: the individual unit managers have no control. Centralised DEA has been applied to a range of sectors and degree of management centralisation: vessels (Färe et al. 2000), fast-food restaurants (Gimenez-Garcia et al. 2007) and public services such as hospitals (Li and Ng, 1995), local authorities (Athanassopoulos 1995), recycling municipalities (Lozano et al. 2004), schools (Mar-Molinero et al. 2014) and other services (Asmild et al. 2009). White and Bordoloi (2015) provide a review of DEA-resource and cost allocation models evidencing a relevance of financial and banking studies compared to other industries. The literature review indicates that there are few applications of Centralised DEA in transportation, e.g. in ports (Lozano et al. 2011) and human resources allocation in airports (Yu et al. 2013). In this paper a Centralised DEA approach is applied to the Spanish airport system. Most of the studies in the Spanish airport system use DEA following the traditional models (e.g. Lozano and Gutierrez 2011a), in some cases considering undesirable outputs (e.g. Lozano and Gutierrez 2011b) using a network DEA approach (e.g. Lozano et al. 2013) or combining DEA with a second stage or a stochastic frontier analysis (see Ripoll-Zarraga and Mar-Molinero 2017 for a review).

DEA-resource allocation approaches can be classified as invariant efficiency (e.g. Yan et al. 2002; Korhonen and Syrjänen, 2004; Amirteimoori, 2006; Hadi-Vencheh et al. 2008) and changeable efficiency after the resource reallocation (e.g. Beasley 2003; Korhonen and Syrjänen 2004; Lozano et al. 2009; Mar-Molinero et al. 2014). In this study, the second approach is considered. The idea is to provide managerial guidance to reallocate inputs and increase outputs between different airports in order to increase the overall efficiency of the Spanish airport system. It is important to bear on mind that this is possible due to the type of management applied in this case. In order to simplify the model, undesirable outputs are not considered (Ripoll-Zarraga and Mar-Molinero, 2017).

The Spanish airports are government owned and managed through a company named AENA under an airport-system structure. The degree of centralisation is very high to the extent that AENA applies similar accounting policies such as depreciation to all the airports. Competition between airports is practically non-existent. Consequently, there are geographical areas with more than one airport even when the catchment area is not congested. Most of the airports have a significant infrastructure for its level of traffic. Investments have been made by the Spanish government based on forecasting models resulting in a system with over-capacity and inefficiencies. The fact that airports' managers are not allowed to decide commercial policies to attract airlines and passengers makes the network unprofitable. Under this degree of centralisation the question to address is if resources under-used by an airport could be transferred to other airports increasing the overall efficiency of the system. It is important to highlight that the structure of an airport system implies a cross-subsidisation from profitable to non-profitable airports. The resource allocation for discretionary inputs (or production overall objectives) could be optimised across the network. In the case of the Spanish airports the centralised DEA model is particularly useful since the optimisation of resources utilisation applies for all the airports as a whole rather than optimising each airport separately.

This paper is organised as follows. Section 2 presents the conventional non-centralised slack-based-inefficiency (SBI) approach as well as the conventional radial centralised DEA approach. Section 3 formulates and discusses the specific centralised SBI approach used in this paper. Section 4 presents the data and the analysis of results. Finally, Section 5 summarizes and concludes.

2. Relevant DEA approaches

2.1 Non-centralised SBI approach

The SBI DEA approach was first proposed by Fukuyama and Weber (2009) and its key feature is that it uses as objective function the maximization of the input and output slacks normalized using the components of a given directional vector $g = (g_j^x, g_i^y)$ The flexibility of being able to choose the slacks normalization constants as well as the fact of not requiring the linearization of the model (unlike the slacks-based measure of Tone, 2001) makes this approach very attractive and easy to use. It can also handle undesirable outputs (e.g. Gutierrez et al. 2017) and it can be used in network DEA contexts (e.g. Fukuyama and Weber 2010; Lozano 2016, 2017).

Let ī and r be indexes for the n DMUs of the system. Let the symbol $x_{j\bar{\imath}}$ represent the consumption of input j by DMU ī and $y_{k\bar{\imath}}$ the production of output k by DMU ī. Let r be the DMU to be projected. Let s_j^xands_k^y represent, respectively, the different input and output slacks of DMUr, i.e. the corresponding amounts that each input can be reduced and each output can be increased. The conventional non-centralised SBI model can be formulated as

$$Max \sum_j \frac{s_j^x}{g_j^x} + \sum_k \frac{s_k^y}{g_k^y}$$

$s.t.$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}} x_{j\bar{\imath}} = x_{jr} - s_j^x \;\; \forall j$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}} y_{k\bar{\imath}} \geq y_{kr} + s_k^y \ \ \forall k$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}} = 1$$

$$\lambda_{\bar{\imath}} \geq 0 \ \forall \bar{\imath}, \qquad s_j^x \geq 0 \ \forall j, \qquad s_k^y \geq 0 \ \ \forall k$$

2.2 Radial centralised DEA approach

Lozano and Villa (2004) presented two input-oriented centralised DEA resource allocation approaches, one radial and another non-radial. The radial model (labelled CRA-BCC) maximizes the radial increase of the total outputs that can be achieved without increasing the total inputs. The input-oriented CRA-BCC model can be formulated as

$$Min \ \ \theta$$

$$s.t.$$

$$\sum_{r=1}^{n} \sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}r} x_{j\bar{\imath}} \ \leq \ \theta \sum_{r=1}^{n} x_{jr} \ \forall j$$

$$\sum_{r=1}^{n} \sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}r} y_{k\bar{\imath}} \ \geq \ \sum_{r=1}^{n} y_{kr} \ \forall k$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}r} = 1 \ \ \forall r$$

$$\lambda_{\bar{\imath}r} \geq 0 \ \forall \bar{\imath} \ \forall r, \quad \theta \ free$$

Note that a key feature of centralised DEA approaches is that all the DMUs are projected simultaneously so that a centralised (i.e. system-wide) criterion can be used to determine the target of each DMU and the resource reallocation among the DMUs. Thus, in order to project each DMU its own set of intensity variables lambda is required. The constraints of the model, apart from the convexity constraints that indicate that Variables Returns to Scale (VRS) is assumed, guarantee that the total output level is maintained and that the total inputs are reduced uniformly (i.e. equi-proportionally). The objective function aims at maximizing that radial input reduction. Note that, as in all radial DEA approaches, a phase II is required to exhaust all possible input and output slacks so that the targets are guaranteed to lie on the efficient frontier.

Mar-Molinero et al. (2014) developed a simplified version of the above CRA-BCC model where the most efficient units are "cloned" system-wide. Also, Asmild et al. (2009) extended the above model by suggesting changes only for the inefficient units, maintaining the efficient DMU intact. They labelled their approach CRAI-BCC. Denoting by E the set of efficient DMUs the input-oriented CRAI-BCC model can be formulated as

$$Min \quad \theta$$

$$s.t.$$

$$\sum_{r \notin E} \sum_{\bar{\imath} \in E} \lambda_{\bar{\imath}r} x_{j\bar{\imath}} \leq \theta \sum_{r \notin E} x_{jr} \quad \forall j$$

$$\sum_{r \notin E} \sum_{\bar{\imath} \in E} \lambda_{\bar{\imath}r} y_{k\bar{\imath}} \geq \sum_{r \notin E} y_{kr} \quad \forall k$$

$$\sum_{\bar{\imath} \in E} \lambda_{\bar{\imath}r} = 1 \quad \forall r \notin E$$

$$\lambda_{\bar{\imath}r} \geq 0 \quad \forall \bar{\imath} \in E \; \forall r \notin E, \quad \theta \; free$$

Note that this model uses a radial and oriented metric while, in this study, a non-radial and non-oriented approach is used.

3. Proposed SBI centralised DEA approach

Since all the airports are managed by the same company (AENA), the assumption made in this paper assumes a degree of flexibility regarding reallocation of inputs and/or transfer outputs among the different DMUs (e.g. Athanassopoulos 1995; Lozano and Villa 2004). Centralised DEA can also consider certain inflexibility as regards resource reallocation (e.g. Nesterenko and Zelenyuk 2007; Asmild et al. 2009). In particular, certain inputs may not be transferable and therefore cannot be reallocated. The advantage of using centralised DEA is that it projects all the DMUs simultaneously in one single linear programming problem. The common aim is to reduce the total input consumption of the system and/or globally increase the production of all the outputs. Note that some resources may be transferred from some DMUs to others that, consequently, will be able to increase their outputs.

The proposed centralised DEA approach uses the idea of Asmild et al. (2009) of maintaining the efficient DMUs are they are and jointly project only the inefficient DMUs. This means that we have to carry out two steps. Step I identifies the efficient and inefficient units. Although for this step a conventional BBC model (Banker at al. 1984) could be used, in our case, for convenience and consistency, the non-centralised SBI model of section 2.1. is used. In Step 2 a centralised projection of the inefficient units is carried out so as to maximize an SBI measure involving the total input and output slacks. Note that the reallocation of inputs is possible only for transferable ones, but not for inputs such as capital. In particular, in this study, depreciation is one such non-discretionary and non-transferable input. Another feature of the proposed model that neither the CRA-BCC approach of Lozano and Villa (2004) nor the CRAI-BCC approach of Asmild and Pastor (2009) consider is to impose constraints that guarantee that none of the DMUs reduce their outputs. That is a realistic assumption (otherwise the DMU managers may not concur with the proposed approach) and one perfectly consistent with the aim of increasing the total system outputs. The model also provides a peer group for each inefficient unit. $\{\bar{\imath} \in E: \lambda_{\bar{\imath}r} > 0\}$. The value of the lambda variables provides clues about the relevance of each specific efficient DMU as benchmark (i.e. reference unit) for each inefficient DMU. Larger values indicate more importance of the efficient DMU as reference unit for the corresponding inefficient DMU.

Let $Slack_o^{Input_j}$ represent the reduction achievable for the consumption of the input j by the DMU o and $Slack_o^{Ouput_k}$ represent the increase achievable for the output k for the same unit. Let us assume that the components of the directional vector are the sum of the corresponding input or output for the whole system, i.e. the sum of the observed value for the different DMUs. Those amounts will be the amounts used to normalize the corresponding input and output slacks. The inputs considered are labour costs (excluding air traffic control services), operating costs and depreciation of assets (including the terminals for passengers and cargo). In the output side, the variables considered are the number of passengers, air traffic movements, cargo, commercial revenues and percentage of flights on time. All the inputs are transferable except the depreciation of assets as capital cannot be reallocated to other airports.

Hence, the non-centralised SBI DEA model used in Step I can be formulated as

$$SBI_o = Max\ \frac{1}{7}\left(\frac{Slack_o^{Labour}}{\sum_{r=1}^{n} Labour_r} + \frac{Slack_o^{Operating}}{\sum_{r=1}^{n} Operating_r} + \frac{Slack_o^{PAX}}{\sum_{r=1}^{n} PAX_r} + \frac{Slack_o^{ATM}}{\sum_{r=1}^{n} ATM_r} + \frac{Slack_o^{Cargo}}{\sum_{r=1}^{n} Cargo_r} + \frac{Slack_o^{Commercial}}{\sum_{r=1}^{n} Commercial_r} + \frac{Slack_o^{Flights}}{\sum_{r=1}^{n} Flights_r}\right)$$

$s.t.$ (1)

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, Labour_{\bar{\imath}} = Labour_o - Slack_o^{Labour}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, Operating_{\bar{\imath}} = Operating_o - Slack_o^{Operating}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, Depreciation_{\bar{\imath}} \leq Depreciation_o$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, PAX = PAX_o + Slack_o^{PAX}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, ATM = ATM_o + Slack_o^{ATM}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, Cargo = Cargo_o + Slack_o^{Cargo}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, Commercial = Commercial_o + Slack_o^{Commercial}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}}\, Flights = Flights_o + Slack_o^{Flights}$$

$$\sum_{\bar{\imath}=1}^{n} \lambda_{\bar{\imath}} = 1$$

$$\lambda_{\bar{\imath}} \geq 0 \quad \forall \bar{\imath} \epsilon E, \qquad Slack_o^{Labour} \geq 0, Slack_o^{Operating} \geq 0, Slack_o^{PAX} \geq 0$$

$$Slack_o^{ATM} \geq 0, Slack_o^{Cargo} \geq 0, Slack_o^{Commercial} \geq 0, Slack_o^{Flights} \geq 0$$

Note that when one or more input or output slacks is greater than zero then $SBI_o > 0$ and then DMU o is not efficient. Let be $E^c = \{\bar{\imath}: SBI_{\bar{\imath}} > 0\}$ and $E = \{\bar{\imath}: SBI_{\bar{\imath}} = 0\}$ the sets of inefficient and efficient DMUs, respectively.

Note that the model does not include in the objective function a slack variable for the input depreciation in the objective function as it is assumed to be a non-discretionary input. Therefore, no changes are allowed in the short-term. The corresponding constraint only imposes that the target reference unit does not have a value greater than that of DMU o.

For Step II the following centralised SBI DEA model is solved

$$Max\ \frac{1}{7}\left(\frac{Slack^{Labour}}{\sum_{r=1}^{n} Labour_r}+\frac{Slack^{Operating}}{\sum_{r=1}^{n} Operating_r}+\frac{Slack^{PAX}}{\sum_{r=1}^{n} PAX_r}+\frac{Slack^{ATM}}{\sum_{r=1}^{n} ATM_r}+\frac{Slack^{Cargo}}{\sum_{r=1}^{n} Cargo_r}+\frac{Slack^{Commercial}}{\sum_{r=1}^{n} Commercial_r}+\frac{Slack^{Flights}}{\sum_{r=1}^{n} Flights_r}\right)$$

$s.t.$ (2)

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} Labour_{\bar{\imath}} \leq Labour_r^* \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} Labour_r^* = \sum_{r\epsilon E^c} Labour_r \ - Slack^{Labour}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} Operating_{\bar{\imath}} \leq Operating_r^* \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} Operating_r^* = \sum_{r\epsilon E^c} Operating_r \ - Slack^{Operating}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} Depreciation_{\bar{\imath}} \leq Depreciation_r^* \qquad \forall r\epsilon E^c$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} PAX_{\bar{\imath}} \geq PAX_r^* \geq PAX_r \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} PAX_r^* = \sum_{r\epsilon E^c} PAX_r \ + Slack^{PAX}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} ATM_{\bar{\imath}} \geq ATM_r^* \geq ATM_r \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} ATM_r^* = \sum_{r\epsilon E^c} ATM_r \ + Slack^{ATM}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} Cargo_{\bar{\imath}} \geq Cargo_r^* \geq Cargo_r \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} Cargo_r^* = \sum_{r\epsilon E^c} Cargo_r \ + Slack^{Cargo}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} Commercial_{\bar{\imath}} \geq Commercial_r^* \geq Commercial_r \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} Commercial_r^* = \sum_{r\epsilon E^c} Commercial_r \ + Slack^{Commercial}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} Flights_{\bar{\imath}} \geq Flights_r^* \geq Flights_r \qquad \forall r\epsilon E^c$$

$$\sum_{r\epsilon E^c} Flights_r^* = \sum_{r\epsilon E^c} Flights_r \ + Slack^{Flights}$$

$$\sum_{\bar{\imath}\epsilon E} \lambda_{\bar{\imath}r} = 1 \quad \forall r\epsilon E^c$$

$$\lambda_{\bar{\imath}r} \ \geq 0 \quad \forall \bar{\imath}\epsilon E \ \ \forall r\epsilon E^c$$

$$All\ Slacks \geq 0$$

where the superscript asterisk (*) identifies the target input and output variables.

Note that only the inefficient DMUs ($r \epsilon\, E^c$) are projected and that their corresponding targets are computed using only the efficient DMUs ($\bar{\imath}\, \epsilon\, E$). No inefficient DMU reduces its outputs. Their inputs, however, can change in any direction so long as the total input consumption of the system does not increase. Actually, the objective function tries to reduce those total inputs as well as to increase the total outputs. The treatment of the non-transferrable input (depreciation of airside assets and terminals) is different to that of the other two inputs in the sense that they are not supposed to change for any inefficient DMU. The corresponding constraint is the same as in the non-centralised DEA approach and follows the conventional way of handling non-discretionary inputs proposed by Banker and Morey (1986).

4. Results

The Spanish airport system contains 49 airports, including two heliports and four general aviation airports34. Financial data were extracted directly from the AENA's annual reports for 2013 except for depreciation of assets since it is highly correlated with operating costs. Following Ashford et al. (1996), the assets were previously classified in airside and landside assets and depreciated accordingly to the standard coefficients used in the airport industry (Ripoll-Zarraga and Mar-Molinero, 2017). Examples of airside assets used are runways, aprons, taxiway, aviation terminals, air traffic control and visualisation systems (beacons). In this study, passengers and cargo terminals, though generally considered landside assets, have been both included to compute the value of depreciation. Note that for Madrid Torrejon and Son Bonet no information regarding capital investments were available. Instead of removing them from the sample and losing potential relevant information, the corresponding missing values were substituted by the average value plus 0.3 times the standard deviation of that variable for the rest of airports. Since depreciation is a non-discretionary input, imputing this data should not have a significant influence in the corresponding objective function. Additionally, the fact that both airports have very low civilian traffic ensures that the results are not biased. There were also four missing values for the variable percentage of flights on time and in those cases the nearest neighbour imputation criterion was used (Ripoll-Zarraga and Mar-Molinero, 2017). Two airports were identified having similar infrastructure or aeronautical activity (i.e. regarding level of traffic) as the missing: Son Bonet with 50% of flights on time becomes the nearest

[34] Madrid Torrejon allowed general aviation operations until January 31st, 2013

neighbour for Algeciras, Ceuta and Huesca-Pirineos and Sabadell with 56.25% for Madrid Cuatro Vientos.

Table 1: Summary statistics of dataset

Variable	Observations	Mean	Standard Dev.	Minimum	Maximum
Labour Costs (€)	49	6,113.92	9,082.62	108.12	48,934.72
Operating Costs (€)	49	19,035.00	49,084.02	333.38	299,582.10
Depreciation Airside and Terminals (€)	47	3,989.57	9,817.64	27.00	65,429.59
Passengers	49	3,824,594.47	8,105,923.78	273	39,735,618
Air Traffic Movements	49	36,549.96	64,081.76	476	333,056.00
Cargo (t)	49	13,039,859.65	51,368,116.40	0	346,602,597.00
Commercial Revenues (€)	49	12,865.38	30,489.78	9.01	161,391.76
Flights on Time (%)	45	48.85	12.97	100.00	27.27

The results of Step I of the proposed approach indicate that 21 out of the 49 airports are efficient. In terms of size, eight out of the 14 large airports (i.e. with more than 3.5 million passengers) are efficient: Alicante and Barcelona (both located in the Mediterranean corridor); Gran Canaria, Lanzarote and Tenerife South (in the Canary Islands); Ibiza and Palma de Mallorca (in the Balearic Islands); and Madrid (which is a hub). There rest of the efficient airport corresponds to one medium size airport (Murcia, also in the Mediterranean corridor) and 12 smaller airports with a range of geographical locations: Albacete, Badajoz, Algeciras, Burgos, Logroño; Vitoria and Zaragoza (both cargo-oriented airports); La Gomera (located in the Canary Islands); and the four general aviation airports (Madrid Cuatro Vientos, Madrid Torrejon, Sabadell, Son Bonet).These results confront previous findings regarding specific geographical locations and frontier airports(Martin and Roman, 2001; Tapiador et al. 2008; Tovar and Martin-Cejas, 2010). On the other hand, cargo oriented airports such as Vitoria and Zaragoza are clearly efficient (Coto-Millan et al. 2016). Table 2 shows the SBI efficiency scores computed by the non-centralised DEA model used for the Step I to identify the efficient and the inefficient airports.

Table 2: SBI efficiency scores computed by non-centralised DEA model used for the Step I

Airport	SBI Value	E^c; E	Airport	SBI Value	E^c; E
A Coruña	0.008667	Inefficient	Madrid Barajas	0	Efficient
Albacete	0	Efficient	Madrid CuatroVientos	0	Efficient
Algeciras	0	Efficient	Madrid Torrejon	0	Efficient
Alicante	0	Efficient	Malaga	0.017004	Inefficient
Almeria	0.004731	Inefficient	Melilla	0.007056	Inefficient
Asturias	0.008047	Inefficient	Menorca	0.015807	Inefficient
Badajoz	0	Efficient	Murcia	0	Efficient
Barcelona	0	Efficient	Palma de Mallorca	0	Efficient
Bilbao	0.007372	Inefficient	Pamplona	0.010417	Inefficient
Burgos	0	Efficient	Reus	0.009166	Inefficient
Ceuta	0.000856	Inefficient	Sabadell	0	Efficient
Cordoba	0.002448	Inefficient	Salamanca	0.001322	Inefficient
El Hierro	0.000532	Inefficient	San Sebastian	0.001178	Inefficient
Fuerteventura	0.008925	Inefficient	Santander	0.002923	Inefficient
Girona	0.009149	Inefficient	Santiago	0.017136	Inefficient
Gran Canaria	0	Efficient	Sevilla	0.005614	Inefficient
Granada-Jaen	0.011746	Inefficient	Son Bonet	0	Efficient
Huesca-Pirineos	0.001093	Inefficient	Tenerife North	0.007131	Inefficient
Ibiza	0	Efficient	Tenerife South	0	Efficient
Jerez	0.002550	Inefficient	Valencia	0.004733	Inefficient
La Gomera	0	Efficient	Valladolid	0.008476	Inefficient
La Palma	0.011329	Inefficient	Vigo	0.009085	Inefficient
Lanzarote	0	Efficient	Vitoria	0	Efficient
Leon	0.002478	Inefficient	Zaragoza	0	Efficient
Logroño	0	Efficient			

Table 3 shows, for the inefficient airports, the input and output changes computed by the non-centralised DEA model used for the Step I. Note that the input slacks correspond to input reductions (i.e. negative increments) while the output slacks represent increases (i.e. positive changes).

Table 3: Input and output slacks computed by the non-centralised DEA model

Airports	Labour	Operating	PAX	ATM	Cargo	Commer. revenues	% Flights on Time
A Coruña	-506	0	0	11,428	31,243,240	292	7.8
Almeria	-948	0	0	24,408	9,346,526	0	4.1
Asturias	-1,188	0	0	16,954	27,227,960	176	0
Bilbao	0	0	939,986	0	29,323,100	0	1.7
Ceuta	0	0	8,592	2,332	1,839,103	80	3.9
Cordoba	0	0	61,502	0	10,296,360	179	1.0
El Hierro	-539	-395.11	0	905	0	226	1.5
Fuerteventura	0	0	41,969	0	36,060,840	0	14.0
Girona	0	0	0	0	39,128,790	15	6.7
Granada-Jaen	-368	0	0	5,700	45,440,820	579	13.9
Huesca-Pirineos	0	0	25,265	0	3,620,766	22	4.4
Jerez	-1,037	0	603,218	0	4,854,956	365	7.2
La Palma	-358	0	0	0	43,740,470	763	20.3
Leon	-97	0	23,939	6,924	7,804,067	515	0
Malaga	-3,350	0	1,771,797	12,934	58,253,670	0	0
Melilla	0	-869.01	0	12,391	21,359,290	939	15.9
Menorca	-1,651	0	178,026	0	65,560,040	820	0.7
Pamplona	0	-118.47	113,403	0	42,457,260	247	12.9
Reus	-413	0	0	9,573	32,834,400	446	12.9
Salamanca	0	-1,506.64	0	2,472	2,129,210	90	6.7
San Sebastian	-992	-624.10	58,234	3,058	96,889	0	5.0
Santander	-943	0	0	0	10,426,390	629	0
Santiago	-1,288	0	0	1,354	71,795,950	410	4.5
Sevilla	-2,320	0	0	3,217	16,146,670	0	10.8
Tenerife North	-574	0	1,112,040	0	20,937,370	3,414	9.3
Valencia	0	0	915,375	0	17,703,540	0	1.3
Valladolid	0	-1,761.33	0	6,162	31,233,570	369	10.9
Vigo	-868	0	0	13,641	27,916,230	215	21.8
Sum	**-17,439.74**	**-5,274.66**	**5,853,348**	**133,453**	**708,777,477**	**10,791**	**2.47**[a]

[a] Weighted average

Table 4 shows the input and output changes computed by the proposed centralised DEA model for the inefficient airports. Note that the total reduction in the inputs is minimal. The improvement potential corresponds to the outputs, especially in cargo. In order to achieve an efficient use of the system resources the estimated total slack for that variable is 142%.

Table 4: Input and output slacks computed by the centralised DEA model

Airports	Labour	Operating	PAX	ATM	Cargo	Commer. revenues	% Flights on Time
A Coruña	-622.05	-515.85	0	0	31,616,593	103.58	13.99
Almeria	-953.69	-126.38	0	25,474.61	9,254,338	0	2.51
Asturias	-1,098.43	-463.91	0	12,027.49	27,823,556	0	0
Bilbao	1,074.45	81.37	744,151	0	41,206,924	0	0
Ceuta	515.84	1,397.17	0	26,182.87	74	490.46	8.82
Cordoba	1,687.03	1,801.95	279,228	0	46,185,076	953.57	0
El Hierro	-554.21	-473.38	0	0	0	185.47	1.96
Fuerteventura	910.33	1,219.50	526,556	3,621.64	59,112,762	0	7.34
Girona	627.90	478.70	0	0	57,035,845	44.13	6.31
Granada-Jaen	-481.93	-1,073.51	0	0	45,561,756	279.59	11.84
Huesca-Pirineos	1,607.51	2,279.76	198,230	21,926.04	30,911,998	878.76	2.69
Jerez	105.56	2,438.82	1,494,311	0	17,547,440	2,483.69	5.30
La Palma	-573.28	-1,887.20	0	0	43,325,930	298.94	9.51
Leon	2,286.84	2,737.80	389,054	5,096.26	65,624,703	1,200.90	0
Malaga	-257.64	-7,664.84	6,600,689	43,770.40	9,230,005	0	0
Melilla	-20.02	-1,349.69	0	0	21,061,007	720.78	28.01
Menorca	-1,682.52	-730.17	201,098	0	63,875,029	604.87	0.64
Pamplona	415.34	152.75	139,462	11,556.54	46,644,629	528.29	3.66
Reus	-401.27	-554.27	0	0	33,476,822	232.11	16.42
Salamanca	495.74	-352.28	0	23,112.88	1,660,336	465.03	8.82
San Sebastian	-1,019.12	-747.16	10,503	1,619.56	465,595	0	5.41
Santander	-109.68	813.07	0	2,835.45	33,252,937	729.41	0
Santiago	-1,261.65	-2,367.45	267,199	2,641.81	64,717,655	0	4.34
Sevilla	-2,327.12	-854.75	0	9,802.41	15,619,738	0	0.96
Tenerife North	1,405.19	4,224.85	2,655,714	0	42,925,033	7,084.34	6.04
Valencia	622.56	3,904.49	2,642,612	0	41,862,022	1,789.98	0.66
Valladolid	118.54	-1,571.07	0	6,105.19	29,903,394	373.66	20.65
Vigo	-864.46	-798.32	0	13,459.53	28,030,354	0	16.46
Sum (%)	**-354.24 (0.12%)**	**-0.02 (0.00%)**	**16,148,808 (8.62%)**	**209,232.69 (11.68%)**	**907,931,552 (142.10%)**	**19,447.59 (3.8%)**	**2.24[a] (5.06%)**

[a] Weighted average

Malaga suffers from a significant over-capacity. The new terminal was opened in March 2010 with a forecast of 30 million passengers, but in 2016 traffic still remains at 16.7 million. The infrastructure is underused for operating activities, but consumes maintenance services. This is confirmed by the computed slacks in passengers (+6,600,689) and aircraft movements (+43,770) to contribute to the overall efficiency of the system[35].

There are 15 airports that must increase their operations (aircraft movements). With the exception of Malaga, these are mainly small airports: Ceuta (+26,182.87); Almeria (+25,474.61); Salamanca (+23,112.88); Huesca-Pirineos (+21,926.04); Vigo (+13,459.53) and Pamplona (+11,556.54). Note that this is independent of the slacks in the number of passengers. In fact, some of these airports are not required to increase their number of passengers at all. Consequently, the small airports are inefficient mainly due to their reduced number of aircraft movements more than their number of passengers.

The positive/negative value of the operating costs slacks of some airports indicates that they need to increase/decrease their budget. Thus, Malaga is the airport that should reduce its operating costs the most (-7,664.84). Compared to Tenerife North, which may increase its operating costs the most (+4,224.85). Other airports which may significantly increase their operating costs are Valencia (+3,904.49); Jerez (+2,438.82); Leon (+2,737.79) and Huesca-Pirineos (+2,279.76). For these airports their current budget may be limiting their output potential. Examples of airports required to reduce their operating costs are Santiago (-2,367.45); La Palma (-1,887.20); Valladolid (-1,571.07); and Granada (-1,073.51). In general, these airports are too expensive to run at their current operating levels.

Fifteen airports require reducing their labour costs, suggesting that most of the airports have human resources over-capacity to generate traffic. Thus, the situation convergences to that studied in Yu et al. (2013) in which different human resources reallocation policies of Taiwan airports allowed increasing the overall traffic. Sevilla (-2,327.12) has the highest reduction requirement in labour costs. Apart from Sevilla and Bilbao (+1,074.45) the rest of airports with significant changes in labour are medium and small airports.

Two large airports, namely Tenerife North and Valencia, are required to significantly increase their level of passengers (+2,655,714; +2,642,612, respectively), but not the labour costs (+1,405; +622, respectively). In these cases, it seems that labour and airport infrastructures are used efficiently to generate aircraft movements (with small punctuality slacks) but without enough passengers or cargo.

Overall most of the airports are operating at adequate levels of passengers and aircraft movement (13 to 15 inefficient units require increases), but not for cargo, where 27 airports

[35] Additionally, both values correspond to the maximum increases for the whole set of airports.

should increase the amount of cargo handling. These results confirm that airports have enough traffic in relation with their capacity (infrastructure) but that it is essential to enhance the commercial aspect of the airports in order to attract passengers and, above all, cargo activities. Some inefficient airports should re-consider the cargo activities altogether in order to enhance the efficiency of the airport system. On the other hand, small airports, such as El Hierro or Ceuta, may focus on civilian transport rather than cargo, ensuring in any case the connectivity of these peripheral regions.

Congestion seems to be a generalised problem since most of the inefficient airports need to increase the percentages of flights on time. In fact, the average of percentage of flights on time for the overall system (excluding the four missing data) is just 48.85%. Melilla, although being the airport with more punctuality slack of the system (+28.01%), does not however require changing the number of passengers or movements. Usually, the smaller the punctuality slack, the higher the slack in aircraft movements. Thus, Almeria requires increasing the percentage of flights on time +2.51% and the number of aircraft movements +25,474.61. For Huesca-Pirineos, the corresponding figures are +2.69% and +21,926.04 and for Pamplona, +3.66%, +11,556.54. This does not apply to Ceuta (+8.82% and +26,182.87) and Salamanca (+8.82% and +23,112.88) with a similar behaviour between them but different to that of the stated airports. Conversely, the larger the punctuality slacks, the smaller the aircraft movement slack. Thus La Palma (+9.51%), Granada (11.84%), A Coruña (+13.99%), Reus (+16.42%) and Melilla (+28.01%) with significant punctuality slacks, but do not require increases in the number of movements and passengers. These results suggest that some airports must focus more on reducing delays and becoming punctual than on increasing other outputs such as aircraft movements. At the same time, airports with no congestion problems will require more increments in operations to become more efficient. The airport size seems not to determine the punctuality, suggesting that the slots' current distribution is not a restriction to be efficient.

Since commercial policies such as the quality of the service provided or the price are decided centrally (by AENA) rather than by individual managers, the non-existent competition goes in detriment of generating more traffic (new airlines and routes). As regards commercial revenues, a large number of inefficient airports require increasing them. There is no correlation between the size of airports and the increase needed although Tenerife North clearly shows a high dependency of this type of income in comparison with aeronautical revenues. Diversification towards commercial activities is associated with privatisation processes (Humphreys, 1999). Despite AENA being government-owned at that time, it did not receive any subsidies from the government. Consequently, the Spanish airports have to engage in commercial activities as an alternative source of income (Ripoll-Zarraga et al. 2017). A strong centralised management seems not to help in increasing the aeronautical aspect of airports unless airports can compete to attract passengers and airlines.

The analysis of peer group of each inefficient DMU helps identifying the efficient units the inefficient units should use as best practice reference to achieve the computed targets (see Table 5). There are only nine efficient airports with non-zero lambdas. Five of them are small-sized: Algeciras (a heliport that is reference to three airports), Logroño (3), Madrid Cuatro Vientos (19), Vitoria (2) and Zaragoza (26) in the mainland and La Gomera (11), in the Canary Islands. The other benchmarks are all the large airports located in the islands: Gran Canaria (4), Ibiza (10) and Palma de Mallorca (13). The relevance of a benchmark for a specific inefficient airport is identified by the value of lambda. For example, Algeciras is a clear reference for El Hierro (lambda=0.8985) and San Sebastian (0.8393), but not for Ceuta (0.0759) in spite of the latter being also a heliport. Note also that, although Ibiza is a benchmark for a many inefficient airports, its relevance is very low (0.01 to 0.13).

The size and location of efficient airports that are not benchmarks to inefficient airports is diverse. There are five large airports two of them located in the Mediterranean seaside (Alicante and Barcelona), a hub in the centre (Madrid Barajas) and two airports in the Canary Islands (Lanzarote and Tenerife South). There is also one medium airport, Murcia (in the Mediterranean corridor) and six small airports geographically dispersed: Albacete, Badajoz and Burgos; including three of the four general aviation airports (Madrid Torrejon, Sabadell and Son Bonet). Regarding the fact that both Barcelona and Madrid are not benchmarks for any airport other than themselves suggest that they are mavericks that do not have an influence on the rest of the system as regards efficiency. Therefore, in this case, the methodology does not seem to be affected by the presence of extreme cases in inputs and outputs potentially biasing the efficiency frontier as may happen in general in DEA.

Madrid Cuatro Vientos and Zaragoza are benchmarks with relatively high lambdas for a relative high number of inefficient airports. In particular, Madrid Cuatro Vientos is the main reference to some airports with low number of passengers such as Almeria (lambda=0.84), Salamanca (0.83), Ceuta (0.76), Jerez (0.67), Huesca-Pirineos (0.57) and Vigo (0.45). Madrid Cuatro Vientos is a general aviation airport, which suggests that specialisation and diversification of activities could help civilian airports to improve the efficiency levels.

Zaragoza, on the other hand, is a cargo-oriented airport that acts as main reference for 15 inefficient airports, with lambdas values ranging between 0.42 (Bilbao)and 0.91 (Leon). These airports are relatively similar in labour and operating costs as well as in some of the outputs except cargo. These results confirm that cargo-activities should be re-considered by AENA to enhance the overall efficiency of the airport system. Vitoria is also a cargo-oriented airport, but is not such an important reference as Zaragoza for neither Bilbao (0.2361) nor for El Hierro (0.2277)

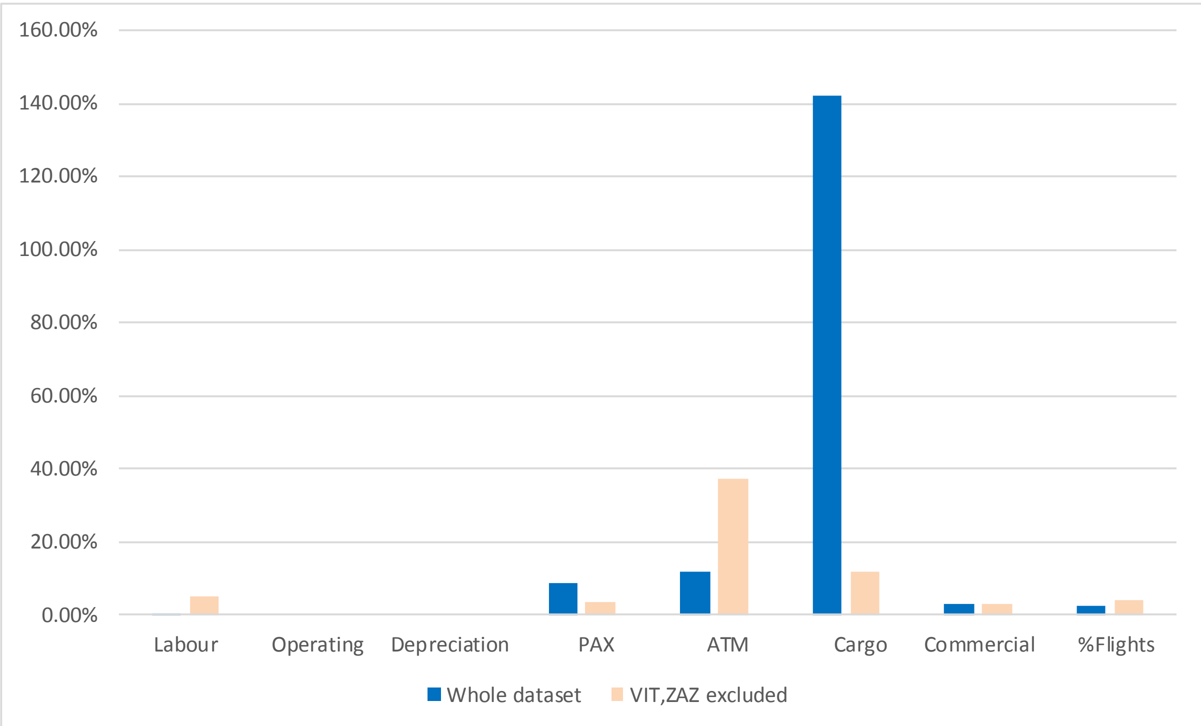
Malaga, which as indicated above has significant input and outputs slacks, has Palma de Mallorca as its main reference (0.86) Both airports are very similar as regards their commercial revenues, flights on time, labour and operating costs. Nevertheless, the depreciation in the case of Malaga is almost four times than of Palma de Mallorca. Although both airports have very similar runways (i.e. same area), Malaga's new terminal, with a significantly higher capacity compared to Palma de Mallorca, but with lower traffic explains its over-capacity and higher capital cost that burden this airport. Thus, while the number of passengers of Malaga airport represents 57% of that of Palma de Mallorca, the aircraft movements 60% and cargo just 22% both have similar labour costs (Malaga airport 88% of those of Palma), suggesting a high degree of over-employment to run and maintain Malaga's airport premises. The results show clear evidence of the impact of wrong investment decisions (overly optimistic traffic forecasts) in airports efficiency and potentially, financial results since with so much input and output slacks it is not unreasonable to expect Malaga to be unprofitable and a financial burden for the system.

Table 5: Peer Group and lambda values for the inefficient Airports

Airport	Algeciras	Gran Canaria	Ibiza	La Gomera	Logroño	Madrid CuatroVientos	Palma de Mallorca	Vitoria	Zaragoza
A Coruña	0	0	0.1100	0.3626	0	0.0886	0	0	0.4388
Almeria	0	0.0083	0	0	0	0.8439	0.0249	0	0.1229
Asturias	0	0	0.0912	0.1860	0	0.3238	0.0148	0	0.3843
Bilbao	0	0.1653	0	0	0	0.0554	0.1201	0.2361	0.4231
Ceuta	0.0759	0	0	0.1623	0	0.7618	0	0	0
Cordoba	0	0	0	0	0.2454	0	0.0018	0.2277	0.5251
El Hierro	0.8985	0	0.0237	0.0237	0	0.0535	0	0	0.0007
Fuerteventura	0	0	0	0	0	0	0.1939	0	0.8061
Girona	0	0	0.0604	0	0	0.0708	0.0894	0	0.7794
Granada-Jaen	0	0	0.0597	0.2513	0	0.0548	0	0	0.6341
Huesca-Pirineos	0	0	0	0	0	0.5686	0	0	0.4314
Jerez	0	0	0	0	0	0.6749	0.0966	0	0.2284
Leon	0	0	0	0	0.0842	0	0	0	0.9158
Malaga	0	0	0	0	0.1232	0	0.8571	0	0.0196
Melilla	0	0	0.0244	0.5885	0	0.0917	0	0	0.2954
Menorca	0	0	0	0	0	0	0.1035	0	0.8965
Pamplona	0	0	0	0	0	0.3491	0	0	0.6509
Reus	0	0	0.1314	0.2475	0	0.1580	0	0	0.4631
Salamanca	0	0	0	0.1474	0	0.8294	0	0	0.0232
San Sebastian	0.8393	0.0259	0	0	0	0.1349	0	0	0
Santander	0	0	0.1320	0.3057	0	0.1023	0	0	0.4600
Santiago	0	0	0	0	0	0	0.0844	0	0.9156
Sevilla	0	0.2536	0	0	0	0.4834	0.0488	0	0.2142
Tenerife North	0	0	0	0	0	0	0.2565	0	0.7435
Valencia	0	0	0	0	0	0	0.3049	0	0.6951
Valladolid	0	0	0.0103	0.3966	0	0.1757	0	0	0.4174
Vigo	0	0	0.0865	0.0672	0	0.4515	0	0	0.3948

The results of the proposed centralised DEA model provide targets for each airport in order to improve the overall efficiency of the network. It is not surprising that the largest system slack occurs in cargo activities. Although the system also requires increasing the number of total passengers (8.62%), aircraft movements (11.68%) and commercial revenues (3.08%), these are significantly lower than the increase required in handling (142.10%). In order to gain insight into these results, a sensitivity analysis has been performed by removing the two cargo-oriented efficient airports (Vitoria and Zaragoza) from the sample. In that case, the results of Step I identifies Tenerife North as an additional efficient airport. Figure 1 shows the total input and output slacks computed by the centralised DEA model when the cargo-oriented airports are removed from the sample. Note that the total cargo slack is significantly smaller (11.59% compared to 142.10% of the whole dataset case) which means that the cargo targets for the inefficient DMUs are less ambitious but more realistic to achieve in the short-term. These findings suggest that Vitoria and Zaragoza may be distorting the cargo requirements for the rest of the airports to become efficient. As regards the other variables, more labour costs and aircraft movement slacks are estimated and less passengers slack. For commercial revenues and percentage of flights on time the total slacks do not change much.

Figure 1: Total input and output slacks when Vitoria and Zaragoza are excluded from the dataset



5. Conclusions

In this study we evaluate the efficiency level of the Spanish airports centralised managed under the same government agency (AENA). The proposed approach uses firstly a conventional (i.e. non-centralised DEA) non-oriented SBI model to identify the efficient and the inefficient airports. Then a centralised DEA approach is used to compute input and output targets for each the inefficient airports looking for the overall improvement of the system performance. The results show that out of the 49 airports studied 21 airports (of different sizes) are technical efficient. Hence, not always larger airports are more efficient compared to medium and small airports that may be using better their resources for the level of traffic they have. These results confront previous findings in the Spanish airports where airports with more passengers are more technically efficient. Overall the propose approach estimates that the system requires more aircraft movements and handling increases than increases in the number of passengers. The labour costs are adequate for the current activity. The overall margin of improvement as regards punctuality is very small, suggesting that most of that airports are punctual and do not suffer from significant delays.

The efficient frontier does not change when the two cargo-oriented airports (Vitoria and Zaragoza) are removed from the sample, with just one new airport, Tenerife North, becoming technical efficient. The cargo target computed in that case are, however, much lower and, hence, easier to reach in the short-term. The aircraft movements, however, would still have to be increased, actually more than before.

The proposed centralised DEA approach clearly shows an individual pathway for each airport to contribute to increase the overall efficiency of the system, carrying out an improved reallocation of the available resources. It has been found that the results are not biased by the existence of exceptional observations (i.e. observations with much large inputs and outputs than the rest) as it may happen in DEA. Previous studies have also applied DEA models, but their results do not provide a clear indication of which resources should be reduced or perhaps increased in each airport, although they may provide an overall reduction of the inputs (input-oriented) or an overall increase of the outputs (output-oriented). Additionally, airports are treated as decision making units assuming that the consumption of inputs and production targets are decided by airports' managers, which is unlikely to happen under a strong centralised management existing in the Spanish regulatory framework.

Although airports are treated as public utilities and the Spanish government insists on keeping all the airports open to aeronautical activities, the fixed costs of this policy seems not to have been factored in the analysis. Overall, the employment level is adequate for the actual traffic. Nevertheless, this does not apply to certain outputs, as implied by the fact that 28 out of 49 airports being technically inefficient. From an accounting perspective and assuming that all the efficient airports are able to cover their fixed costs and become profitable, the 21 efficient airports are financially sustaining the whole system. The question to be addressed is if the inefficient, and potentially not profitable, airports are strictly required for specific reasons such as the island airports to ensure connectivity even though from a financial perspective they may be a burden for the system. Previous studies mention certain environmental factors that could enhance the efficiency of some airports in detriment of others, such as the geographical location. Nevertheless, the results found in this study indicate that, at least in the Spanish case, passengers are not as essential as attracting airlines (air traffic movements) and increasing cargo. Some airports are suffering from over-capacity due to the fact that the significant investments in infrastructure carried out have been followed by an increase in traffic of the same order. Another finding of this study is that airports' specialisation help increasing the overall efficiency of the system. This is only possible if airports provide a better quality of the services provided to make the Spanish airports attractive for opening new routes. Consequently, airports must be differentiated regarding the product offered and must compete with each other. The current strong centralised management may make these targets hard to achieve. Airports' managers need to be granted the power to decide price policies and negotiate directly with specific airlines, opening new routes and making secondary airports as airlines hubs.

References

Amirteimoori, A. (2006): 'Data envelopment analysis in dynamic framework' *Applied Mathematics and Computation* 181 (1), 21–28

Amirteimoori, A. and Emrouznejad, A. (2012): 'Optimal input/output reduction in production processes' *Decision Support Systems* 52(3), 742–747

Amirteimoori, A. and Shafiei, M. (2006): 'Characterizing an equitable omission of shared resources: a DEA-based approach' *Applied Mathematics and Computation*177 (1), 18–23

Ashford, N., Stanton, H., and Moore, C. (1996): *'Airport Operations'* New York, McGraw-Hill Education (second edition)

Asmild, M.; Paradi, J.C. and Pastor, J.T. (2009): 'Centralized resource allocation BCC Models' *Omega* 37, 40–49

Athanassopoulos, A.D. (1995): 'Goal programming & Data Envelopment Analysis (GoDEA) for target-based multi-level planning: allocating central grants to the Greek local authorities' *European Journal of Operational Research*87 (3), 535−550

Banker, R.D.; Charnes, A. and Cooper, W.W. (1984):'Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis' *Management Science*30(9), 1078–1092

Banker, R.D. and Morey, R. (1986):'Efficiency analysis for exogenously fixed inputs and outputs' *Operations Research* 34, 513–521

Beasley, J.E. (2003) 'Allocating fixed costs and resources via Data Envelopment Analysis' *European Journal of Operational Research* 147(1), 198−216

Bogetoft, P. (2013): *'Performance benchmarking: Measuring and managing performance'* Springer, New York

Boussofiane, A.; Dyson, R.G. and Thanassoulis, E. (1991): 'Applied Data Envelopment Analysis' *European Journal of Operational Research* 52(1), 1–15

Cook, W.D.; Tone, K. and Zhu, J. (2014): 'Data Envelopment Analysis: prior to choosing a model' *Omega* 44, 1–4

Coto-Millan, P.; Inglada, V.; Fernandez, X.L.; Inglada-Perez, L. and Pesquera, M.A. (2016): 'The effect procargo on technical and scale efficiency at airports: The case of Spanish airports (2009–2011)' *Utilities Policy* 39, 29–35

Du, J.; Liang, L.; Chen, Y. and Gon-bing, B. (2010): 'DEA-based production planning' *Omega* 38 (1-2), 105–112

Fang, L. (2013): 'A generalized DEA model for centralized resource allocation' *European Journal of Operational Research* 228 (2), 405–412

Fang, L. and Li, H. (2015): 'Centralized resource allocation based on the cost-revenue analysis' *Computers & Industrial Engineering* 85, 395–401

Färe, R.; Grosskopf, S.; Kerstens, K.; Kirkley, J.E. and Squires, D. (2000): 'Assessing short-run and medium-run fishing capacity at the industry level and its reallocation' Microbehavior and Macro results: Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade (IIFET), July 10-14 (2000) Corvallis, Oregon, USA

Fukuyama, H. and Weber, W.L. (2009): A directional slacks-based measure of technical inefficiency, *Socio-Economic Planning Sciences* 43, 274–287

Fukuyama, H. and Weber, W.L. (2010):'A slacks-based inefficiency measure for a two-stage system with bad outputs' *Omega* 38 (5), 398–409

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

Gimenez-Garcia, V.; Martinez-Parra, J.L. and Buffa, F.P. (2007): 'Improving resource utilisation in multi-unit networked organisations: the case of a Spanish restaurant chain' *Tourism Management* 28, 262–270

Gutierrez, E., Aguilera, E., Lozano, S. and Guzman, G.I. (2017): 'A two-stage DEA approach for quantifying and analysing the inefficiency of conventional and organic rain-fed cereals in Spain' *Journal of Cleaner Production* 149, 335–348

Hadi-Vencheh, A.; Foroughi Ali, A. and Soleimani-Damaneh, M. (2008): 'A DEA model for resource allocation' *Economic Modelling* 25 (5), 983–993

Hosseinzadeh Lofti, F.; Noora, A.A.; Jahanshahloo, G.R.; Gerami, J. and Mozaffari, M.R. (2010): 'Centralized resource allocation for enhanced Russell models' *Journal of Computational and Applied Mathematics* 235, 1–10

Humphreys, I. (1999): 'Privatisation and commercialisation Changes in UK airport ownerships patterns' *Journal of Transport Geography* 7, 121–134

Kao, C. (2000): 'Data envelopment analysis in resource allocation: an application to forest management' *International Journal of Systems Science* 31(9), 1059–1066

Korhonen, P. and Syrjänen, M. (2004): 'Resource allocation based on efficiency analysis' M*anagement Science* 50 (8), 1134–1144

Li, S.-K. and Ng, Y. Ch. (1995): 'Measuring the productive efficiency of a group of firms' *International Advances in Economic Research* 1(4), 377–390

Lozano, S. (2016): 'Slacks-based inefficiency approach for general networks with bad outputs: An application to the banking sector' *Omega*60, 73–84

Lozano, S. (2017): 'Technical and environmental efficiency of a two-stage production and abatement system' *Annals of Operations Research*255, 199–219

Lozano, S. and Villa, G. (2004): 'Centralized resource allocation using Data Envelopment Analysis' *Journal of Productivity Analysis* 22, 143–161

Lozano, S. and Villa, G. (2005): 'Centralized DEA models with the possibility of downsizing' *Journal of the Operational Research Society* 56 (4), 357–364

Lozano, S.; Villa, G. and Adenso-Diaz, B. (2004):'Centralized target setting for regional recycling operations using DEA' *Omega* 32, 101–110

Lozano, S.; Villa, G. and Brännlund, R. (2009): 'Centralised reallocation of emission permits using DEA'. *European Journal of Operational Research* 193(3), 752–760

Lozano, S.; Villa, G. and Canca, D. (2011):'Application of centralised DEA approach to capital budgeting in Spanish ports´ *Computers & Industrial Engineering* 60, 455–465

Lozano, S. and Gutierrez, E. (2011a): 'Efficiency analysis and target setting of Spanish airports' *Networks and Spatial Economics* 11, 139–157

Lozano, S. and Gutierrez, E. (2011b): ‘Slacks-based measure of efficiency of airports with airplanes delays as undesirable outputs’ *Computers & Operations Research* 38, 131–139

Lozano, S.; Gutierrez, E. and Moreno, P. (2013): ‘Network DEA approach to airports performance assessment considering undesirable outputs’ *Applied Mathematical Modelling*37, 1665–1676

Mar-Molinero, C.; Prior, D.; Segovia, M.M. and Portillo, F. (2014): ‘On centralized resource utilization and its reallocation by using DEA’ *Annals of Operations Research* 221(1), 273–283

Martin, J.C. and Roman, C. (2001): ‘An application of DEA to measure the efficiency of Spanish airports’ *Journal of Air Transportation Management* 7,149–157

Martin, J. C. and Roman, C. (2006): ‘A benchmarking analysis of Spanish commercial airports. A comparison between SMOP and DEA ranking methods’ *Networks and Spatial Economics* 6(2), 111–134

Nesterenko, V. and Zelenyuk, V. (2007): ‘Measuring potential gains from reallocation of resources’ *Journal of Productivity Analysis* 28 (1-2), 107–116

Pels, E.; Nijkamp, P. and Rietveld, P. (2001): ‘Relative efficiency of European airports’. Transport Policy 8, 183–192

Ripoll-Zarraga, A.E. and Mar-Molinero, C. (2017): ‘Spanish airports: a visual study of management efficiency’ *Funcas Working Papers* September, 791 (available on-line, http://www.funcas.es/publicaciones/Sumario.aspx?IdRef=7-05791, last accessed January 2018)

Ripoll-Zarraga, A.E.; Portillo, F. and Mar-Molinero, C. (2017): ‘The impact of the 2008 Economic Crisis in the efficiency of Spanish airports: A DEA Analysis’ *Funcas Working Papers* December, 794 (available on-line, http://www.funcas.es/publicaciones/Sumario.aspx?IdRef=7-05794, last accessed January 2018)

Tapiador, F.J.; Mateos, A. and Martí-Henneberg, J. (2008): ‘The geographical efficiency of Spain's regional airports: a quantitative analysis’ *Journal of Air Transport Management* 14(4), 205–212

Thanassoulis, E. (2001): *‘Introduction to the theory and application of Data Envelopment Analysis’* Springer, New York

Tone, (2001): ‘A slacks-based measure of efficiency in Data Envelopment Analysis’ *European Journal of Operational Research* 130, 498–509

Tovar, B. and Martin-Cejas, R.R. (2010): ‘Technical efficiency and productivity changes in Spanish airports: A parametric distance functions approach’. *Transportation Research Part E* 46(5), 249–260

Varmaz, A.; Varwig, A. and Poddig, T. (2013): ‘Centralized resource planning and yardstick competition’ *Omega* 41(1), 112–118

White, S. and Bordoloi, S. (2015): ‘A Review of DEA-based Resource and Cost Allocation models: Implications for services’ *Operations and Supply Chain Management Faculty Publications*, 54 (available online, http://ir.stthomas.edu/ocbopmtpub/54, last accessed January 2018)

Wei, Q.L.; Zhang, J. and Zhang, X. (2000): ‘An inverse DEA model for input/output estimate’ *European Journal of Operational Research* 121 (1), 151–163

Wu, J.; An, Q.; Ali, S. and Liang, L. (2013): ‘DEA based recourse allocation considering environmental factors’ *Mathematical and Computer Modelling* 58, 1128–1137

Yan, H.; Wei, Q.L.; Hao, G. (2002): ‘DEA models for resource reallocation and production input/output estimation’ *European Journal of Operational Research* 136(1), 19–31

Yu M.-M.; Chern, Ch.-Ch. and Hsiao, B. (2013): ‘Human resource rightsizing using centralized data envelopment analysis: Evidence from Taiwan’s Airports’ *Omega* 41, 1

Chapter five

Can airports' inefficiency be determined by tourism variables?

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List of Tables

List of Figures

*Can airports' inefficiency be determined by tourism variables?**

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Abstract

The Spanish airports are managed centrally by a government-owned company named AENA. The public investments made in the latest years, airports managers' inability to decide commercial policies and the lack of competition end in regional areas no-congested, but with more than one airport within an amenity distance. Airports' managerial decisions should acknowledge regional needs. The geographical location of airports and specialization should be questioned as drivers of airports' efficiency. In this study, we use a stochastic frontier analysis to estimate the technical inefficiency of the Spanish airports with the inclusion of firm effects to control special features affecting airports' individual efficiency. A second stage regression is performed with tourism indicators of the areas where airports are located. The results show that airports' special features are relevant to avoid model misspecifications. Therefore, wrong managerial decisions regarding inputs and outputs. In terms of tourism regional aspects, the type of accommodation is a relevant factor affecting airports' efficiency in popular touristic areas. The existence of campsites in comparison with the number of hotels becomes a negative externality for airports' efficiency. In areas that are not usually chosen as a tourist destination, the inefficiency is mostly caused by the financial crisis enhancing alternative transport modal choices. The conclusions refer to airports' differentiation to attract more passengers and airlines to improve the inefficiencies.

Keywords: *Airports Inefficiency; Stochastic Frontier Analysis (SFA)*; *Fixed Effects; Touristic Areas; AENA*

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http://identitatcorporativa.gencat.cat/web/.content/Documentacio/descarregues/dpt/BN/Vice_Economia/scunirec_bn_h3.jpg

1. Introduction

The liberalization of the aviation market in Europe towards a single sky along with the aviation strategy adopted in Europe (European Commission, December 2015) confirms the importance of aviation sector underpinning connectivity to international places at more competitive prices. The aviation sector becomes then a core driver of economic growth, jobs, trade, and mobility for the European Union. Regions growing in population and national and international economic activity have an increase in air travel demand (Goetz, 1992). Although the European Commission (2011) stresses the requirement of an inter-modal and competitive air transport system, the Spanish regulatory framework seems not committed starting for not allowing competition between airports[36]. Additionally, the Spanish airports are managed by a central authority named AENA, a government-owned company. Airports within the same regional areas frequently suffer from low traffic since these are not differentiated in terms of the quality of the services provided. The airports' charges are also decided by AENA rather than by the airports' individual managers. Consequently, areas are usually overcrowded with more than one regional airport, but without enough routes and connection options for passengers.

The relevance in making the Spanish airport system attractive relays on airports being a key factor in the economic development of local economies (Sarkis, 2000). The airport industry has an impact in other sectors such as tourism and trade. The geographical location of airports involves environmental factors related to the socio-economic structure of the population; intermodal connectivity; the industrial potential and others leisure services (Tapiador et al., 2008). The specific airports' location can provide better conditions for competitiveness for some airports in detriment of others. The growth of low-cost carriers' air traffic has driven the use of secondary regional airports used due to the low congestion and lower marginal costs (Barbot, 2006). In fact, the LCC business model is based on secondary airports (Doganis, 2006). LCC airports choices depend on several factors, but overall economic reasons (Warnock-Smith and Potter, 2005; Dziedzic and Warnock-Smith, 2016). Airports enhance economic regional development, but the adequate market conditions must be provided.

[36] The European airports must provide worldwide connectivity with an efficient mobility of passengers and freight by 2050.

A centralized management treating all the airports as a whole seems not to address the needs of the city and region where regional airports are located. It is important to increase the awareness of differences across airports regarding capacity and location in order to make decisions according to regional needs (for example, regarding connecting remote areas or serving enough routes to help business to be developed locally)

One of the key aspects is to seek the reason for some airports having less operational activity (traffic) in detriment of others. On this basis, benchmarking allows comparing airports performance to confirm which aspects affect some airports' operational efficiency against other airports. Airports benchmarking has an extensive literature including several methodological approaches. Most of the studies in the airport industry use data development analysis (DEA) (for example, Gillen and Lall 1997, 2001; Adler and Berechman, 2001; Martin and Roman, 2001; Pels et al., 2001; Yoshida 2004; Yoshida and Fujimoto, 2004; Lin and Hong, 2006; Barros, 2008). Few studies use parametric methods such as stochastic frontier analysis (Pels et al., 2001; Martin-Cejas, 2002; Barros, 2008a, 2008b) and stochastic frontier based on a Bayesian approach (Assaf 2008, 2010a, 2010b). Differentiating by airports' homogeneity in the data (Pels et al., 2003) compared to heterogeneity (Barros 2008a; Assaf, 2010b). Overall although the literature in the Spanish airport system attempts to investigate the reasons for differences in efficiency, this is usually explained by the number of passengers (Ripoll-Zarraga and Mar-Molinero, 2017). In tourism literature at micro and macro levels (tourism industry), the studies using DEA represent a 74% of the total (Assaf and Josiassen, 2015). Authors found aspects such as geographical location enhanced by the population resources; airports associated with tourism, industry and available services affecting efficiency. For instance, Assaf (2010) suggested that factors such as privatization; economic growth; price regulation; location; and quality standards could have contributed improvements in efficiency. Otherwise, Yu (2004) pointed out the importance of the development of tourism to explain the prosperity of the offshore airports in Taiwan. In this sense, Tapiador et al. (2008) evaluated tourism potential and existing leisure-related services as geographical efficiency determinants of Spanish regional airports. They use a tourist index and found that coastal tourism-based airports were better placed than others to compete in a liberalized market. The location may constraint improvements in efficiency for some specific airports. The

Spanish airports clearly require individual management strategies (Tapiador et al., 2008).

The overall conclusions refer to the requirement of analysing the determinants of efficiency from frontier studies (Assaf and Josiassen, 2015). This may be related to controllable factors such as inputs (resources) and outputs (namely traffic), but also due to operational barriers such as the population density in the airport catchment area and environmental aspects (weather) As far as our knowledge is concerned literature has not investigated the role of individual tourism variables as determinants of airports' inefficiency. Although previous studies refer to decisions among inputs affecting airports' efficiency in the case of the Spanish airport system this relation is not that clear. One of the reasons is the strong centralized management forbidden airports' managers to freely decide among inputs and outputs. Consequently, it is not that clear that straight decisions regarding inputs (or outputs) will be determining airports' efficiencies. In the same way, it would be expected tourism demand and supply not only affecting airports' operating environment, but their efficiency.

In a first stage, we use stochastic frontier analysis under Battese and Coelli (1992) specification of the inefficiency term. Following Greene (2003) fixed effects are also enclosed in the production function to capture other factors affecting the individual inefficiencies. Fixed effects refer to special features identified in specific individual airports, but not in others. These are assumed to be time-invariant and correlated with the explanatory variables. On this basis, this study becomes a new empirical methodological approach in SFA within the Spanish airport system. The homogeneity is assumed across the panel data, but taking into account potential unobserved heterogeneity in some special cases. Following Battese and Coelli (1992) the unrestricted specification allows efficiency to vary over-time for random effects, but not for specific effects. A regression model is used in the second stage accounting for tourism variables potentially explaining the airports' individual efficiencies. The main idea in using two phases is to differ from the inefficiency caused by the management and unobserved heterogeneity related to airports' infrastructure versus the inefficiency potentially affected by the airports' geographical location. Based on the centralized management, the first inefficiency is considered fully controllable including the firm effects since investments' decisions are decided by the Spanish government through AENA. The results provide insights regarding the inefficiency that could be reduced by AENA and the inefficiency caused by touristic environmental variables (not-controllable).

The paper is structured as follows. Section 2 describes the Spanish airports' management model and provides some figures about the importance of Spain as a relevant tourism destination. Section 3 shows the models used. Section 4 the data description. Section 5 presents the results for both phases and the discussion. Section 6 summarizes the main conclusions.

2. The Spanish airports' regulatory framework

The Spanish airports are government owned and managed by a public company named AENA (Aeropuertos Españoles y Navegación Aérea). AENA manages 49 civil aviation airports including four general aviation airports and two heliports. The management is fully centralised including commercial and accounting policies. In an airport-system, airports are cross-subsidized meaning that financial resources from profitable airports finance no-profitable airports. The fact that AENA is not subsidized by the Government has promoted the airports' commercial development with a relevant presence of commercial activities versus aeronautical in some cases (Ripoll-Zarraga and Mar-Molinero, 2017). The requirement of the Spanish airport-system financial sustainability implies new sources of income, but essentially cost reduction strategies to assure covering the financial costs from borrowings used to finance the investments made in the past years. The excess of investments made in the last decade in Europe (European Commission, European Court of Auditors, 2014) highlights the inadequacy of having a centralised management and the requirement of transferring competences to the regional level (Ripoll-Zarraga and Mar-Molinero, 2017).

One of the consequences of the centralised management is that the Spanish airports do not compete. There are several geographical areas with more than one airport within an amenity distance serving the same areas. Consequently, these are not congested becoming cost inefficient (Martin et al., 2011). The network contains a significant number of small and medium airports not used for aeronautical purposes. Previous studies in the Spanish airport system analyse the relation between infrastructure and traffic within the same catchment area and the geographical location (Martin and Roman, 2001 and 2006; Tapiador et al., 2008). The findings conclude airports' location affecting efficiency and large and small airports being more geographical efficient. A review of previous studies in the Spanish airport system and the main findings are summarized in Ripoll-Zarraga and Mar-Molinero (2017)

The question to be addressed is if part of this traffic could be explained by geographical characteristics of airports and more specifically tourism variables rather than the inputs and outputs.

Figure 1: The Spanish Airport System (Source: AENA, 2013)

Spain is the third European country in terms of the volume of passengers transported by air, after the United Kingdom and Germany. In addition, three Spanish airports, Madrid-Barajas; Barcelona and Palma de Mallorca are in the European ranking of the 15 busiest airports. Madrid-Barajas is coming as number four. Spain is one of the most popular tourist destinations worldwide, occupying the third place in 2016 in the world ranking of tourist arrivals after France and the United States. In terms of tourism revenue is also the third tourism destination after the US and China (WTO). From the point of view of tourism's contribution to the Spanish economy, the Tourism Satellite Account (TSA) represents around the 11% of GDP[37].

The physical environment positively influences the choice of Spain as a tourist destination. The country has 108 days per year of temperatures above 25 degrees, 2,451 hours of sunshine, which is equivalent to 6.7 hours of daily sun. It boasts 8,000 km of coastline and the highest number of blue flag beaches in the world. Moreover, 24% of Spanish territory is classified as a protected area coming third in the European ranking. Spain has a total of 44 world heritage monuments and sites being the second

[37] The Tourism Satellite Account allows measuring the relevance of tourism activities on the economy as a whole.

country in the world in terms of this factor, preceded only by Italy, which has 47. The range of hotels available positions Spain as the second place in Europe with 1.8 million hotel-beds available, and ranked the fourth in the number of establishments.

The individual geographical and hospitality characteristics clearly reflect different conditions under the Spanish airports operate. This is known as unobserved heterogeneity and since it is not controlled by the airports' operator, creates inefficiency. Unobserved heterogeneity may be caused by economic cycles or market levels characteristics as well as low transfer capacity of inputs (Bottaso and Conti, 2010). The relevance of accounting for heterogeneity is to avoid biasing the estimated efficiency levels. Examples of unobserved heterogeneity are demographic characteristics where airports are located (e.g. population and weather), but also airports' structural characteristics (e.g. longer runways) not changeable at least in the short-term. Overall, these exogenous factors could cause a significant season effect restricting the traffic to a specific period of times during the year. Finally, other factors related to the regulatory framework; government policy and ownership forms could also generate inefficiency. These are particularly relevant in the Spanish airport system since airports' managers are not granted with managerial decision power. Nevertheless, this goes beyond the scope of the paper. In the first stage, the regulatory impact is implicitly captured by accounting for firm effects related to infrastructure characteristics since airports' investments are fully decided by AENA. With this regard and in this context the unobserved heterogeneity could be discussed to be controlled by the centralized management. This is identified as airports' time-invariant singularities and enclosed in the production function. In the second stage, the unobserved characteristics are related to the airports' specific geographical location. Therefore, these are considered not to be under AENA´s control. These correspond to region-specific effects classified as touristic and no-touristic areas that can variate across time.

3. Methodology

The first stage consists of applying stochastic frontier analysis (SFA). The main advantage of the stochastic frontier approach over DEA is that it isolates the influence of factors other than inefficient behavior. The model specification follows Battese and Coelli (1992), but accounting for entity fixed effects (Greene, 2003) in the production function. The model is a translog distance function being the most adequate framework since airports are multi-output firms (Coelli and Perelman, 1999; Kumbhakar and Lovell, 2000).

Prior to deciding the stated SFA model, several SFA models were tested including environmental variables as a function of the inefficiency term (Battese and Coelli, 1995). The results show few explanatory causes of the overall inefficiency of the network, but without relevant impact (Ripoll-Zarraga, 2018). These may be a consequence of the particularities of the Spanish airport system avoiding extrapolating to other countries. On this basis, to the best of our knowledge, this is a different methodological approach: SFA with the inclusion of fixed effects in a first phase and an independent regression in a second phase.

Following Greene (2003) fixed effects are considered within the model to account for singularities of certain airports that remain constant over time (unobserved heterogeneity). The assumption made is that these fixed effects may bias the predictor variables. Therefore, by considering fixed effects the impact of the time-invariant characteristics is removed. Another important assumption behind fixed effects is that the singular effect of the individual decision-making unit is not correlated to the rest of the characteristics of the same unit.

The translog function has a flexible functional form. The use of the translog production function is based on its properties of flexibility and homogeneity (Lovell et al., 1994) allowing partial elasticities of inputs-substitution to vary. Assuming m outputs and k inputs; choosing arbitrary one of the inputs as the $\varsigma - th$ input for normalising purposes ($k = \frac{1}{x_{\varsigma it}}$) and normalising the rest of the k -1 inputs by k, the translog distance function follows,

$$ln({}^{1}/_{X_{\varsigma it}}) = \beta_0 + \sum_{j=1}^{k} \beta_j \ln(x^*_{jit}) + \frac{1}{2}\sum_{j=1}^{k}\sum_{j'}^{k} \beta_{jj'} \ln(x^*_{jit})\, ln\,(x^*_{j'it}) + \sum_{l=1}^{m} \alpha_l \ln(y_{lit}) + \frac{1}{2}\sum_{l=1}^{m}\sum_{l'=1}^{m} \alpha_{ll'} \ln(y_{lit}) \ln(y_{l'it}) + \sum_{j=1}^{k}\sum_{l=1}^{m} \beta_j\, \alpha_l \ln(x^*_{jit}) \ln(y_{lit}) + (v_{it} - u_{it}) \quad (1)$$

The homogeneity restrictions (Lovell et al., 1994) follow,

$$\sum_{l=1}^{m} \alpha_l = 1, \sum_{l'=1}^{m} \alpha_{ll'} = 0, \sum_{l=1}^{m} \beta_j \alpha_l = 0 \ (2)$$

The error contains a random error (v_{it}) and the inefficiency term (u_{it}). Random effects allow a more consistent and unbiased estimation compared to fixed effects. Battese and Coelli (1992) specification of the inefficiency term (u_{it}) depends on a pattern term (η), which allows changes over-time and on an invariant component (u_i). Since efficiency can change over time, this model is more flexible compared to Pitt and Lee (1981) that imposed a constant level of efficiency $(\eta_{it} = 1;\ \eta = 0)$. The inefficiency error term has a non-negative truncated normal distribution with non-zero mean and constant variance $ui \sim N^{+}(\mu, \sigma_u^2)$. The random error is assumed to have zero mean and constant variance $vi \sim N^{+}(0, \sigma_v^2)$

$$u_{it} = u_i \,.(\exp(-\eta(t - T_i) \ (3)$$

η is the rate of inefficiency decay for each airport i from a period t to T_i, which is the last and the reference period. A shortcoming of the time-varying decay model is that the inefficiency decays monotonically, increasing or decreasing towards a reference period. Therefore, the inefficiency cannot decrease over some periods and rise again.

The frontier function is estimated by the maximum likelihood method, as the inefficiency is estimated from the residuals of the regression.

The individual estimation of inefficiency can be obtained using the distribution of the inefficiency term conditioned to the estimation of the composite error term (Jondrow et al., 1982). Robust stochastic frontier analysis has been applied in order to test heteroscedasticity.

The specific airports' characteristics (fixed effects) are introduced as dummies ($D_{ï}$) in the production function. Each dummy represents one specific airport ï identified for containing special features compared to the rest $(n - ï)$. Airport-specific effects are assumed to be correlated with the regressors. Therefore, the equation (1) becomes,

$$\ln({}^{1}/_{X_{\kappa it}}) = \beta_0 + \sum_{j=1}^{k} \beta_j \ln(x_{jit}^{*}) + \frac{1}{2}\sum_{j=1}^{k}\sum_{j'}^{k} \beta_{jj'} \ln(x_{jit}^{*})\, ln\left(x_{j'it}^{*}\right) + \sum_{l=1}^{m} \alpha_l \ln(y_{lit})$$
$$+ \frac{1}{2}\sum_{l=1}^{m}\sum_{l'=1}^{m} \alpha_{ll'} \ln(y_{lit}) \ln(y_{l'it}) + \sum_{j=1}^{k}\sum_{l=1}^{m} \beta_j\, \alpha_l \ln(x_{jit}^{*})\ln(y_{lit}) + D_{ï} + (v_{it} - u_{it}) \quad D_{ï} \in ï = 1, \dots n \ \ (4)$$

In the second stage, a regression is performed. The efficiency scores obtained from the first analysis (SFA) are used as the dependent variable. The explanatory factors are related to the tourism demand and supply within the specific region where airports are located. These factors are proxies of tourism attractiveness assuming enhancing tourists to travel to certain cities in detriment of others. Therefore, airports' technical inefficiencies may be affected. The next section describes the tourism variables used in the second stage.

Note that since the first stage model uses different inputs and outputs, the fixed effects are referred to capacity singularities (usually airports' infrastructure) potentially related to the level of traffic. On this basis, not all the airports are considered having fixed effects. The fixed-effects model controls for all time-invariant differences between units (airports). Therefore, the fixed-effects coefficients are unlikely to be biased because omitted time-invariant characteristics. With this regard, although airports' geographical location could be considered fixed effect (i.e. certain airports may have more passengers due to their location), this potential omitted feature is controlled in the first analysis. In the same way, tourism indicators are considered being independent of fixed effects. This also assures potential endogeneity problems when performing the second stage regression.

4. Data Description

The stochastic frontier analysis has been applied to 48 airports for a period of five years (2009-2013). Individual financial information before 2009 is not released. The Spanish regulatory framework based on a fully centralised management without airports operators' flexibility to apply commercial policies, supports the use of airports rather than airlines. This is also evidenced in the literature (see Ripoll-Zarraga and Mar-Molinero, 2017). The number; type of airlines and routes are conditioned to how the Spanish market operates that is not being liberalised. There is a clear increment of an additional passenger when airports decide freely the fares (price differentiation). Additionally, the airlines studies are usually focused on the impact of low-cost carriers and hubs (e.g. Castillo-Manzano et al., 2017; Marti et al., 2015). The divergence shown in terms of traffic and regulation regarding civilian airports compared to general aviation (Madrid cuatro-vientos; Madrid-Torrejon[38]; Sabadell and Son Bonet)

[38] Madrid-Torrejon is a military base used as support to Madrid-Barajas until the end of January 2013.

and heliports (Algeciras and Ceuta) have been tested through a sensitivity analysis. Finally, all the airports have been enclosed in the final analysis except Son Bonet due to missing regarding infrastructure (depreciation). Following Ripoll-Zarraga and Mar-Molinero (2017) the network is classified in terms of passengers containing 14 large airports (i.e. more than 3.5 million of passengers per year); 13 medium and 22 small-sized airports (with less than 750,000 passengers per year).

Airports	Size	Min PAX	Max PAX
Alicante; Barcelona; Bilbao; Fuerteventura; Gran Canaria; Ibiza; Lanzarote; Madrid Barajas; Malaga; Palma de Mallorca; Sevilla; Tenerife-North; Tenerife-South; Valencia	> 3,500,000	3,524,470	39,735,618
A Coruña; Almeria; Asturias; Girona-Costa Brava; Granada; Jerez; La Palma; Menorca; Murcia; Reus; Santander; Santiago; Vigo	≤ 3,500,000 > 750,000	638,288	2,736,867
Albacete; Algeciras; Badajoz; Burgos; Ceuta; Cordoba; El Hierro; Huesca-Pirineos; La Gomera; Leon; Logroño; Madrid 4 vientos; Madrid Torrejon; Melilla; Pamplona; Sabadell; Salamanca; San Sebastián; Son Bonet; Valladolid; Vitoria; Zaragoza	≤ 750,000	273	457,595

Table 1: Airports Size in terms of Passengers per year (Source AENA 2013 in Ripoll-Zarraga and Mar-Molinero, 2017)

The summary statistics for the 49 airports managed by AENA are shown in Table 2[39].

Variable	Observations	Mean	Standard Dev.	Minimum	Maximum
PAX (th)	245	3,944.68	8,529.97	0	49,900
ATM (th)	245	41.41	71.74	0.24	435.19
Cargo (th tones)	245	13,000	52,400	0	394,000
Commercial (th €)	245	11.71	27.83	0	169.51
Labour (th €)	245	7.23	10.19	0.11	74.24
Operating (th €)	245	19.03	49.86	0.24	318.30
Depreciation AENA (th €)	245	14.40	39.31	0.18	264.45
Depreciation Airside (th €)	240	4.16	11.08	0	79.80
Depreciation Landside (th €)	240	1.09	2.22	0	11.94

Table 2: Summary Statistics (Source: AENA except for Depreciation Airside-Landside, 2009-2013)

[39] Algeciras is under construction in 2009; Madrid Torrejon is assumed to have zero depreciation in 2009 and 2010 for both types of assets: there is no information of initial investments and improvements (Ripoll-Zarraga and Mar-Molinero, 2017)

The statistics show relevant variability suggesting a divergence in terms of infrastructure (capacity) as well as in traffic, for example, comparing passengers and cargo. Overall airports with a significant cargo level have a low number of passengers and vice versa. Aeronautical revenues are accounted in the value of passengers; air traffic movements and cargo. The aeronautical income is clearly more relevant compared to commercial revenues. Labour refers to the cost of AENA's employees working in the airports. These are an indicator of the overall Spanish airport system fixed costs. AENA does not provide information regarding number and type of employees (permanent; fix; full and part-time). The depreciation reported by AENA is significantly higher compared to the new values estimated. Meetings with managers have confirmed the excessive annual charges applied by AENA (Ripoll-Zarraga and Mar-Molinero, 2017). Consequently, AENA's depreciation may not be in accordance with how revenues are generated. The literature shows a divergence regarding the inputs used and essentially when including measures of cost of capital (for example airports physical area, Tovar and Martin-Cejas, 2009 and 2010 and Martin et al. 2011; the number of runways and terminal buildings, Martin-Cejas, 2002; amortization of fixed assets, Martin and Roman, 2001; Martin et al., 2009, 2011 or book value Murillo-Melchor 1999, Salazar de la Cruz 1999, Pestana and Sampaio, 2004, Martin et al., 2009 and Coto-Millan et al., 2014, 2016).

Based on the information provided by AENA, the following inputs are used: labour costs; operating costs and depreciation of assets. In the output side the number of passengers; air traffic movements; cargo and commercial revenues (e.g. passengers, Murillo-Melchor, 1999, Salazar de la Cruz, 1999 and Tovar and Martin-Cejas, 2010; air traffic movements and cargo, Martin and Roman, 2001, Lozano and Gutierrez, 2011, Lozano et al., 2013 and Coto-Millan et al., 2014 and 2016; aeronautical and commercial revenues, Salazar de la Cruz, 1999, Tovar and Martin-Cejas, 2009, 2010 and Martin et al., 2011).

The dependent variable in the translog distance function is the labour costs (input distance function). The idea is to test if there is a relation between airports infrastructure (depreciation) and operational activity (operating costs and traffic) with the labour employed by AENA. Since all the airports are government owned and managed, the Spanish government may treat the Spanish airports as public utilities prioritising social policies (employment or connectivity) rather than industry needs.

All the data have been extracted from the annual reports of AENA except for the depreciation since it is highly correlated with operating costs (Ripoll-Zarraga and Mar-Molinero, 2017)[40]. The airports' infrastructure refers to airside and landside assets (Ashford et al., 1996) Airside assets is infrastructure directly related to the aeronautical activity. Landside assets refer to other assets not strictly necessary for air transport purposes. Examples of airside assets include aviation terminals; aprons; taxiway; runways; air traffic control and visualisation systems (beacon). Landside assets account for passengers and cargo terminals; parking; emergency services buildings and other investments including recycling system and access roads. The relevance of including depreciation rather than physical measures such as the number or extension of runways; the number of terminals, etc. correspond to being a reflection of the use of airports' infrastructure in the operational activity. The depreciation policy should follow the accruals and matching conventions accounting for a relation between the usage (cost) and income earned. In this case, since AENA depreciation is not used, a risk of over-depreciating does not occur: accruing more expenses compared to the traffic generated (income earned).

The data has been deflated by the Spanish gross domestic product deflator (base Spain, 2010) and standardized by the respective geometric mean, which allows estimating elasticities at sample means (Cuesta et al., 2009) Table 3 shows the descriptive of the variables used in the second stage.

Variable	Observations	Mean	Standard Dev.	Minimum	Maximum
Technical Efficiency	189	0.722	0.081	0.513	0.919
Hotels (th)	189	0.474	0.314	0.131	1.118
Camp Sites (th)	189	0.090	0.102	0.003	0.456
Apartments (th)	189	11.14	15.46	0.272	59.55
Expenditure (€)	189	86.418	33.48	20	163
Length (days)	189	3.402	1.953	1.4	8
Arrivals (mill)	189	6.286	14.052	0.144	14.32
Labour Force (mill)	189	0.259	0.225	0.010	1.143
Price Index	189	98.06	1.496	94	101

Table 3: Summary Statistics (2009-2013)

[40] The new depreciation shows a significant lower correlation coefficients with the operating costs (Ripoll-Zarraga and Mar-Molinero, 2017)

For the second- step tourism variables refer to accommodation supply and demand. The inclusion of these variables addresses the potential relation between the tourism attractiveness of a city and the passengers' choice of the city airport as the final destination. A range of type of accommodation in quality and price or the concentration of touristic services in specific areas could explain the reasons because some destinations are preferred in detriment of others (Butler, 1980). From an initial sample of 240 airports (48 airports from 2009 to 2013), the final data refers to 189 observations due to missing in tourism variables. The technical efficiency scores correspond to the results obtained in the first analysis following Battese and Coelli (1992) accounting for fixed effects (see table 5). The tourism data statistics reveal a significance in the number of apartments compared to hotels or campsites. This is evidence for a change in the tourism behaviour pattern since the financial crisis started (Tussyadiah and Pesonen, 2016) Tourists tend to rent apartments based on a lower cost per day compared to hotels. With this regard, tourists have a higher daily budget potentially enhancing more number of days to spend at the destination. The labour force is the number of employees working in the touristic sector. The price and employees have been obtained from official statistics provided by the National Institute of Statistics (INE). It has not been possible to obtain more disaggregate data except at the provincial level. We are aware that this may create a potential bias as there is more than one different sized-airport usually within the same province. Therefore, the tourism attractiveness indicator has been relaxed regarding the standard values (Juaneda et al., 2011). The type of accommodation and the employees have been standardized by the number of inhabitants of the province.

Note that due to the significant missing data in the second stage a translog accounting for the inefficiency term as a function of environmental variables (Battese and Coelli, 1995) has not been possible to be performed. The idea when analyzing the overall inefficiency (u_{it}) and environmental variables is to enclose as many airports as possible. On this occasion, some airports have missing data for all the years with variability in terms of size (for example, Lanzarote, large airport; a medium-sized, La Palma and small airports, Ceuta; Huesca-Pirineos; La Gomera and Melilla). Further research has been performed considering external factors potentially influencing airports' inefficiency (environmental variables) enclosed simultaneously within the stochastic frontier (see Ripoll-Zarraga, 2018)[41].

5. Results

First-step estimation

The results of the stochastic frontier analysis are shown in Table 4. The first column corresponds to the translog without considering fixed effects. The second column is the model enclosing fixed effects in the production function as dummies. The fixed effects regression model for panel data running all the airports at once has revealed six airports with fixed effects. Three out of these six airports confirmed a significant absolute value of their coefficients (i.e. from 2 to 4) compared to the rest in the first outcome (the fixed effect model containing all the airports as dummies). The selection of these airports was done by performing sensitivity analysis and resampling the fixed effects model. The model showing the lowest level of noise, a significant value of the expected inefficiency and the parameters of interest was used to identify airports with fixed effects. The results were also supported by observing the physical airports' infrastructure confirming the airports with special features. Fixed effects have been identified in large airports (Barcelona; Madrid; Palma de Mallorca and Malaga), but also in small airports such as Huesca-Pirineos and Vitoria (cargo-oriented airport). As stated, these airports are assumed to have time-invariant features.

The maximum likelihood technique is employed to the estimates of the variable coefficients and the parameters of the two error components. Both models show high values of likelihood estimator with a clear improvement when considering entity fixed-effects. The respective high values support the low-level of noise compared to inefficiency explained. As previously discussed, the distributional assumptions of the two components of the error term are identically and independently distributed.

Due to the extension of the translog function, all the individual effects are shown, but only the significant iterations. The null hypothesis of the no-existence of inefficiency is rejected in the first model since the expected inefficiency is significantly different

[41] The exogenous variables are the number of competitors within the catchment areas; existence of public service obligation routes (PSOs); train facilities to access directly the airport; capacity of the airport subject to air traffic restrictions and main aeronautical activity of the airport.

from zero (μ). When fixed effects are considered the expected value of the inefficiency is significantly lower (39%) compared to when these are not identified (64%). With this regard, the second model has more explanatory power compared to the first one, potentially biased. The significant drop in the overall inefficiency of the system confirms that the fixed effects enclosed capture satisfactorily special features (unobserved heterogeneity). Consequently, if these are not taken into account the results could lead to model misspecifications. It is important to bear on mind that the inefficiency estimated by the number of inputs used and outputs produced (production function) is due to the management (AENA). This means that the inefficiency could be reduced by making decisions among inputs and/or outputs. If fixed effects were not considered, the model would reveal a 64% of inefficiency caused by AENA. Nevertheless, this is not entirely robust as shown by the results when including fixed effects (39%). Gamma ($\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$) is an indicator of the explanatory power of the model ($0 \leq \gamma \geq 1$). When gamma is close to zero, the model has a significant presence of noise. When gamma is close to the unity, the technical inefficiency explains overall the dependent variable. The optimization is parametrised in terms of the inverse logit of gamma (ilgtgamma). The low-level of noise supports the adequacy of stochastic frontier analysis in the first model. The fact that ilgtgamma is not significant, essentially when including fixed effects, reveals that there is further variability to be explained. Additional airports may be enclosed within the production function (fixed effects). This is to be performed in future analysis.

Regarding the individual effects, the results show the coefficients of the basic variables with the expected signs. There is relevance for the passengers and movements effects compared to commercial revenues. The depreciation of assets is not significant evidencing that there is not a relation between airports' infrastructure and labour costs. The vast majority of airports suffer from over-investments since traffic has not increased accordingly (based on AENA's information from 2009 to 2013). Cargo although significant does not have a major impact as shown in previous studies (Ripoll-Zarraga and Mar-Molinero, 2017; Ripoll-Zarraga et al., 2017, Ripoll-Zarraga and Lozano, 2018)[42].

[42] This result is initially supported since there are two cargo-oriented airports: Vitoria and Zaragoza.

The fixed effects model shows similar results regarding both, significance and value of parameters, except for commercial revenues where there is a clear trade-off between the first and the second model[43]: the fixed effects reveal the requirement of commercial revenues co-existing with the number of passengers ($\beta_{45} = -0.1137$). The fixed effects model also shows the relevance of large and hub airports such as Barcelona and Madrid in generating financial resources ($D_1 = -1.0149$; $D_2 = -1.2943$) compared to small airports. Airports not having enough traffic such as Huesca-Pirineos become a burden for the system ($D_5 = +0.3785$). The results also show that airports' specialisation contributes positively from a financial perspective ($D_6 = -0.6384$). Finally, there is a clear season effect when airports are located in touristic areas: Malaga ($D_3 = -0.4784$) and Palma de Mallorca ($D_4 = -0.4346$) are usual tourists' destinations in specific periods of the year. Therefore, these airports do not contribute consistently to finance the overall labour costs in comparison to other large airports considered popular destinations during the whole year (e.g. Barcelona)

Table 5 shows the average of technical efficiencies for each airport in both models. The fixed effects model provides higher values compared to the standard model (Battese and Coelli, 1992). These results confirm that the presence of environmental factors (unobserved heterogeneity) affects airports operational performance independently of the level of traffic. Therefore, it is important to control them. The efficiencies are significantly lower when entity fixed effects are not identified. These results confirm the requirement of identifying fixed effects to avoid misspecifications. As previously stated these singularities are assumed not to change-over-time. In order to understand the scope of the efficiencies and the number of airports located nearby, figures 2 and 3 shows the location of each airport in terms of catchment areas. A catchment area is defined as the influence area within 150 kilometres (Ripoll-Zarraga and Mar-Molinero, 2017). The efficiency level has been ranked within three groups: low, with efficiency scores between 1% and 59%; medium between 60% and 75% and high for airports with more than 75% of efficiency. Note than Gran Canaria is classified as medium-efficient since obtains an efficiency higher than 59%. Apart from the inefficiency caused by the management (AENA) when not considering fixed effects, the maps reveal that somehow the location and the number of airports located in the regional area could also contribute to the overall inefficiency of the system. A further analysis is performed by including touristic factors related to the airports' specific environment.

[43] Commercial revenues are significant in the first model ($\beta_4 = -0.1137$), but not in the fixed effects model. The iteration between commercial revenues and passengers is significant in both models with a higher effect in the second one ($\beta_{45} = -0.1137$)

	Coefficients	SFA_1 (1992)	SFA_2 FE (1992)
β_0	Constant	1.0072*	0.7626
β_4	LnCommercial	-0.1137*	-0.0852[1]
β_5	LnPAX	-0.1975*	-0.2367*
β_6	LnATM	-0.2600*	-0.1503*
β_7	LnCargo	-0.0456*	-0.0389*
β_1	LnOperating	0.4213*	0.4458*
β_2	LnDepreciation Airside	0.0045	0.0071
β_3	LnDepreciation Landside	-0.0115	-0.0050
β'_4	½LnCommercial²	0.0435*	0.0619*
β'_6	½LnATM²	0.0381	0.1034[1]
β'_7	½LnCargo²	-0.0062[1]	0.0006
β'_1	½LnOperating²	0.0105	0.0754
β'_2	½LnDepreciation Airside²	-0.0014	-0.0012
β'_3	½LnDepreciation Landside²	-0.0017[1]	-0.0011
β_{45}	½LnCom·LnPAX	-0.0887*	-0.1137*
β_{47}	½LnCom·LnCargo	-0.0339*	-0.0311*
β_{56}	½LnPAX·LnATM	0.0771*	0.0566*
β_{57}	½LnPAX·LnCargo	0.0197	0.0029
β_{13}	½LnOperating·LnDepreciation Landside	0.0244[1]	0.0238[1]
β_{14}	LnOperating·LnCommercial	0.0550	0.0638[1]
D_1	Barcelona	n/a	-1.0149*
D_2	Madrid-Barajas	n/a	-1.2943*
D_3	Malaga	n/a	-0.4784*
D_4	Palma de Mallorca	n/a	-0.4346*
D_5	Huesca-Pirineos	n/a	0.3785*
D_6	Vitoria	n/a	-0.6384*
	mu (μ)	0.6394*	0.3876*
	$lnsigma^2$	-2.9755*	-3.2800*
	$ilgtgamma$	0.6113[1]	0.1624
	eta	-0.0467*	-0.0788*
	$Log\ Likelihood$	89.39	105.73

Table 4: Translog distance function (Battese and Coelli, 1992)

*Significant different from zero at least at 5% [1]SFA_1: The results with the robust model are similar in terms of significance except for ½LnCargo ² $P > |z| = 0.117$; ½LnDepreciationLandside² $P > |z| = 0.218$; ilgtgamma $P > |z| = 0.082$ SFA_2: ditto except for LnCommercial $P > |z| = 0.066$; ½LnATM ² $P > |z| = 0.083$; LnOperating·LnDepreciation Landside $P > |z| = 0.204$; LnOperating·LnCommercial $P > |z| = 0.177$

	Size	SFA_1 (1992)	SFA_2 FE (1992)		Size	SFA_1 (1992)	SFA_2 FE (1992)
A Coruña	Medium	55.75%	75.69%	Logroño	Small	42.70%	58.10%
Albacete	Small	51.97%	62.99%	Madrid 4 vientos	Small	53.16%	66.31%
Algeciras	Small	87.48%	89.91%	Madrid Barajas	Large	48.06%	73.37%
Alicante	Large	58.39%	66.64%	Madrid Torrejon	Small	53.52%	71.74%
Almeria	Medium	45.99%	64.27%	Malaga	Large	48.85%	70.88%
Asturias	Medium	55.63%	75.14%	Melilla	Small	44.11%	58.43%
Badajoz	Small	69.78%	90.46%	Menorca	Medium	56.28%	72.62%
Barcelona	Large	48.39%	74.13%	Murcia	Medium	56.03%	73.39%
Bilbao	Large	64.97%	76.26%	Palma de Mallorca	Large	52.12%	74.22%
Burgos	Small	72.40%	90.51%	Pamplona	Small	42.67%	70.49%
Ceuta	Small	70.89%	86.25%	Reus	Medium	52.74%	69.81%
Cordoba	Small	49.56%	70.72%	Sabadell	Small	62.04%	82.25%
El Hierro	Small	64.99%	81.50%	Salamanca	Small	49.18%	67.54%
Fuerteventura	Large	58.66%	70.54%	San Sebastian	Small	61.64%	80.93%
Girona	Medium	64.31%	82.93%	Santander	Medium	49.97%	67.62%
Gran Canaria	Large	59.42%	62.37%	Santiago	Medium	50.05%	65.92%
Granada-Jaen	Medium	46.88%	65.04%	Sevilla	Large	64.85%	77.09%
Huesca-Pirineos	Small	68.58%	70.38%	Tenerife North	Large	60.45%	71.83%
Ibiza	Large	60.92%	74.07%	Tenerife South	Large	54.15%	66.45%
Jerez	Medium	52.77%	66.45%	Valencia	Large	65.21%	68.06%
La Gomera	Small	50.05%	64.38%	Valladolid	Small	53.82%	70.90%
La Palma	Medium	49.99%	66.23%	Vigo	Medium	50.27%	67.66%
Lanzarote	Large	63.60%	75.93%	Vitoria	Small	44.86%	71.03%
Leon	Small	51.81%	67.38%	Zaragoza	Small	72.23%	82.94%

	SFA_1 (1992)	SFA_2 FE (1992)
Mean	56.37%	71.96%
Maximum	88.29%	91.88%
Minimum	39.26%	53.06%
Standard Deviation	0.0919	0.0832

Table 5: Average Technical Efficiency Airports 2009-2013 (Battese and Coelli, 1992)

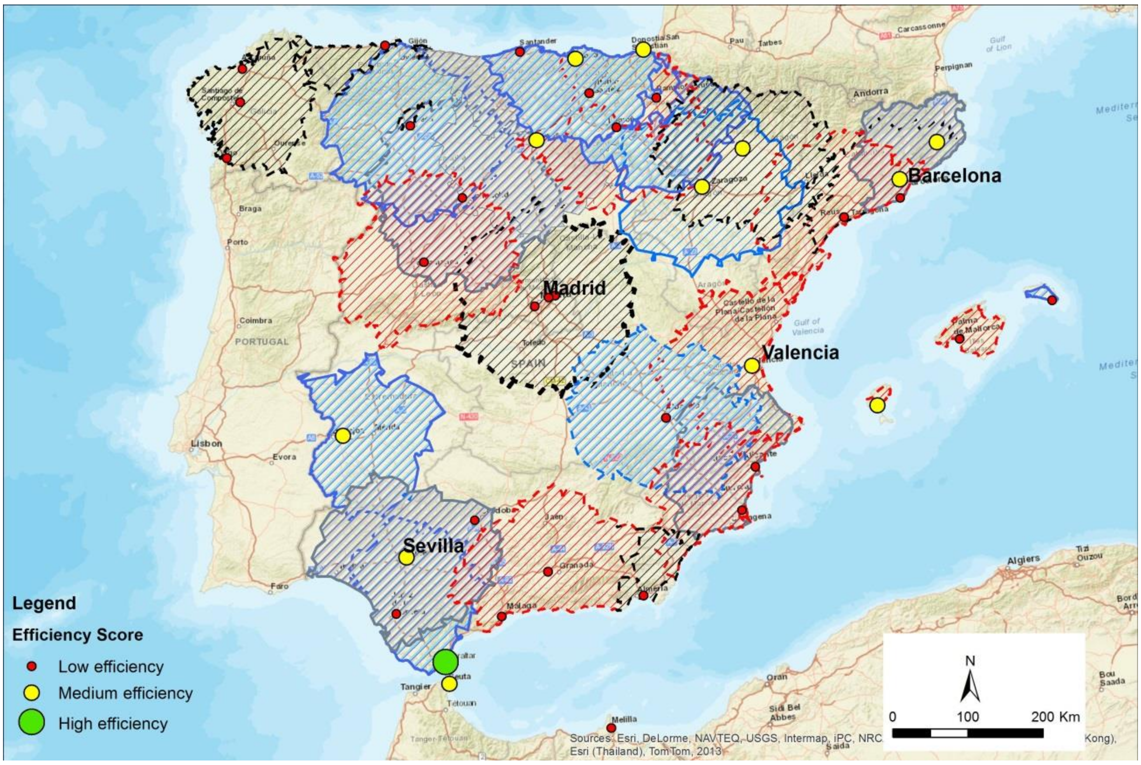

Figure 2: Average Technical Efficiency Mainland (SFA_1)

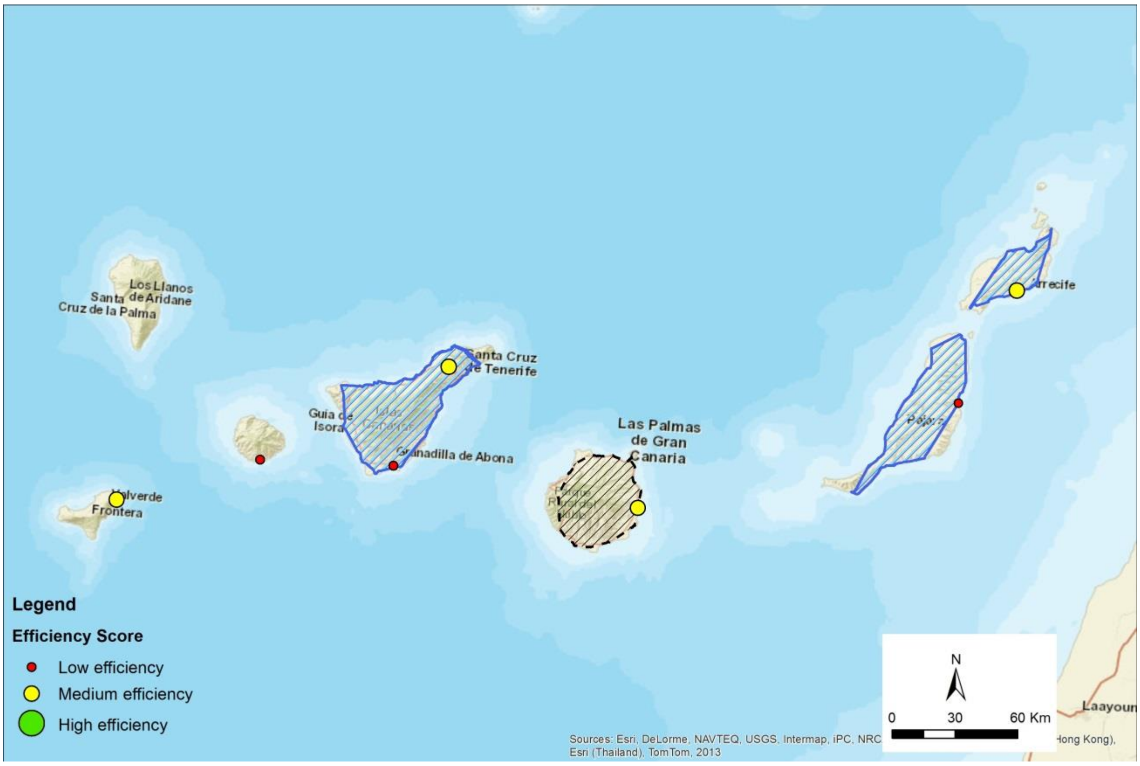

Figure 3: Average Technical Efficiency Islands (SFA_1)

Second-step estimation

Table 6 reports the estimates of the three regression models with the technical efficiency as dependent variable obtained from the SFA model including fixed effects. The first column presents the results for the total sample (i.e. without considering the airports' geographical location). The second and third column differ airports located in areas perceived as touristic and no-touristic respectively.

To divide airports into those located in a touristic (non-touristic) area we use the well-known tourism specialization index[44]. A touristic area is considered if the tourism specialization index is higher than 0.40, indicating substantial tourism[45]. Only six airports have a tourism specialization index over 0.40. These six airports are located in different areas not usually identified as touristic destinations (i.e. not coastal areas)[46]. These are Alicante and Girona located in the Mediterranean seaside. Burgos, Huesca-Pirineos and Pamplona located in the mid-northern area and Sabadell, in the same catchment area than Barcelona.

It is important to bear on mind that based on this criterion traditional touristic destinations may not be identified as a traditional touristic area. For example, Ibiza, Menorca, and Palma de Mallorca in the Balearic Islands; Gran Canaria, Tenerife South, and Tenerife North in the Canary Islands; Malaga and Sevilla are not touristic areas. In these areas, the number of households is very large compared to the second home residences or even empty residences. This is due to have a significant number of tourists' types of accommodation, such as hotels. These locations have approximately between 51,000 and 76,000 first homes compared to 3,500 of second residences (8,000 of empty homes), and 7,000 (16,000) respectively. This implies approximately 40,000-53,000 first residences.

[44] The tourism specialization index is the second homes per first home ratio, which measures the concentration of non-principal homes.

[45] The value of the tourism specialization index equal to the unity indicates a touristic area. Nevertheless, this threshold was established using municipality data (Juaneda et al., 2011). As we have province data (an aggregation of various municipalities), we have relaxed this threshold.

[46] Similar results were obtained using coastal locations instead of the specialization index. The only difference is the insignificant effect for the apartments.

Variable	Total	Touristic Area	No-Touristic Area
Hotels	0.101**	1.708**	-0.060
Campsites	0.003	-2.566*	-0.003
Apartments	-0.002	-0.025***	-0.007
Expenditure	0.001	0.003**	0.001
Length	-0.029**	-0.13**	0.019
Arrivals	0.0001	0.0001*	0.0001
Labour Force	-0.0002	0.004	-0.007
Price Index	-0.001	-0.006	0.005
Year (reference 2013)			
2009	0.007	0.001	0.005
2010	-0.009	0.0050	-0.02
2011	-0.073***	-0.013**	-0.078***
2012	-0.133***	-0.080**	-0.141***
Intercept	0.963***	2.174**	0.320*
R-Squared	0.32	0.94	0.28
Observations	193	24	169

Table 6: Results Estimated Models

When there is no distinction between areas, the number of hotels and the length of the stay are the only variables affecting the airports' efficiency levels. A higher number of hotels increase airports' efficiency by 10% while a higher length diminishes them at -2.9%. Cities with a higher number of hotels are usually cities nearby an airport, enhancing more visitors compared to other locations with a relatively fewer number of hotels, but another type of accommodation (i.e. campsites). At the same time, cities with few hotels will imply lower traffic for the respective airports (number of routes and passengers). Evidence suggests that competitive and efficient aviation services attract a larger number of tourists. The presence of low-cost carriers helps airports attracting more passengers, but due to their lower fares (Windle and Dresner, 1999) and other aspects such as passenger friendly attitude (Heskett and Schlesinger, 1994; Gillen and Lall, 2004). Nevertheless, in terms of product differentiation, the Spanish regulatory framework is not flexible. Spanish' airports not only do not compete, but they are unable to diversify by applying commercial policies (price and quality of the services provided) to make airports attractive to airlines and passengers. AENA applies a fully centralized management even deciding airports' charges. Apart from airfares, the other airport choice determinants are accessibility and flight frequencies (Windle and Dresner, 1995; Pels et al., 2003; Hess and Polak, 2006; Suzuki, 2007; Ishii et al., 2009). Again, these are managerial decisions under AENA's control. Consequently, airports do not attract passengers by providing a better service or price, but due to the airports' geographical location. This excludes potential endogeneity issues in the causality between tourism and airport traffic volume. Finally, in 2011 and 2012 the technical efficiency decreased by 7.3% and 13.3% respectively. The highest significant decrease in efficiency happens from 2011 to 2012 (-6%). This is that according to the trend, the efficiency decreases in the cruder crisis years. This result was also observed by Coto-Millan et al. (2014) for the Spanish airports experimenting a dramatic productivity regress due to the economic crisis. Additionally, previous findings highlighting the relevance of airports' efficiency in terms of passengers between 2010 and 2011 due to the financial crisis (Ripoll-Zarraga et al., 2017)

The results show that for touristic areas, the type of accommodation is a relevant factor affecting airports' technical efficiency. The touristic product is a complex experience enclosing multiple services used by visitors such as transportation; accommodation and attraction services (Gunn, 1988). Thus, a higher number of hotels increase significantly the efficiency for airports located in those areas. In particular, every hotel per 1,000 inhabitants increases the efficiency in 171 percentage points (0.17% per inhabitant). This effect is 1.6 times higher compared to not differentiating between touristic and non-touristic areas. However, every campsite per 1,000 inhabitants reduces the efficiency score by 257%. The apartments also reduce the efficiency of the airports in touristic areas, but with lower impact (-2.5%). The role of the type of accommodation (i.e. international hotel chains) and popular tourists' destinations are (among others) key factors to choose the travel destination product (Mo et al., 1993).

Every incoming tourist increases slightly the efficiency (0.01%) and for each euro spent the efficiency increases in just 0.3% These results suggest that the Spanish airports do not benefit from the number of passengers (tourist arrivals) and the tourists' purchases, unless these take place within the airports' premises: commercial revenues are an important source of income (ICAO, 2013). In the same way, the fact that a passenger stays one additional day at the destination decreases the efficiency by 13%. These findings confirm that tourists use alternative transport modals choices to arrive at the destination. With this regard, tourists visiting Spain do not choose the destination based on for example, lower airfares or availability of LCCs as suggested in literature, but other external factors are prioritized (tourism variables) It is demonstrated that differential pricing could attract

LCCs to airports (Barrett, 2004; Gillen and Lall, 2004). Consequently, airports could benefit from increasing their passengers even above of the forecast levels settled a priori (Cho et al., 2015). Nevertheless as previously discussed, AENA's centralized management makes marketing strategies and airport differentiation unable for the Spanish airports' managers. In non-touristic areas, none of these variables are significant suggesting that a popular tourist destination is a key factor for travelers to decide the airport destination (Gunn, 1988). In touristic areas the higher number of campsites versus hotels the more negative impact in the airports' efficiency located nearby.

The trend shows a lower decrease in efficiency during the crisis period (-1% in 2011 compared to -8% in 2012). For non-touristic areas, no significant effects apart from the trend are observed with a higher decrease in efficiency compared to touristic areas (-7.8% in 2011 and 14.1% in 2012). Due to the financial crisis airports have fewer passengers. Visitors use alternative travel choices potentially travelling to less popular, but cheaper destinations.

The results show that tourism variables do not affect airports' efficiency in areas perceived as non-touristic. Airports located in unpopular destinations are unfairly labelled as inefficient from a pure technical efficiency perspective. This is based on the airports' resources (labour; operating costs incurred and depreciation of infrastructure) in relation to the income generated (passengers; movements; cargo and commercial revenues). The results confirm that part of this inefficiency is due to the geographical location of these airports. These cities are less attractive for visitors who may also have different typologies in terms of sociodemographic characteristics; motivations; tourist activities; travel experiences; lifestyles and values (Cohen 1984; Pitts and Woodside 1986). On this basis, they may choose a different destination or even the same visited city, but using a different transport modal. Consequently, some airports suffer from a lower number of passengers compared to other airports located in popular destinations (heterogeneity unobserved). At the same time, airports located in touristic areas with fewer hotels, but alternative types of accommodation will also have much lower passengers. Visitors prefer other cities with a specific type of hotels or tourist infrastructure (Gunn, 1988). It is clear that situational factors may influence the final decision in terms of city destination (e.g. health; travelling with children and relatives; financial crisis, etc.). Nevertheless, travel behavior could be predicted. Recent travel experiences may determine future travel intentions (Mazursky, 1989). Airports located in popular touristic areas will gain from having more passengers subject to having a good travel experience including accommodation (hotels) and leisure activities. Airports located in other areas will have to make an effort to attract airlines and passengers through price differentiation and quality of the service provided by the airports.

6. Conclusions

The results obtained are of major interest for not only the Spanish airports' management (AENA) but also for tourism authorities. The overall results highlight the relation between airports' operations and the geographical location of airports. Furthermore, the type of accommodation is a clear driver to attract passengers with a potential differentiation of travelers (business versus leisure). These results are relevant to be considered essentially in a strong centralized management background with a lack of managerial flexibility of airports' managers. In the first stage, the results show the passengers and movements as the main explanatory factors of the airports' technical efficiency, and with less relevance cargo. Commercial revenues become a significant source of income with more relevance with a higher number of passengers. The cost of capital (depreciation) is not significant, suggesting that the Spanish airport-system suffers from over-capacity. Adequate managerial decisions must be taken to increase traffic. It is clear that airports' specialization and the airports' location in the seaside help the financing aspect of the system. Nevertheless, not all the inefficiency is due to decisions on inputs (airports' resources) and outputs (traffic). Although potential visitors may be willing to choose a specific destination, the Spanish market is not currently attractive to airlines and passengers. It is essential to enhance the aeronautical aspect of the airports allowing diversify and to provide different products and services (i.e. to differentiate on the quality of the service provided and price). This is only possible if managers are granted with the flexibility to decide commercial policies rather than being decided centralized by AENA. Individual airports' managers are potentially more focused on the regional needs where airports are located. Marketing efforts and price differentiation will also attract more low-cost carriers (LCCs) and airports will be benefiting from a higher volume of passengers (product destination).

Provided the current regulatory framework, the first analysis concludes that inefficiency is overall caused by how airports are managed (i.e. in terms of current inputs and outputs). Additionally, part of the network inefficiency is affected by the airports' geographical location. With this regulatory background where airports are not differentiated and are not competing to attract airlines and passengers, Spain visitors seem to decide the destination first and secondly the travel modal (airport). Tourist behavioral attitude depends on different circumstantial factors (financial crisis; family, etc.), but it is a complex process that goes beyond the destination choice (transport; accommodation and attraction services). Additionally, an integral part of the tourism experience relays on previous experiences regarding the airport chosen and the services provided (e.g. services in check-in, Rendeiro, 2016; food and beverage, Del Chiappa et al., 2016). With this regard, airports identified in touristic areas are becoming more efficient since attracting more visitors in cities with a higher number of hotels compared to campsites or apartments. Cities having campsites are reached by alternative transport choices such as roads and railways. Consequently, airports are more technically inefficient in these latest cities. Airports located in touristic areas are clearly more sensitive to the decisions made by potential visitors in terms of the type of accommodation; the number of staying days and budget. The touristic pattern in the years of the study (2009-2013) reflects that is preferably having visitors spending fewer days in the destination (where the airport is located). The type of accommodation is clearly an essential part of the destination product becoming a driver of airports' efficiency in touristic areas.

The results conclude that the inefficiency of airports located in no-touristic areas is mainly caused by the management (inputs and outputs). This inefficiency is significantly reduced when considering the different peculiarities of certain airports of the system (fixed effects). With this regard, these airports may be treated unfairly by applying similar policies across the network and other airports within the catchment area. The Spanish government requires keeping a significant number of small regional airports with alternative transport choices. Nevertheless, the fact that airports do not compete does not help these smallest airports increasing and attracting traffic. It is essential to consider airports' impact on local economies: as drivers of regional development and economic growth. It is required to enhance competition between airports located in the same geographic areas, but essentially when airports are not located in popular tourist destinations since visitors help the efficiency and financial aspect of the airports.

One of the main contributions of the study is the insights learned from the methodology approach used in an empirical case and demonstrating the change in the inefficiency explained by the airports' resources and the overall traffic generated when including fixed effects. Without considering the specific firm effects, firstly airports would be unfairly treated as technical inefficient, as well as the management (AENA) since the overall inefficiency is significantly higher for the traditional model. But, secondly, wrong managerial decisions would be made since the model assumes that all the inefficiency is caused by the decisions regarding inputs and outputs. Limitations are clearly highlighted such as the inaccessibility to municipality data, but province data. Additionally, to question the consistency of these results if the Spanish airports were managed individually rather than being managed under the same authority. Consequently, benchmark studies could be performed with European airports and similar structure and government ownership forms to confirm these results (i.e. Norway and Poland)

References

Adler, N. and Berechman, J. (2001): ‘Measuring airport quality from the airlines’ viewpoint: an application of Data Envelopment Analysis’. *Transport Policy* 8, 171–181

Aigner, D.; Lovell, K.C.A. and Schmidt, P. (1977): ‘Formulation and estimation of stochastic frontier production function models’. *Journal of Econometrics* 6, 21-37

Ashford, N., Stanton, H., and Moore, C. (1996): *‘Airport Operations’* McGraw-Hill Education (second edition), New York.

Assaf, A. (2008): ‘Accounting for size in efficiency comparisons of airports’. *Journal of Air Transport Management* 15(5), 256-258

Assaf, A. (2010a): ‘Bootstrapped scale efficiency measures of UK airports’. *Journal of Air Transport Management* 16(1), 42-44

Assaf, A. (2010b): ‘The cost efficiency of Australian airports post privatisation: a Bayesian methodology’. *Tourism Management* 31(2), 267–273

Assaf, A. and Josiassen, A. (2015): 'Frontier Analysis: a State-of-the-Art review and meta-analysis'. *Journal of Travel Research,* 1-16

Barbot, C. (2006): ‘Low-cost airlines, secondary airports and State Aid: an economic assessment of the Ryanair-Charleroi Airport Agreement’ *Journal of Air Transport Management* 12, 197–203

Barrett, S.D. (2004): ‘How do the demands for airport services differ between full-service carriers and low-cost carriers?’ *Journal of Air Transport Management* 10(1), 33–39

Barros, C.P. (2008): ‘Airports in Argentina: Technical efficiency in the context of an economic Crisis’. *Journal of Air Transport Management* 14(6), 315–319Barros, C.P. (2008a): ‘Technical efficiency of UK airports’. *Journal of Air Transport Management* 14, 175–178

Barros, C.P. (2008a): ‘Technical Efficiency of UK Airports’ *Journal of Transport Management* 14(4), 175-178

Barros, C.P. (2008b): ‘Technical change and productivity growth in airports: a case study’. *Transportation Research Part A: Policy and Practice* 42 (5), 818–832

Battese, G.E. and Coelli, T. J. (1988): ‘Prediction of Firm-level technical efficiencies with a generalized frontier production function and panel data’ *Journal of Econometrics* 38, 387-399

Battese, G.E. and Coelli, T. J. (1992): ‘Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India’ *Journal of Productivity Analysis* 3, 153-169

Battese, G.E. and Coelli, T. J. (1993): 'A Stochastic Frontier Production Function incorporating a model for technical inefficiency effects' *Working Papers in Econometrics and Applied Statistics* (69), Department of Econometrics University of New England.

Battese, G.E. and Coelli, T. J. (1995): 'A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data' *Empirical Economics* 20, 325-332

Bottaso, A. and Conti, M. (2010): 'An assessment on the cost structure of the UK airport industry: ownership outcomes and long run cost economies' *Working Paper* 13, University of Torino.

Butler, R. W. (1980). The concept of a tourist area cycle of evolution: implications for management of resources. *The Canadian Geographer/Le Géographe canadien* 24(1), 5-12

Castillo-Manzano, J.I.; Castro-Nuño, M.; Lopez-Valpuesta, L. and Pedregal, D.J. (2017): 'Measuring the LCC effect on charter airlines in the Spanish airport system' *Journal of Air Transport Management* 65, 110-117

Cho, W.; Windle, R.J. and Dresner, M. (2015): 'The impact of low-cost carriers on airport choice in the US: A case study of the Washington–Baltimore region' *Transportation Research part E: Logistics and Transportation Review* 81, 141-157

Coelli, T. J. and Perelman, S. (1996): 'Efficiency measurement, multi-output technologies and distance function: with application to European railways' *CREPP Working Paper* 96/05, University of Liege.

Coelli, T. and Perelman, S. (1999): 'A Comparison of Parametric and Non-parametric Distance Functions: with Application to European Railways'. *European Journal of Operational Research* 117, 326-339

Coelli, T.J. and Perelman, S. (2000): 'Technical efficiency of European railways: a distance function approach' *Applied Economics* 23, 1967-1976

Coelli, T. J.; Perelman, S. and Romano, E. (1999): 'Accounting for Environmental Influences in Stochastic Frontier Models: with application to International Airlines' *Journal of Productivity Analysis* 11, 251-273

Coelli, T. J.; Prasada Rao, D.S. and Battese, G.E. (1998): *'An Introduction to Efficiency and Productivity Analysis'* Kluwer Academic Publishers, New York.

Coelli, T. J.; Rao, D.S.P.; O'Donnell, C.J. and Battese, G.E. (2005): 'An Introduction to Efficiency and Productivity Analysis' Springer (second edition), New York.

Cohen, E. (1984): 'The Sociology of Tourism: Approaches, Issues and Findings' *Annual Review of Sociology* 10, 373-392

Coto-Millan, P.; Casares-Hontañon, P.; Inglada, V.; Agüeros, M.; Pesquera, M.A. and Badiola, A. (2014): 'Small is beautiful? The impact of economic crisis, low cost carriers, and size on efficiency in Spanish airports (2009–2011)' *Journal of Air Transport Management* 40, 34-41

Coto-Millan, P.; Inglada, V.; Fernandez, X.L.; Inglada-Perez, L. and Pesquera, M.A. (2016): 'The effect procargo on technical and scale efficiency at airports: The case of Spanish airports (2009–2011)' *Utilities Policy* 39, 29-35

Cuesta, R. A., Lovell, C. A. K. and Zofio, J. L., (2009): 'Environmental efficiency measurement with translog distance functions: A parametric approach' *Ecological Economics* 68, 2232-2242

Del Chiappa, G.; Martin, J. and Roman, C. (2016): 'Service quality of airports' food and beverage retailers: A fuzzy approach' *Journal of Air Transport Management* 53, 105-113

Doganis, R. (2006): *'The Airline Business'* Routledge, London.

Dziedzic, M. and Warnock-Smith, D. (2016): 'The role of secondary airports for today's low-cost carrier business models: The European case' *Research in Transportation Business and Management* 21, 19-32

Färe, R.; Grosskopf, S. and Lovell, C.A.K. (1994): 'Production Frontiers' Cambridge University Press.

Gillen, D. and Lall, A. (1997): 'Non-Parametric Measures of Efficiency of US Airports' *International Journal of Transport Economics* 28, 283-306

Gillen, D. and Lall, A. (2001): 'Developing measures of airport productivity and performance: an application of Data Envelopment Analysis' *Transportation Research Part E: Logistics and Transportation Review* 33 (4), 261-273

Gillen, D., Lall, A. (2004): 'Competitive advantage of low-cost carriers: some implications for airports' *Journal of Air Transport Management* 10 (1), 41–50

Goetz, A. R. (1992): 'Air passenger transportation and growth in the US urban system, 1950–1987' *Growth and Change* 23, 218-242

Greene, W. (2003): *'Econometric Analysis'* Prentice Hall, Englewood Cliffs 5th Edition

Greene W. (2005a): 'Reconsidering heterogeneity in panel data estimators of the stochastic frontier model' *Journal of Econometrics* 126, 269-303

Greene W. (2005b): 'Fixed and Random Effects in Stochastic Frontier Models' *Journal of Productivity Analysis* 23, 7-32

Gunn, C. (1988): *'Tourism Planning'* New York: Taylor and Francis.

Hattory, T. (2002): 'Relative Performance of U.S. and Japanese Electricity Distribution: an application of Stochastic Frontier Analysis' *Journal of Productivity Analysis* 18, 269-284

Heskett, J.L. and Schlesinger, L. (1994): ‘Putting the service-profit chain to work’ *Harvard Business Review* 72 (2), 164–174

Hess, S. and Polak, J.W. (2006): ‘Exploring the potential for cross-nesting structures in airport-choice analysis: a case-study of the Greater London area’ *Transportation Research Part E: Logistics and Transportation Review* 42 (2), 63–81

Ishii, J.; Jun, S. and Van Dender, K. (2009): ‘Air travel choices in multi-airport markets’ *Journal of Urban Economics* 65 (2), 216–227

Jondrow, J.; Lovell, C.A.K.; Materov, I.S. and Schmidt, P. (1982): ‘On the estimation of technical inefficiency in stochastic frontier production function model’ *Journal of Econometrics* 19 (2-3), 233-238

Juaneda, C.; Raya, J.M. and Sastre, F. (2011): ‘Pricing the time and location of a stay at a hotel or apartment’ *Tourism Economics* 17(2), 321-338

Kumbhakar, S.C. (1990): ‘Production frontiers, panel data and time varying technical inefficiency’ *Journal of Econometrics* 46, 201-2012

Kumbhakar, S.C.; Ghosh, S. and McGuckin, J.T. (1991): ‘A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Frontier Approach for Estimating Determinants of Inefficiency in U.S.Dairy Firms’ *Journal of Business and Economic Statistics* 9, 279-286

Kumbhakar, S.C.; Lien, G. and Hardaker J.B. (2014): ‘Technical efficiency in competing panel data models: a study Norwegian gran farming’. *Journal of Productivity Analysis*, Volume 41 (2), 321-337 (first online September 2012)

Kumbhakar, S.C. and Lovell, C.A.K. (2000): *‘Stochastic Frontier Analysis’* Cambridge University Press, Cambridge, United Kingdom.

Lin, L.C. and Hong, C.H. (2006): ‘Operational performance evaluation of international major airports: an application of Data Envelopment Analysis’ *Journal of Air Transport Management* 12(6), 342–351

Lozano S. and Gutierrez, E. (2011): ‘Slacks-based measure of efficiency of airports with airplanes delays as undesirable outputs’**.** *Journal Computers and Operations Research* 38(1), 131-139

Lozano S.; Gutierrez, E. and Moreno, P. (2013): ‘Network DEA approach to airports performance assessment considering undesirable outputs’**.** *Applied Mathematical Modelling* 37, 1665-1676

Luisa Marti, L.; Puertas, R. and Calafat, C. (2015): ‘Efficiency of airlines: Hub and Spoke versus Point-to-Point’ *Journal of Economic Studies* 42(1), 157-166

Martin J.C. and Roman, C. (2001): 'An application of DEA to measure the efficiency of Spanish airports prior to privatization' *Journal of Air Transport Management* 7(3), 149-157

Martin, J. C. and Roman, C. (2006): 'A benchmarking analysis of Spanish commercial airports. A comparison between SMOP and DEA ranking methods' *Networks and Spatial Economics* 6(2), 111-134

Martin J.C.; Roman, C. and Voltes-Dorta, A. (2009): 'A stochastic frontier analysis to estimate the relative efficiency of the Spanish airports' *Journal of Productivity Analysis* 31(3), 163-176

Martin J.C.; Roman, C. and Voltes-Dorta, A. (2011): 'Scale economies and marginal costs in Spanish airports' *Transportation Research Part E: Logistics and Transportation Review* 47, 238-248

Martin-Cejas, R.R. (2002): 'An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier' *Journal of Air Transport Management* 8 (4), 233–238

Mazursky, D. (1989): 'Past Experience and Future Tourism Decisions' *Annals of Tourism Research* 16, 333-344

Mo, C.; Howard, D. and Havitz, M. (1993): 'Testing an International Tourist Role Typology' *Annals of Tourism Re*search 20 (2), 319-335

Murillo-Melchor, C. (1999): 'An Analysis of technical efficiency and productivity changes in Spanish Airports using the Malmquist Index'. *International Journal of Transport Economics 26(2), 271-292*

Pels, E.; Nijkamp, P. and Rietveld, P. (2001): 'Relative efficiency of European airports'. *Transport Policy* 8, 183-192

Pels, E.; Nijkamp, P. and Rietveld, P. (2003): 'Inefficiencies and scale economies of European airport operations' *Transportation Research Part E: Logistics and Transportation Review* 39, 341-361

Pestana, B. C. and Sampaio, A. (2004): 'Technical and allocative efficency in airports' *International Journal of Transport Economics* 31, 355-377

Pit, M. and Lee, L. (1981): 'The measurement and sources of technical inefficiency in Indonesian weaving industry' *Journal of Development Economics* 9, 43-64

Pitts, R.E. and Woodside, A. G. (1986): 'Personal Values and Travel Decisions' *Journal of Travel Research* 25, 20-25

Rendeiro, R. (2006): 'Tourism service quality begins at the airport' *Tourism Management* 27(5), 874-877

Ripoll-Zarraga, A.E. (2018): 'Airports' capacity and efficiency: the Spanish airport system' *Funcas Working Papers* (expected submission July 2018)

Ripoll-Zarraga, A.E. and Mar-Molinero, C. (2017): 'Spanish airports: a visual study of management efficiency' *Funcas Working Papers* September, 791 (available on-line, http://www.funcas.es/publicaciones/Sumario.aspx?IdRef=7-05791, last accessed January 2018)

Ripoll-Zarraga, A.E.; Portillo, F. and Mar-Molinero, C. (2017): 'The impact of the 2008 Economic Crisis in the efficiency of Spanish airports: A DEA Analysis' *Funcas Working Papers* December, 794 (available on-line, http://www.funcas.es/publicaciones/Sumario.aspx?IdRef=7-05794, last accessed January 2018)

Ripoll-Zarraga, A.E. and Lozano, S. (2018): 'A centralised DEA approach to resource reallocation in Spanish airports' *Annals of Operations Research* Special Issue on 'Advances in DEA: 40 years on' (expected submission April 2018)

Salazar de la Cruz, F. (1999): 'Technical, allocative and economic efficiency in transport'. *International Journal of Transport Economics 26(2), 255-270*

Sarkis, J. (2000): 'An analysis of the operational efficiency of major airports in the United States' *Journal of Operations Management* 18, 335–351

Suzuki, Y. (2007): 'Modeling and testing the ''two-step'' decision process of travellers in airport and airline choices' *Transportation Research Part E: Logistics and Transportation Review* 43 (1), 1–20

Tapiador, F.J.; Mateos, A. and Marti-Henneberg, J. (2008): 'The geographical efficiency of Spain's regional airports: a quantitative analysis' *Journal of Air Transport Management* 14(4), 205-212

Tovar, B. and Martin-Cejas, R.R. (2009): 'Are outsourcing and non-aeronautical revenues important drivers in the efficiency of Spanish airports?' *Journal of Air Transport Management* 15(5), 217-220

Tovar, B. and Martin-Cejas, R.R. (2010): 'Technical efficiency and productivity changes in Spanish airports: A parametric distance functions approach'. *Transportation Research Part E* 46(5), 249-260

Tussyadiah, I. P. and Pesonen, J. (2016): 'Impacts of peer-to-peer accommodation use on travel patterns' *Journal of Travel Research 55*(8), 1022-1040

Wang, H. and Schmidt, P. (2001): 'One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels' *Munich Personal RePec Archive MPRA*, 31,075

Warnock-Smith, D. and Potter, A. (2005): 'An exploratory study into airport choice factors for European low-cost airlines' *Journal of Air Transport Management* 11(6), 388–392

Windle, R. and Dresner, M. (1995): 'Airport choice in multiple-airport regions' *Journal of Transportation Engineering* 121 (4), 332–337

Windle, R. and Dresner, M. (1999): 'Competitive responses to low cost carrier entry' *Transportation Research Part E: Logistics and Transportation Review* 35 (1), 59–75

Yoshida, Y. (2004): 'Endogenous-weight TFP measurement: methodology and its application to Japanese-airport benchmarking' *Transportation Research Part E: Logistics and Transportation Review* 40(2), 151–182

Yoshida, Y. and Fujimoto, H. (2004): 'Japanese-airport benchmarking with the DEA and endogenous-weight TFP methods: testing the criticism of overinvestment in Japanese regional airports' *Transportation Research Part E: Logistics and Transportation Review* 40(6), 533–546

Yu, M.-M. (2004): 'Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors' *Journal of Air Transport Management* 10(5), 295-303

Reports

European Commission (2011): 'European Strategies: Mobility and Transport White Paper' https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en

European Commission European Court of Auditors (2014): *'EU-funded airport infrastructures: poor value for money'* Special Report, 21 http://www.politico.eu/article/eu-wasted-money-on-new-airports-say-auditors/

European Commission (December, 2015): 'An Aviation Strategy for Europe' https://ec.europa.eu/transport/modes/air/aviation-strategy_en

International Civil Aviation Organization (ICAO) (March 2013): '*Worldwide Air Transport Conference (ATCONF) Sixth meeting: Airport Competition'* https://www.google.com/maps/d/viewer?mid=zylWTnxRlUJE.kU5cVv1m27wk&hl=en_US

Chapter six

The case of the Spanish airports: fair capacity utilisation or over-capacity?

List of Tables

List of Figures

The case of the Spanish airports: fair capacity utilisation or over-capacity?

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Abstract

The Spanish airport-system contains a significant number of regional airports government owned with a strong centralised management by a company named AENA. Airports managers' inability to decide commercial policies and the lack of competition end in most of the airports not being attractive to passengers and airlines. In an airport system, non-profitable airports are cross-subsided by larger airports that achieve positive margins. The Spanish airport system does not generate sufficient revenues to cover the overall fixed costs. In this study, an SFA is performed accounting for environmental variables and fixed effects to split between the inefficiency caused by the management and external factors. Further analysis is performed to decide unnecessary airports taking into account their respective catchment areas. Closure recommendations are provided minimising the impact on connectivity. The results show that there is not a relation between capacity; traffic and efficiency. Most of the airports' inefficiency is due to managerial decisions between inputs and outputs, rather than environmental features. Small and medium airports are more efficient reflecting a better use of their infrastructure. Finally, airports' features are relevant to be accounted to avoid model misspecification and biased managerial decisions between inputs and outputs.

Keywords: *Stochastic Frontier Analysis (SFA); Environmental Variables; Fixed Effects; Catchment Areas; Spanish airport system; AENA*

1. Introduction

Airports publicly owned are perceived as public utilities, natural monopolies that do not compete with each other, but contribute to the economic development of regions. There is a concern of natural monopolies as providers of certain activities within the airport infrastructure supporting the need of regulators to ensure considering the social perspective (Martin and Roman, 2001). Pricing decisions must be optimal since pricing policies have a direct impact on demand and congestion. In the case of the Spanish airports, the charges are decided without an apparently relation with the quality of the service provided questioning if these enhance competition between airports. The Spanish airports are government owned and managed by a company named AENA. AENA is a publicly owned company (51% from February 2015) that has full control of the whole network including a legal entitlement regarding pricing policies; investment and development and other managerial decisions such as accounting policies[47]. The airport-system structure implies cross-subsidies transferring financial resources from profitable airports to no-profitable airports. AENA manages 49 civil aviation airports including four general aviation airports (GAs) and two heliports. Despite being government owned, AENA does not receive public subsidies. To obtain extra funds, Spanish airports have engaged in commercial activities alongside with their aeronautical mission. Amongst these commercial activities, some examples are duty-free shops; car rental; food services; shops; advertising; VIP lounges; banking; travel agencies; and vending machines. Although diversification towards commercial activities is normally associated with privatisation processes (Humphreys, 1999), in the Spanish case commercial revenues could be as important as aeronautical revenues. The need of the Spanish airport system's financial sustainability has made seeking new sources of income, but still requires the implementation of strategies to reduce costs including the financial costs due to borrowings used to finance the investments made. The excess of investments made in the last decade in Europe (European Commission, European Court of Auditors, 2014) based on wrong forecast models has enhanced the debate about the inadequacy of having a centralised decisions making process and the requirement of transferring the management to the local authorities at the regional level. The Spanish airport network not only would win in terms of flexibility, but decisions would be made in accordance with the current needs of specific areas from

[47] After a first attempt in 2011 of AENA's privatisation, a partial privatisation of AENA has been effective on the 11th of February 2015 with the 21% of the equity in hands of a cornerstone consortia previously agreed (*Ferrovial Aeropuertos* 6.5%; *Corporación Financiera Al*ba 8% and the UK Children's investment fund 6.5%) and the initial public offering (IPO) on the remaining 28% shared between institutional and private shareholders and employees. For the study purposes the current situation of the AENA's equity in 2015 is not considered.

industrial and social perspectives. Additionally, the un-existence of an independent regulator such as the Civil Authority Aviation (CAA) in the UK to ensure fair pricing and no-monopoly practices recalls a critical assessment of the reality of the Spanish airport-system. The single till still applied by AENA with no distinction between aeronautical and commercial activities becomes an unfair basis to decide air fees policies. The Spanish competition authority (CNMC)[48] reported the requirement of changing from single to dual till in order to differentiate costs (CNMC, July 2014). During 2016, AENA dropped the air fees in a 1.9%, but the Commission requirement was a -3.5%. Following the new regulation to be applied for five years with effects from January 2017 (DORA, 2017-2021)[49], AENA has been gradually moving to a dual till to calculate the airport charges with effect January 2018. Additionally, AENA is forced to reduce the previous airport charges in an additional 2.22% for 2018 (November 2017). AENA aeronautical charges refer to all the services except for security and slot allocation taxes. AENA uses discriminatory charges depending on the level of traffic. Usually charges are differentiated between six mainland airports, except for Heliports, and the islands (AENA, 2018). Consequently, airports with a lower level of traffic become a burden from the financial perspective. Competitive prices between airports based on the quality of the service provided could attract a significant number of new airlines and routes. One explanation to support an airport-system regarding profitable airports co-financing non-profitable ones is the need of maintaining services in remote areas. Nevertheless, the Spanish network contains a significant number of small airports in an amenity distance with alternative transport modals questioning the requirement of certain airports to ensure connectivity. The fact that all the small and medium airports are no-profitable recalls firstly for analysing the adequacy between the feasible resources (airport's infrastructure) and the existent traffic; and secondly, the number of airports in the same geographical area. Airports do not compete with each other. Therefore, some areas are overcrowded with more than one airport with very low traffic. The current situation requires determining the individual efficiency in order to decide the airports required to remain open. In this study, a second stage is performed based on the analysis of catchment areas. A catchment area is defined as the influence area within 150 kilometres (Ripoll-Zarraga and Mar-Molinero, 2017). Firstly, a discussion of over-capacity based on having more than one airport within an amenity distance is built. Secondly, closure recommendations are provided

[48] *Comisión Nacional de los Mercados y Competencia* (CNMC) is the Spanish competition authority and macro-regulator.

[49] *Documento de Regulación Aeroportuaria* (DORA) approved by the Spanish Government in January 2017

considering airports' individual inefficiencies within the same catchment areas and minimising the impact on connectivity.

This paper is organised as follows. Section 2 presents the literature review in the Spanish airport industry. Section 3 provides a review of stochastic frontier analysis and specifically within the distance function context. In Section 4 the data and the model specification used are described. The results are discussed in Section 5 and Section 6 provides concluding remarks.

2. Literature Review

The estimation of technical efficiency is widely used in the airport industry. Airports are typically multi-output firms. Consequently, an appropriate framework must be considered to estimate the efficiencies such as stochastic distance functions (Coelli and Perelman, 1999; Kumbhakar and Lovell, 2000) There are several stochastic frontier models for panel data, nevertheless there are few studies applied to empirical research (Kumbhakar et. al 2014). The stochastic frontier analysis assumes that not all the technical inefficiency is possible to be explained under management's control at least in the short-term. The geographical location of the airports; the number of airports within an influence area and airports' capacity (infrastructure) are examples of decisions that managers cannot influence in a relatively short period of time, but still may be affecting the airports' technical efficiencies. In the Spanish case, the potential impact on the airports' inefficiencies is even more relevant due to AENA's centralised decision making power.

The literature review in the Spanish airport system reveals most of the studies using non-parametric analysis mainly data envelopment analysis (DEA) (for example, Murillo-Melchor, 1999; Salazar de la Cruz, 1999; Martin and Roman, 2001 and 2006) and different DEA approaches (Lozano and Gutierrez, 2011; Lozano et al. 2013). Few studies use parametric methodologies such as stochastic frontier analysis (SFA), but more focused on cost functions (for example, Coto-Millan et al. 2007; Martin et al. 2011). Additionally, the studies in the airport industry and specifically in the Spanish case do not include a reliable cost of capital. Airports' infrastructure is not always in the regime of operating and finance leases allowing using rent expenses (Parker, 1999). Therefore, a physical proxy is used based on airport's physical area (Tovar and Martin-Cejas, 2009 and 2010); terminals' and other buildings surface and runways length (Martin et al. 2011) or the number of runways and terminal buildings (Martin-Cejas, 2002). Some studies use a more directly measure of capital by using the depreciation directly obtained from the AENA's annual reports under the concept amortization of fixed assets (Martin et al. 2001, 2009, 2011) or book value (Murillo-Melchor 1999; Salazar de la Cruz 1999; Pestana and Sampaio, 2004; Martin et al., 2009; Coto-Millan et al., 2014 and 2016). Nevertheless, the Spanish airports differ broadly in the initial value of the investments (historical cost of the assets) and traffic, requiring following the accrual convention and matching principle to ensure a fair measure of capital usage. The depreciation applied by AENA is an overall measure without differing between airports' size and current traffic. The published data is an aggregate value that could include intangible assets not related to the airports' operational activity. The same depreciation method may breach the accrual convention and certainly, it will not represent a fair and true view of the Spanish airports. In this study, following the international financial reporting standards (IFRSs) an accurate and reliably depreciation measure is used based on the useful life commonly applied in the airport industry to the individual historical cost of the airports' assets (Ripoll-Zarraga and Mar-Molinero, 2017).

Regarding the outputs used there is a harmonisation in terms of aeronautical measures such as passengers (Murillo-Melchor, 1999; Salazar de la Cruz, 1999; Tovar and Martin-Cejas, 2010); air traffic movements and cargo (Martin and Roman, 2001; Lozano and Gutierrez, 2011; Lozano et al., 2013; Coto-Millan et al., 2014 and 2016) as well as aeronautical and commercial revenues (Salazar de la Cruz, 1999; Tovar and Martin-Cejas, 2009 and 2010; Martin et al. 2011). Few authors use workload units (Martin-Cejas, 2002; Martin et al. 2009 and 2011)[50]; average of aircraft size (Tovar and Martin-Cejas, 2009 and 2010)[51] or undesirable outputs such as delays (Lozano and Gutierrez, 2011; Lozano et al., 2013). The most usual inputs are labour costs (Murillo-Melchor, 1999; Martin and Roman, 2001; Martin et al., 2009 and 2011; Martin-Cejas, 2002; Coto-Millan et al., 2014 and 2016) rather than full-time equivalent number of employees (Martin et al., 2009 and 2011) or the average of employees (Tovar and Martin-Cejas, 2009 and 2010). Other inputs less commonly used are materials costs (Martin and Roman, 2001; Martin et al., 2009 and 2011) and an aggregate value of expenses (Murillo-Melchor, 1999)

Overall, the results show the relation between traffic in terms of passengers and higher efficiency. Few studies attempt to seek plausible explanations behind the individual

[50] This is defined as one passenger or 100 kilogrammes of cargo. The WLU assumes that a passenger with luggage has the same impact than 100 kilogrammes of cargo.
[51] Aircraft size is defined as a proxy based on the relation between the number of passengers and ATM.

efficiencies beyond traffic (e.g. Coto-Millan et al., 2014 and 2016). Therefore, second stages to explain the efficiency levels are not a common practice. Ripoll-Zarraga and Mar-Molinero (2017) provide a review of the main findings in the different studies applied to the Spanish airports. The literature clearly demonstrates the requirement of searching for further explanations of inefficiencies apart from the number of passengers or cargo level or presence of low cost carriers (LCCs). The fact that accountability and commercial policies are decided at the governmental level (AENA) for the overall network along with the inability of airports to compete require a critical assessment.

3. Methodology

In industries based on network services such as air transport where the output is a derived demand and being exogenously determined by the final consumers' demand (passengers), the input distance function approach is more reliable compared to cost function estimation (Coelli et al., 2005). The inputs distance function allows the estimation of airports' inefficiencies (firm-specific inefficiency) in absence of inputs' prices. It is also essential to account for environmental factors, such as region-specific demand conditions (Hattori, 2002). Although these are not under the control of the airports' managers, the obligation to supply services based on the same public nature of the ownership as well as for connectivity purposes may be affecting the airport operational activity and maintenance. The environmental variables are initially assumed to be beyond the management's control since these are not identifiable (unobserved heterogeneity). Therefore, these are unchangeable at least in the short-term. In this study, several translog models have been tested within the stochastic frontier analysis for panel data context for both time-varying and invariant inefficiencies and different distribution assumptions of the inefficiency term[52]. Finally, following Battese and Coelli (1995) the inclusion of environmental variables has allowed differing between the inefficiency mainly explained through managerial decisions (production function) and external factors affecting the airports' overall inefficiency (μ). Additionally, the inclusion of fixed effects (Greene, 2003) controlling invariant features of specific airports in order to avoid biases in the inefficiency explained by the model and value of the parameters.

The translog form of the stochastic distance function $lnD_{it}(X,Y)$ assuming m outputs and k inputs and choosing arbitrary the $\varsigma - th$ input for normalisation purposes follows,

[52] Battese and Coelli (1988; 1992; 1995) and Kumbhakar (1990)

$$\ln\left(\frac{D_{it}^{I}}{X_{\kappa it}}\right) = \beta_0 + \sum_{j=1}^{k}\beta_j \ln(x_{jit}^{*}) + \frac{1}{2}\sum_{j=1}^{k}\sum_{j'}^{k}\beta_{jj'}\ln(x_{jit}^{*})\, ln\,(x_{j'it}^{*}) + \sum_{l=1}^{m}\alpha_l \ln(y_{lit})$$
$$+\frac{1}{2}\sum_{l=1}^{m}\sum_{l'=1}^{m}\alpha_{ll'}\ln(y_{lit})\ln(y_{l'it}) + \sum_{j=1}^{k}\sum_{l=1}^{m}\beta_j\,\alpha_l \ln(x_{jit}^{*})\ln(y_{lit}) \quad (1)$$

Where the asterisk indicates the respective input normalised $x_{jit}^{*} = {}^{x_{jit}}/_{x_{\kappa it}}$

Applying to (1) the logarithms' properties,

$$ln(D_{it}^{I}) - ln(X_{\kappa it}) = Translog\,({}^{x_{jit}}/_{x_{\kappa it}}, y_{lit}, \alpha, \beta, \alpha\beta)\,;$$
$$-ln(X_{\kappa it}) = Translog\,\left({}^{x_{jit}}/_{x_{\kappa it}}, y_{lit}, \alpha, \beta, \alpha\beta\right) - ln(D_{it}^{I}) \quad (2)$$

Where $-\,ln(D_{it}^{I})$ is not observable. Therefore, the error term becomes $-\,ln(D_{it}^{I}) = (v_{it} - u_{it})$

The negative sign in (2) can be ignored for interpretation proposes resulting in the signs of the coefficients being reversed more consistent with the expected signs of the conventional production functions (Coelli & Perelman, 1996). Replacing $-ln(X_{\kappa it})$ by $= ln({}^{1}/_{X_{\kappa it}})$ due to the properties of the logarithms $ln({}^{1}/_{X_{\kappa it}}) = ln(X_{\kappa it})^{-1} = -1\cdot ln(X_{\kappa it})$, the equation (1) yields,

$$ln({}^{1}/_{X_{\kappa it}}) = \beta_0 + \sum_{j=1}^{k}\beta_j \ln(x_{jit}^{*}) + \frac{1}{2}\sum_{j=1}^{k}\sum_{j'}^{k}\beta_{jj'}\ln(x_{jit}^{*})\, ln\,(x_{j'it}^{*}) + \sum_{l=1}^{m}\alpha_l \ln(y_{lit})$$
$$+\frac{1}{2}\sum_{l=1}^{m}\sum_{l'=1}^{m}\alpha_{ll'}\ln(y_{lit})\ln(y_{l'it}) + \sum_{j=1}^{k}\sum_{l=1}^{m}\beta_j\,\alpha_l \ln(x_{jit}^{*})\ln(y_{lit}) + (v_{it} - u_{it}) \quad (3)$$

The error contains a random error (v_{it}) and the inefficiency term (u_{it}). In the first model and following Battese and Coelli (1992), the inefficiency term has a non-negative truncated normal distribution with non-zero mean and constant variance $ui{\sim}N^{+}(\mu,\,\sigma_u^2)$ The random error has zero mean and constant variance $vi{\sim}N^{+}(0,\,\sigma_v^2)$. Following Battese and Coelli (1995) the inefficiency term u_{it} depends on p environmental factors $u_{it} = \sum_{o=1}^{p} z_{oit}\,\delta_l + \omega_{it}$ (4) being δs unknown scalar quantities to be estimated. These are assumed to be beyond managerial control. Therefore, these are unchangeable at least in the short-term. The coefficient δ_0 represents the level of inefficiency of a specific airport without considering the existence of uncontrolled external factors. It can be interpreted as the inefficiency caused by the management: as consequence of managerial decisions between inputs and outputs. The rest of the coefficients (δ_l) refers to exogenous factors and represent the individual effect of the respective environmental variable explaining the technical inefficiency. A negative value $(\delta_l < 0)$ indicates that the related environmental variable reduces the airports' technical inefficiencies in δ_l. A positive coefficient $(\delta_l > 0)$ would imply that the corresponding environmental variable increases the airports' inefficiencies. Since these are by definition environmental variables the effects are understood as positive or negative exogenous factors respectively. The environmental variables (z_{it}) are included in the translog function to avoid substantial biases when using two-step procedures (Wang and Schmidt, 2001).

Both models assume time-variant efficiency. Following Ripoll-Zarraga and Raya (2018) six airports are assumed to have features not shared by others that are enclosed in the production function. The firm effects are individual and invariant structural characteristics of airports and correlated with the regressors.

The variance parameters reflect to what extent the variables used in the translog explain the dependent variable and the overall inefficiency. The sigma squared (σ^2) is used to analyse the normal distribution of the random variables (v_{it}) independent of the inefficiency (u_{it}) and identically distributed $v_{it} \sim N(0, \sigma_v^2)$. The noise variance (σ_v^2) represents the variability of the error explained by factors that go beyond the control of the airports' management. This variance is used to estimate the variability of the model due to technical inefficiencies through lambda (λ)[53].

A high value of lambda implies that technical inefficiency of the airports is likely to influence significantly the value of the dependent variable, in this case, the labour costs. This is an indication of the explanatory power of the model regarding the inputs and outputs used in the estimation. Low values are signal of a significant weight of noise compared to explained inefficiency; this is the model does not have discriminatory power. The inputs and outputs used are not relevant when determining both the value of the dependent variable and the inefficiency term.

[53] This is equivalent to the γ-gamma coefficient in Battese and Coelli (1988). In this model, gamma indicates how much of the variance of the composed error term is attributed to the technical inefficiency term $(\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2})$. The rejection of the null hypothesis $H_0\colon \gamma = 0$ implies the existence of a stochastic production frontier.

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \quad (5)$$

$$\lambda = \sqrt[2]{\frac{\sigma_u^2}{\sigma_v^2}} = \frac{\sigma_u}{\sigma_v} \quad (6)$$

4. Data description

The Spanish airport-system contains 49 civilian airports including four general aviation airports (Madrid Cuatro Vientos; Sabadell; Son Bonet and Madrid Torrejon[54]) and two heliports (Algeciras and Ceuta). All of the airports are government owned and managed through a public company (AENA). The airport-system structure implies the existence of cross-subsidies. The divergence shown in terms of traffic; regulation and activities have been tested through a sensitivity analysis. No significant differences have been found. The final panel data refers to 48 airports used for civilian air transport from 2009 to 2013 (239 observations)[55]. The network is classified in terms of number of passengers per year. On this basis, there are 14 large airports (i.e. more than 3.5 million passengers per year). The remaining 35 airports have a high variability in terms of passengers and cargo (Ripoll-Zarraga and Mar-Molinero, 2017). Additionally, there is a divergence in the production function containing one hub (Madrid) and 12 touristic airports where more than 50% of the passenger connect with international flights (Coto-Millan et al., 2016). These are located in the Mediterranean seaside (Barcelona; Malaga; Alicante; Girona and Reus) and in the Balearic (Palma de Mallorca; Ibiza; Menorca) and Canary Islands (Gran Canaria; Tenerife South; Lanzarote; Fuerteventura and Tenerife North)

Following the most common variables used in literature and the accessibility to data, three inputs and four outputs are used to estimate the technical inefficiency of the Spanish airports. The inputs are resources required for aeronautical operations: labour; operating costs and depreciation of assets (Ripoll-Zarraga and Mar-Molinero 2017; Ripoll-Zarraga and Raya, 2018). The outputs are the number of passengers; air traffic movements (ATM); cargo and commercial revenues. The financial data has been extracted directly from AENA's annual reports except for the depreciation of assets since it is highly correlated with operating costs (Ripoll-Zarraga and Mar-Molinero, 2017). There is no information regarding individual financial data per airports before 2009 or disclosures regarding number and type of

[54] Madrid-Torrejon is a military base used as support to Madrid-Barajas for private civilian flights until the end of January 2013.

[55] Algeciras is under construction during 2009, but ready to be used from July 2010. Son Bonet is a general aviation airport (GA) not enclosed in this study due to missing information regarding works performed.

employees. The assets have been classified in airside and landside assets (Ashford et al., 1996; Ripoll-Zarraga and Mar-Molinero, 2017; Ripoll-Zarraga et al., 2017; Ripoll-Zarraga and Raya, 2018). The airports' assets have been depreciated according to standard coefficients used in the air transport sector (Ripoll-Zarraga and Mar-Molinero, 2017). Cost of capital measures are a reflection of the usage of the airports' infrastructure in the operational main activity (airports' capacity). Therefore, airports that do not generate enough revenues to meet the cost of capital (depreciation), not only will be suffering from over-capacity (becoming technically inefficient), but will be a financial burden for the system.

In order to avoid convergence problems, all the data has been deflated by the Spanish gross domestic product base 2010 (Ripoll-Zarraga et al., 2017). The inputs and outputs are standardized by the respective geometric mean prior to enclosing them in the stochastic translog distance function. This allows summarizing normalised benchmark results, estimating elasticities at the sample means (Cuesta et al., 2009). Table 1 shows the statistics for the 49 airports managed by AENA.

Variable	Observations	Mean	Standard Dev.	Minimum	Maximum
PAX (th)	245	3,944.68	8,529.97	0	49,900
ATM (th)	245	41.41	71.74	0.24	435.19
Cargo (th tones)	245	13,000	52,400	0	394,000
Commercial (th €)	245	11.71	27.83	0	169.51
Labour (th €)	245	7.23	10.19	0.11	74.24
Operating (th €)	245	19.03	49.86	0.24	318.30
Depreciation AENA (th €)	245	14.40	39.31	0.18	264.45
Depreciation Airside (th €)	240	4.16	11.08	0	79.80
Depreciation Landside (th €)	240	1.09	2.22	0	11.94

Table 1: Summary Statistics 2009-2013 (in Ripoll-Zarraga and Raya, 2018)

The translog distance function (3) for each airport i and period t choosing the staff costs as the input for normalisation purposes follows,

$$
\begin{aligned}
& ln\left({}^{1}/_{Labour_{it}}\right) \\
&= \beta_0 + \beta_1 ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) + \beta_2 ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_3 ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) + \frac{1}{2}\beta_1'(ln\ {}^{Operating_{it}}/_{Labour_{it}})^2 \\
&+ \frac{1}{2}\beta_2' \ln({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}})^2 \\
&+ \frac{1}{2}\beta_3' \ln({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}})^2 \\
&+ \frac{1}{2}\beta_{12} ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \frac{1}{2}\beta_{13} ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \frac{1}{2}\beta_{23} ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_4 ln(Commercial\ Revenues_{it}) + \beta_5 ln(PAX_{it}) + \beta_6 ln(ATM_{it}) + \beta_7 ln(Cargo_{it}) \\
&+ \frac{1}{2}\beta_4'(lnCommercial\ Revenues_{it})^2 + \frac{1}{2}\beta_5'(lnPAX_{it})^2 + \frac{1}{2}\beta_6'(lnATM_{it})^2 + \frac{1}{2}\beta_7'(lnCargo_{it})^2 \\
&+ \frac{1}{2}\beta_{45} ln(Commercial\ Revenues_{it}) ln(PAX_{it}) + \frac{1}{2}\beta_{46} ln(Commercial\ Revenues_{it}) ln(ATM_{it}) \\
&+ \frac{1}{2}\beta_{47} ln(Commercial\ Revenues_{it}) ln(Cargo_{it}) + \frac{1}{2}\beta_{56} ln(PAX_{it}) ln(ATM_{it}) + \frac{1}{2}\beta_{57} ln(PAX_{it}) ln(Cargo_{it}) \\
&+ \frac{1}{2}\beta_{67} ln(ATM_{it}) ln(Cargo_{it}) + \beta_{41} ln(Commercial\ Revenues_{it}) ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{51} ln(PAX_{it}) ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) + \beta_{61} ln(ATM_{it}) ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{71} ln(Cargo_{it}) ln\left({}^{Operating_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{42} ln(Commercial\ Revenues_{it}) ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{52} ln(PAX_{it}) ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{62} ln(ATM_{it}) ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{72} ln(Cargo_{it}) ln\left({}^{Depreciation\ Airside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{43} ln(Commercial\ Revenues_{it}) ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{53} ln(PAX_{it}) ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{63} ln(ATM_{it}) ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) \\
&+ \beta_{73} ln(Cargo_{it}) ln\left({}^{Depreciation\ Landside\ Assets_{it}}/_{Labour_{it}}\right) + (v_{it} - u_{it})
\end{aligned}
$$
[56]

The component u_i of the error in (4) in terms of the specific environmental variables is modelled,

$$
\begin{aligned}
u_i = {} & \delta_0 + \delta_1(Catchment\ Area) + \delta_2(PSOs) \\
& + \delta_5(Accessibility) + \delta_6(Capacity\ Utilisation) + \delta_7(Type\ of\ Airport) + \omega_{it}
\end{aligned}
$$

The environmental variables are external factors not controlled by AENA, but affecting the airports' inefficiencies. More than several exogenous variables have been tested including the

[56] Note that for practical interpretation purposes α_l has been substituted by β_l

type of airport based on charges and runways surface and geographical factors of the city where airports are located (e.g. GDP per capita; population and density; labour force; the number of hotel rooms; the number of sunny days compared to rain, snow, etc.). Finally, five environmental variables have been identified: catchment area; the existence of public service obligation routes (PSOs); accessibility to the airport; slot allocation and the category of the airport depending on the main activity. A catchment area is understood as the area of influence of an airport to attract visitors and customers, depending on the population nearby and the surface transport possibilities (European Court of Auditors, 2014). In this study, a catchment area is defined as the number of airports within 150 kilometres from a specific airport. The catchment areas include military airports' infrastructure shared with civilian airports; general aviation airports and heliports used as support to civilian transport. These also include Lleida and Andorra-Pirineus airports owned and managed by a local authority named *Aeroports de Catalunya*. PSOs are intra-insular routes to ensure connectivity in remotes areas. These currently exist in the Canary and the Balearic Islands and from April 2009, from Almeria to Sevilla (both airports are in the mainland). Accessibility refers to the existence of a railway to access the airport. There are currently five airports with railway infrastructure: four large airports (Alicante; Barcelona; Madrid and Malaga) and one medium (Jerez). Capacity utilisation is the potential capacity under-used due to air traffic restrictions. This variable is classified depending on the air traffic restrictions to take off and landing in the following categories: airports with very low coordination used for civilian transport and general aviation activities; airports fully coordinated (slots); airports coordinated during the summer; airports with schedules the whole year; military basis. Airports with few traffic restrictions are assumed to satisfy the current and potential demand of airlines; these are normally small airports with a surplus of capacity due to the low demand of traffic. Slots are usually large airports with high demand and with a significantly lower capacity compared to their current and forecast demands[57]. Airports with schedules provided are usually medium airports with a capacity close to their current demand and airports located closely may be used in congestion periods. The type of airport refers to the main operational purpose of the airport: fully civilian airports; fully military; civilian airports used for both civilian and air force operations; military airports sharing infrastructure partially or fully for civilian

[57] There are 11 fully coordinated airports (AECFA, 2014): Alicante; Barcelona; Bilbao; Madrid; Malaga; Valencia; in the Canary Islands, Fuerteventura; Gran Canaria; Lanzarote; Tenerife South and in the Balearic Islands, Palma de Mallorca.

transport[58]; private airports and heliports. With the exception of catchment areas, all the environmental variables are introduced as dummies in the production function. With this purpose, the categories have been aggregated to define airports fully civilian and airports shared with military activities (case). In the same way, airports may be fully (slots) or partially coordinated (case) or not coordinated.

5. Results

Stochastic Frontier Analysis

The results presented in this section correspond to the alternative production frontier models for panel data with the inclusion and exclusion of environmental variables. Battese and Coelli (1995) accounts for observable time-varying heterogeneity by modelling the mean of the inefficiency term as a function of the estimated parameters of inputs and outputs. As previously discussed, the environmental are factors not controlled by the airports' managers (AENA), but with a potential effect in the airports' technical inefficiencies (u_i).

Table 2 summarizes the main results. Due to the extension, all the individual effects are shown, but only the significant iterations between inputs and outputs. The first column is the corresponding translog following Battese and Coelli (1992) with special features enclosed within the production function (Ripoll-Zarraga and Raya, 2018) Fixed effects are diverse since are not observed. For example, these could be structural characteristics such as significantly longer runways. The second column shows the translog following Battese and Coelli (1995) with also fixed effects, but the environmental variables in the inefficiency term.

The null hypothesis of the no existence of inefficiency effects is rejected in the first model in favour of the inclusion of environmental variables. The overall inefficiency is 39%. The individual variables have the expected signed. All the variables are significant at 95% level of confidence except for the commercial revenues (in the first model); air traffic movements and the depreciation of airside and landside. Although airports' commercial orientation is usually related to privatisation process (Humphreys, 1999), in the Spanish airports the results highlight the requirement of having more traffic (passengers) in order to earn more commercial revenues (β_{45}=-11.4% and -14.4%). Air traffic movements are not relevant since these may not imply having a higher number of passengers. Although air movements involve air traffic control services incurring in approach and route taxes, the variable component of

[58] For example, Leon is a military base sharing the runway and Zaragoza is used as cargo centre.

the taxes depends on the distance and/or aircraft size (ENAIRE, 2018). Fixed effects are relevant for large airports (Barcelona and Madrid) compared to large airports with peaks of demand (Malaga and Palma de Mallorca) or small airports. Nevertheless, although the model has a high value of the log likelihood gamma is no significant. These results indicate the presence of noise compared to the variability explained by the model. On this basis, environmental variables are enclosed in the inefficiency term to attempt explaining part of the overall inefficiency not controlled by AENA (u_{it}). The results show that the inefficiency explained in terms of inputs and outputs and environmental variables is relevant. The significant and relevant value of lambda (13.84) with a significant inefficiency error sigma (0.17) compared to a no significant random error sigma (0.012) clearly supports the explanatory power of the second model. This model contains the highest value of the likelihood estimator (106.84) and a very low level of noise. The results obtained in the translog stochastic distance function are similar to Coelli, Perelman and Romano (1999) since the environmental variables have an influence in the air transport and neglecting them would bias the estimation of the model (Hattori, 2002). The significance of the environmental variables confirms that airports having train facilities increase the inefficiency of the system (δ_3=21.37%). This is sensible since there are only five airports with train facilities being four of them large. Large airports concentrate a significant level of traffic that makes the rest of the airports technically inefficient from an operating perspective. This is due to airports not competing with each other. The type of airport also affects the inefficiency of the system (δ_5=-6.71%), but in a positive way: the higher number of military infrastructure shared with civilian transport the more efficient the system is. Again, this is sensible since civilian airports require the use of other airports or infrastructure when the traffic exceeds their capacity. The existence of PSOs increases slightly the overall inefficiency (δ_2=7.2%). The government ensures that airlines operate these routes for connectivity purposes even if there are no passengers using them. Finally, the number of airports within the catchment area does not affect airports' efficiency. The Spanish airports do not compete and managers do not have the power to decide commercial policies to make the airports attractive to airlines and passengers. Consequently, some areas although are overcrowded do not have congested airports[59]. The analysis of catchment areas will be discussed further.

Turning the attention to the individual effects for the second model, the results show a low-impact of cargo (β_7=-4.7%) compared to passengers or commercial revenues (β_5=-23.9%;

[59] The extreme case is Vitoria with five other airports in the same catchment area.

β_4=-10.7%). The operating costs are the loading factor increasing the labour costs the most (β_1=55.9%). The depreciation of airside assets would be expected to be significant. This is the higher the airports' infrastructure (aeronautical assets) the higher the traffic developed. These results confirm that there is not a relation between airports' infrastructure and capacity usage. Consequently, the Spanish airports suffer from an overall over-capacity. Competition between airports should be enhanced and individual managers should be granted with flexibility to apply commercial policies to avoid airports being a burden for the system. This is also evidenced by the significant and high values of the constant in both models. When all the inputs and outputs are zero (i.e. assuming there is no traffic), the airport-system incur in labour costs equal to the constant (β_0=76%) The airports have permanent staff independently of their traffic, but related to their investments to ensure the maintenance of infrastructure and installations. These results confirm the public utility nature of the Spanish airports: the social welfare may be considered before the industry needs (i.e. for connectivity purposes or public employment). With this regard, not all the large airports are a relevant financial source of income such as Barcelona (FE_1=-69%) or Madrid (FE_2=-116%). For example, Malaga had a new terminal finished in 2010, but with a very low increase in passengers in the latest years (FE_3=-55%); Palma de Mallorca potentially suffering from a season effect shows a similar impact to the smallest airports such as Vitoria (FE_6=-45%) The fixed effects show some small airports contributing to the financial aspect of the network (Vitoria) and some becoming a burden for the system (Huesca-Pirineos). The Spanish government seems committed keeping all the airports open even being loss-makers (Ripoll-Zarraga and Mar-Molinero, 2017). It is necessary to confirm if the airports' investments (infrastructure) are required for connectivity purposes even being underused or are not essential. In this latest case, the results would confirm an overall over-capacity of the Spanish airport-system. Further analysis is performed to critically discuss the requirement of AENA of keeping opened all the airports by estimating individual efficiencies and comparing them to the efficiencies of the airports located within the same catchment area. Closing recommendations are provided attempting to minimise the impact on connectivity (i.e. to avoid affecting remote areas without multimodal travel)

	Coefficients	$SFA_1\ FE\ (1992)$		$SFA_2\ FE\ (1995)$
$\boldsymbol{\beta_0}$	Constant	0.76259*		0.75867*
$\boldsymbol{\beta_4}$	LnCommercial	-0.08523[1]		-0.10659*
$\boldsymbol{\beta_5}$	LnPAX	-0.23668*		-0.23874*
$\boldsymbol{\beta_6}$	LnATM	-0.15029[1]		-0.09307
$\boldsymbol{\beta_7}$	LnCargo	-0.03890*		-0.04726*
$\boldsymbol{\beta_1}$	LnOperating	0.44579*		0.55930*
$\boldsymbol{\beta_2}$	LnDepreciation Airside	0.00710		0.01232
$\boldsymbol{\beta_3}$	LnDepreciation Landside	-0.00505		-0.01068
$\boldsymbol{\beta'_4}$	½LnCommercial^2	0.06187*		0.06942*
$\boldsymbol{\beta'_5}$	½LnPAX^2	-0.02062		-0.02334
$\boldsymbol{\beta'_6}$	½LnATM^2	0.10337		0.05348
$\boldsymbol{\beta'_7}$	½LnCargo^2	0.00061		0.00069
$\boldsymbol{\beta'_2}$	½LnDepreciation Airside^2	-0.00119		-0.00036
$\boldsymbol{\beta'_3}$	½LnDepreciation Landside^2	-0.00113		-0.00114
$\boldsymbol{\beta_{45}}$	½LnCom·LnPAX	-0.11367*		-0.14429*
$\boldsymbol{\beta_{47}}$	½LnCom·LnCargo	-0.03111*		-0.03979*
$\boldsymbol{\beta_{56}}$	½LnPAX·LnATM	0.05663*		0.08008*
$\boldsymbol{\beta_{57}}$	½LnPAX·LnCargo	0.00287		0.02483*
$\boldsymbol{\beta_{13}}$	½LnOperating·LnDepreciation Landside	0.02385[1]		0.03146*
$\boldsymbol{\beta_{14}}$	LnOperating·LnCommercial	0.06378[1]		0.04799
$\boldsymbol{\beta_{27}}$	LnDepreciation Airside·LnCargo	0.00072		0.00175*
$\boldsymbol{FE_1}$	Barcelona	-1.01491*		-0.69258*
$\boldsymbol{FE_2}$	Madrid Barajas	-1.29434*		-1.15646*
$\boldsymbol{FE_3}$	Malaga	-0.47841*		-0.55501*
$\boldsymbol{FE_4}$	Palma de Mallorca	-0.43461*		-0.42923*
$\boldsymbol{FE_5}$	Huesca-Pirineos	0.37853*		0.50991*
$\boldsymbol{FE_6}$	Vitoria	-0.63838*		-0.44939*
	mu (μ)	0.38756*		
			$\delta_1\ Catchment$	-0.0011
			δ_2 PSOs	0.07223[1]
			$\delta_3\ Accessibility$	0.21373*
			$\delta_4\ Capacity$	-0.00245
			$\delta_5\ Type\ of\ Airport$	-0.06714*
			$\delta_0\ Constant$	0.45170*
	$lnsigma^2$	-3.27998*	$Sigma\_u\ (\sigma_u)$	0.16776*
	$ilgtgamma$	0.16238	$Sigma\_v(\sigma_v)$	0.01212
	eta	-0.07879*	$Lambda$	13.84*
	$Log\ Likelihood$	105.73		106.84

Table 2: Translog distance functions *Significant different from zero at least at 5%

[1] SFA_1: LnCommercial $P > |z| = 0.082$; LnATM $P > |z| = 0.067$; ½LnATM^2 $P > |z| = 0.097$; ½LnOperating·LnDepreciation Landside $P > |z| = 0.083$; LnOperatingLnCommercial $P > |z| = 0.096$); SFA_2: PSOs $P > |z| = 0.063$)

Analysis of airports' efficiencies and catchment areas

Table 3 shows the individual technical efficiency per airport and year. The estimated efficiency for the raw model (without considering fixed effects or environmental variables) is enclosed for comparison purposes (Battese and Coelli, 1992).

The differences in terms of technical efficiency levels show higher values when considering environmental variables (Battese and Coelli, 1995) compared to the raw model (Battese and Coelli, 1992), but similar values when both models include fixed effects (see Figure 1). It is evidenced that the inclusion of environmental variables helps reducing noise. Nevertheless, this does not assure endogeneity potential issues that should be investigated further.

The results show that on average the smallest airports are more technically efficient (see Figure 2). These results confront with previous findings where larger airports are more efficient (for example, Murillo-Melchor, 1999; Salazar de la Cruz, 1999; Martin and Roman, 2001 and 2006; Coto-Millan et al., 2007 and 2014). One explanation could be the growth in demand due to low cost carriers with more impact on the scale efficiency of regional airports (Coto-Millan et al., 2016). The effect of changes in traffic since the financial crisis started in 2008 is clearly evidenced in 2012 where all the airports drop their efficiencies. Less than half of the airports (48%) achieve a higher efficiency than the average of the network (68.72%) with certain variability in terms of size (Lozano and Gutierrez, 2011)

The individual efficiencies used for the analysis of the catchment areas correspond to Battese and Coelli (1995) including fixed effects since has a higher value of likelihood and lower noise. Table 4 shows the geographical location of the specific airports that have at least another airport within the same catchment area; the size in terms of passengers; the average of the population and density of the city where a specific airport is located and the average of the EBITDA (in thousands of euro) provided by AENA. The results clearly show that the most profitable airports are not always the most efficient. Tenerife South is one of the extreme examples with a significant EBITDA, but a relatively low technical efficiency (other examples are Barcelona; Palma de Mallorca; Madrid Barajas and Alicante). With this regard and although EBITDA is a proxy of economic profitability, this value is only shown for comparison purposes.

			SFA (1992)		SFA_1 (1992) FE		SFA_2 (1995) FE	
Airport	**Size**	**Year**	TE_t	**Average**	TE_t	**Average**	TE_t	**Average**
A Coruña	Medium	LCG_09	0.588		0.789		0.810	
		LCG_10	0.573		0.774		0.700	
		LCG_11	0.558		0.758		0.650	
		LCG_12	0.542		0.741		0.630	
		LCG_13	0.527	55.75%	0.723	75.69%	0.751	70.80%
Albacete	Small	ABC_09	0.551		0.675		0.677	
		ABC_10	0.536		0.653		0.511	
		ABC_11	0.520		0.631		0.524	
		ABC_12	0.504		0.608		0.646	
		ABC_13	0.488	51.97%	0.583	62.99%	0.740	61.96%
Algeciras	Small	AEI_10	0.883		0.910		0.808	
		AEI_11	0.878		0.903		0.978	
		AEI_12	0.872		0.896		0.886	
		AEI_13	0.866	87.48%	0.888	89.91%	0.970	91.03%
Alicante	Large	ALC_09	0.613		0.708		0.706	
		ALC_10	0.599		0.688		0.659	
		ALC_11	0.584		0.667		0.548	
		ALC_12	0.569		0.646		0.462	
		ALC_13	0.554	58.39%	0.623	66.64%	0.622	59.94%
Almeria	Small	LEI_09	0.493		0.686		0.563	
		LEI_10	0.477		0.666		0.651	
		LEI_11	0.460		0.644		0.584	
		LEI_12	0.443		0.621		0.540	
		LEI_13	0.426	45.99%	0.597	64.27%	0.725	61.25%
Asturias	Medium	OVD_09	0.586		0.784		0.763	
		OVD_10	0.572		0.769		0.771	
		OVD_11	0.557		0.752		0.652	
		OVD_12	0.541		0.735		0.657	
		OVD_13	0.526	55.63%	0.717	75.14%	0.662	70.12%
Badajoz	Small	BJZ_09	0.721		0.918		0.926	
		BJZ_10	0.710		0.912		0.850	
		BJZ_11	0.698		0.905		0.726	
		BJZ_12	0.686		0.898		0.853	
		BJZ_13	0.674	69.78%	0.890	90.46%	0.929	85.68%
Barcelona	Large	BCN_09	0.516		0.775		0.535	
		BCN_10	0.500		0.759		0.523	
		BCN_11	0.484		0.742		0.549	
		BCN_12	0.468		0.724		0.543	
		BCN_13	0.451	48.39%	0.705	74.13%	0.619	55.37%

Table 3: Individual Technical Efficiency (2009-2013)

(continued)

			SFA (1992)		SFA_1 (1992) FE		SFA_2 (1995) FE	
Airport	**Size**	**Year**	TE_t	**Average**	TE_t	**Average**	TE_t	**Average**
Bilbao	Large	BIO_09	0.676		0.794		0.787	
		BIO_10	0.663		0.779		0.753	
		BIO_11	0.650		0.764		0.708	
		BIO_12	0.637		0.747		0.609	
		BIO_13	0.623	64.97%	0.729	76.26%	0.756	72.28%
Burgos	Small	RGS_09	0.746		0.919		0.699	
		RGS_10	0.735		0.912		0.822	
		RGS_11	0.724		0.906		0.851	
		RGS_12	0.713		0.898		0.913	
		RGS_13	0.702	72.40%	0.890	90.51%	0.982	85.34%
Ceuta	Small	JCU_09	0.731		0.882		0.666	
		JCU_10	0.720		0.873		0.826	
		JCU_11	0.709		0.863		0.860	
		JCU_12	0.698		0.853		0.983	
		JCU_13	0.686	70.89%	0.842	86.25%	0.844	83.60%
Cordoba	Small	ODB_09	0.528		0.745		0.678	
		ODB_10	0.512		0.727		0.612	
		ODB_11	0.496		0.708		0.619	
		ODB_12	0.480		0.688		0.854	
		ODB_13	0.463	49.56%	0.668	70.72%	0.806	71.36%
El Hierro	Small	VDE_09	0.676		0.840		0.697	
		VDE_10	0.663		0.828		0.756	
		VDE_11	0.650		0.816		0.665	
		VDE_12	0.637		0.802		0.646	
		VDE_13	0.623	64.99%	0.788	81.50%	0.981	74.89%
Fuerteventura	Large	FUE_09	0.615		0.743		0.702	
		FUE_10	0.601		0.725		0.706	
		FUE_11	0.587		0.706		0.650	
		FUE_12	0.572		0.687		0.548	
		FUE_13	0.557	58.66%	0.666	70.54%	0.701	66.14%
Girona	Medium	GRO_09	0.669		0.853		0.978	
		GRO_10	0.657		0.842		0.923	
		GRO_11	0.643		0.830		0.675	
		GRO_12	0.630		0.818		0.631	
		GRO_13	0.616	64.31%	0.804	82.93%	0.773	79.62%
Gran Canaria	Large	LPA_09	0.623		0.669		0.635	
		LPA_10	0.609		0.647		0.587	
		LPA_11	0.594		0.625		0.555	
		LPA_12	0.580		0.601		0.495	
		LPA_13	0.565	59.42%	0.576	62.37%	0.601	57.47%

(continued)

			SFA (1992)		SFA_1 (1992) FE		SFA_2 (1995) FE	
Airport	**Size**	**Year**	TE_t	**Average**	TE_t	**Average**	TE_t	**Average**
Granada-Jaen	Small	GRX_09	0.502		0.693		0.697	
		GRX_10	0.486		0.673		0.661	
		GRX_11	0.469		0.651		0.563	
		GRX_12	0.452		0.629		0.520	
		GRX_13	0.435	46.88%	0.605	65.04%	0.572	60.26%
Huesca-Pirineos	Small	HSK_09	0.710		0.742		0.837	
		HSK_10	0.698		0.724		0.697	
		HSK_11	0.686		0.705		0.557	
		HSK_12	0.674		0.685		0.677	
		HSK_13	0.661	68.58%	0.664	70.38%	0.709	69.53%
Ibiza	Large	IBZ_09	0.637		0.775		0.782	
		IBZ_10	0.623		0.759		0.753	
		IBZ_11	0.609		0.742		0.612	
		IBZ_12	0.595		0.724		0.585	
		IBZ_13	0.581	60.92%	0.705	74.07%	0.727	69.20%
Jerez	Medium	XRY_09	0.559		0.706		0.797	
		XRY_10	0.544		0.686		0.689	
		XRY_11	0.528		0.666		0.638	
		XRY_12	0.512		0.644		0.469	
		XRY_13	0.496	52.77%	0.621	66.45%	0.577	63.40%
La Gomera	Small	GMZ_09	0.533		0.687		0.633	
		GMZ_10	0.517		0.667		0.570	
		GMZ_11	0.501		0.645		0.577	
		GMZ_12	0.484		0.622		0.601	
		GMZ_13	0.468	50.05%	0.598	64.38%	0.697	61.56%
La Palma	Medium	SPC_09	0.532		0.704		0.661	
		SPC_10	0.516		0.684		0.620	
		SPC_11	0.500		0.663		0.541	
		SPC_12	0.484		0.641		0.542	
		SPC_13	0.467	49.99%	0.618	66.23%	0.658	60.43%
Lanzarote	Large	ACE_09	0.662		0.791		0.776	
		ACE_10	0.650		0.776		0.746	
		ACE_11	0.636		0.760		0.664	
		ACE_12	0.623		0.743		0.541	
		ACE_13	0.609	63.60%	0.726	75.93%	0.784	70.22%
Leon	Small	LEN_09	0.550		0.715		0.687	
		LEN_10	0.534		0.695		0.714	
		LEN_11	0.518		0.675		0.688	
		LEN_12	0.502		0.653		0.521	
		LEN_13	0.486	51.81%	0.631	67.38%	0.806	68.31%

(continued)

			SFA (1992)		SFA_1 (1992) FE		SFA_2 (1995) FE	
Airport	**Size**	**Year**	TE_t	**Average**	TE_t	**Average**	TE_t	**Average**
Logroño	Small	RJL_09	0.461		0.630		0.642	
		RJL_10	0.444		0.606		0.597	
		RJL_11	0.427		0.582		0.521	
		RJL_12	0.410		0.557		0.403	
		RJL_13	0.393	42.70%	0.531	58.10%	0.518	53.64%
Madrid Cuatro Vientos	Small	MCV_09	0.563		0.705		0.959	
		MCV_10	0.547		0.685		0.929	
		MCV_11	0.532		0.664		0.86	
		MCV_12	0.516		0.642		0.48	
		MCV_13	0.500	53.16%	0.619	66.31%	0.983	84.22%
Madrid Barajas	Large	MAD_09	0.513		0.768		0.692	
		MAD_10	0.497		0.752		0.701	
		MAD_11	0.481		0.735		0.698	
		MAD_12	0.464		0.716		0.673	
		MAD_13	0.448	48.06%	0.697	73.37%	0.731	69.89%
Madrid Torrejon	Small	TOJ_09	0.566		0.754		0.572	
		TOJ_10	0.551		0.737		0.507	
		TOJ_11	0.535		0.718		0.629	
		TOJ_12	0.520		0.699		0.622	
		TOJ_13	0.504	53.52%	0.679	71.74%	0.596	58.53%
Malaga	Large	AGP_09	0.521		0.746		0.818	
		AGP_10	0.505		0.728		0.72	
		AGP_11	0.489		0.71		0.635	
		AGP_12	0.472		0.69		0.637	
		AGP_13	0.456	48.85%	0.669	70.88%	0.69	70.00%
Melilla	Small	MLN_09	0.475		0.633		0.468	
		MLN_10	0.458		0.609		0.511	
		MLN_11	0.441		0.585		0.43	
		MLN_12	0.424		0.56		0.388	
		MLN_13	0.407	44.11%	0.534	58.43%	0.597	47.90%
Menorca	Medium	MAH_09	0.593		0.762		0.621	
		MAH_10	0.578		0.745		0.757	
		MAH_11	0.563		0.727		0.65	
		MAH_12	0.548		0.708		0.668	
		MAH_13	0.532	56.28%	0.689	72.62%	0.689	67.70%
Murcia	Medium	MJV_09	0.59		0.769		0.859	
		MJV_10	0.576		0.752		0.756	
		MJV_11	0.561		0.735		0.694	
		MJV_12	0.545		0.717		0.708	
		MJV_13	0.530	56.03%	0.697	73.39%	0.753	75.39%

(continued)

			SFA (1992)		SFA_1 (1992) FE		SFA_2 (1995) FE	
Airport	**Size**	**Year**	TE_t	**Average**	TE_t	**Average**	TE_t	**Average**
Palma de Mallorca	Large	PMI_09	0.553		0.776		0.693	
		PMI_10	0.537		0.760		0.698	
		PMI_11	0.521		0.743		0.615	
		PMI_12	0.505		0.725		0.630	
		PMI_13	0.489	52.12%	0.706	74.22%	0.843	69.58%
Pamplona	Small	PNA_09	0.460		0.635		0.707	
		PNA_10	0.444		0.612		0.710	
		PNA_11	0.427		0.587		0.570	
		PNA_12	0.410		0.562		0.469	
		PNA_13	0.393	42.67%	0.536	58.65%	0.544	60.01%
Reus	Medium	REU_09	0.559		0.737		0.627	
		REU_10	0.543		0.718		0.807	
		REU_11	0.528		0.699		0.635	
		REU_12	0.512		0.679		0.555	
		REU_13	0.496	52.74%	0.658	69.81%	0.564	63.74%
Sabadell	Small	QSA_09	0.648		0.847		0.970	
		QSA_10	0.634		0.836		0.910	
		QSA_11	0.621		0.823		0.835	
		QSA_12	0.607		0.810		0.711	
		QSA_13	0.592	62.04%	0.796	82.25%	0.982	88.17%
Salamanca	Small	SLM_09	0.524		0.716		0.744	
		SLM_10	0.508		0.697		0.723	
		SLM_11	0.492		0.676		0.536	
		SLM_12	0.476		0.655		0.554	
		SLM_13	0.459	49.18%	0.633	67.54%	0.834	67.80%
San Sebastian	Small	EAS_09	0.644		0.835		0.843	
		EAS_10	0.631		0.823		0.815	
		EAS_11	0.617		0.810		0.750	
		EAS_12	0.603		0.796		0.652	
		EAS_13	0.588	61.64%	0.782	80.93%	0.822	77.62%
Santander	Medium	SDR_09	0.532		0.717		0.759	
		SDR_10	0.516		0.697		0.661	
		SDR_11	0.500		0.677		0.684	
		SDR_12	0.484		0.656		0.583	
		SDR_13	0.467	49.97%	0.634	67.62%	0.702	67.76%
Santiago	Medium	SCQ_09	0.533		0.701		0.738	
		SCQ_10	0.517		0.681		0.708	
		SCQ_11	0.501		0.660		0.547	
		SCQ_12	0.484		0.638		0.429	
		SCQ_13	0.468	50.05%	0.615	65.92%	0.614	60.72%

(continued)

			SFA (1992)		SFA_1 (1992) FE		SFA_2 (1995) FE	
Airport	**Size**	**Year**	TE_t	**Average**	TE_t	**Average**	TE_t	**Average**
Sevilla	Large	SVQ_09	0.674		0.802		0.761	
		SVQ_10	0.662		0.787		0.731	
		SVQ_11	0.649		0.772		0.679	
		SVQ_12	0.636		0.756		0.606	
		SVQ_13	0.622	64.85%	0.738	77.09%	0.714	69.80%
Tenerife North	Large	TFN_09	0.633		0.755		0.739	
		TFN_10	0.619		0.737		0.726	
		TFN_11	0.605		0.719		0.650	
		TFN_12	0.590		0.700		0.536	
		TFN_13	0.576	60.45%	0.680	71.83%	0.681	66.65%
Tenerife South	Large	TFS_09	0.572		0.706		0.660	
		TFS_10	0.557		0.686		0.647	
		TFS_11	0.542		0.665		0.575	
		TFS_12	0.526		0.644		0.528	
		TFS_13	0.510	54.15%	0.621	66.45%	0.645	61.10%
Valencia	Large	VLC_09	0.678		0.721		0.624	
		VLC_10	0.665		0.702		0.682	
		VLC_11	0.652		0.682		0.639	
		VLC_12	0.639		0.660		0.570	
		VLC_13	0.626	65.21%	0.638	68.06%	0.733	64.94%
Valladolid	Small	VLL_09	0.569		0.746		0.804	
		VLL_10	0.554		0.729		0.794	
		VLL_11	0.538		0.710		0.639	
		VLL_12	0.523		0.690		0.531	
		VLL_13	0.507	53.82%	0.670	70.90%	0.560	66.57%
Vigo	Small	VGO_09	0.535		0.717		0.864	
		VGO_10	0.519		0.698		0.719	
		VGO_11	0.503		0.678		0.497	
		VGO_12	0.487		0.656		0.525	
		VGO_13	0.470	50.27%	0.634	67.66%	0.690	65.89%
Vitoria	Small	VIT_09	0.482		0.747		0.815	
		VIT_10	0.465		0.730		0.705	
		VIT_11	0.449		0.711		0.553	
		VIT_12	0.432		0.692		0.518	
		VIT_13	0.415	44.86%	0.671	71.03%	0.875	69.33%
Zaragoza	Small	ZAZ_09	0.744		0.853		0.849	
		ZAZ_10	0.733		0.842		0.972	
		ZAZ_11	0.723		0.830		0.758	
		ZAZ_12	0.712		0.818		0.816	
		ZAZ_13	0.700	72.23%	0.804	82.94%	0.924	86.40%

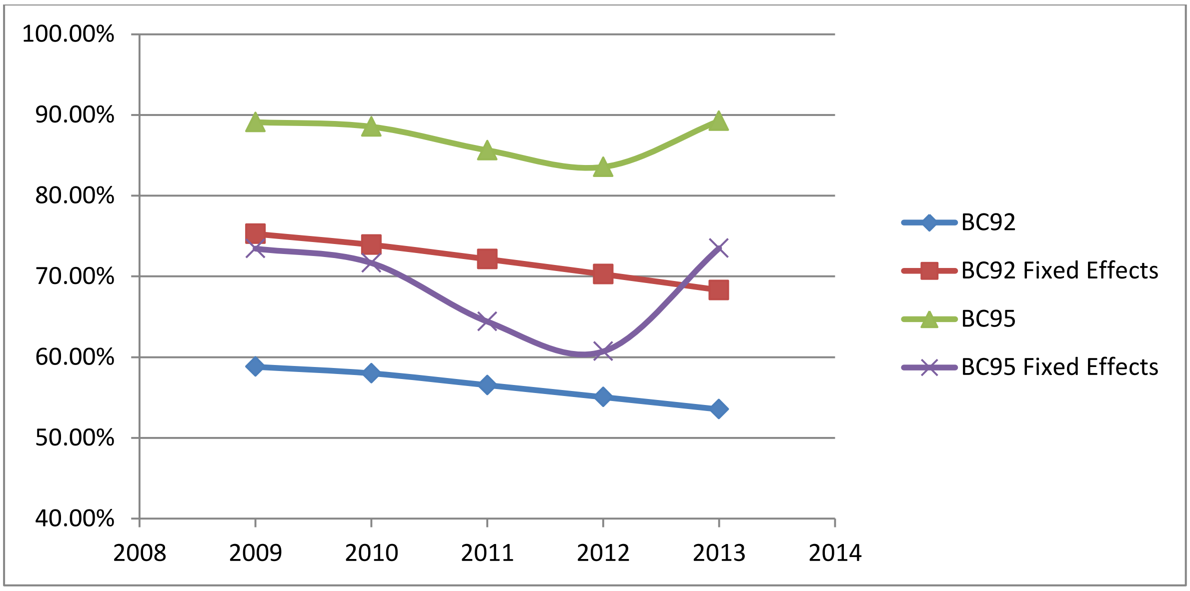

Figure 1: SFA models: average technical efficiency (2009-2013)

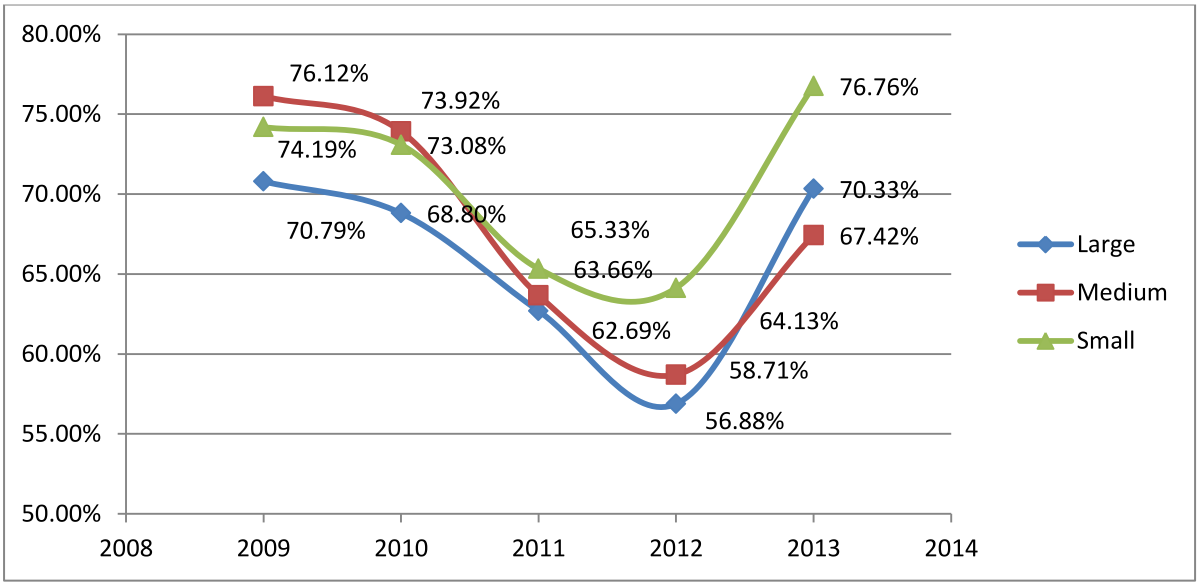

Figure 2: Average technical efficiency per size (2009-2013)

As it is seen in Table 4 the northern area contains a significant number of small airports that are technically inefficient with more than one airport within their respective catchment areas. These geographical areas are not congested and airports become cost inefficient (Martin et al., 2011). Table 5 summarizes the closing recommendations. The table also shows the increment of traffic in the airports within the same catchment area absorbing the passengers from the airports closed. The assumption made is that when having a large airport in a catchment area, smaller airports transfer their traffic to the large one to improve its efficiency. The rationale is based on the higher density of the city where large airports are located potentially with more demand compared to other regions. Additionally, airports' capacity is taken into consideration. Figure 3 shows the airports regarding their classification in terms of air navigation constraints.

Figure 3: Coordinated and schedules facilitated airports (Source: AECFA)

Initially, airports not coordinated (level one) and airports with schedules facilitated (level two) should not have congestion or problems of capacity. The coordinated airports identified in red, require a slot clearance request (SCR) to take off and land. Without this permission, the use of the airport infrastructure is not allowed. The airports with facilitated schedules have slight shortfalls in capacity (level two). There is not a formal approval required. These are airports with schedule movement advice (SMA). In the map are identified in yellow and include Menorca and Ibiza during winter. These latest airports are coordinated during the summer season.

For example, Santander (1,017,220); San Sebastian (271,441) and Pamplona (243,019) are recommended transferring their respective traffic to Bilbao. This represents an overall increment of 39% for Bilbao that ends with 5,444,065 passengers per year. Vitoria (28,304) and Logroño (21,586) would be transferring their traffic to Burgos since it is highly efficient. Both airports are located in the same catchment area as Burgos (118 km and 145 km, respectively). In the same way, Valladolid (371,923) located at 142 kilometres from Burgos and being less technical efficient. Burgos would increment its traffic in 421,812 passengers per year representing an increment of 94%. Since Burgos is a non-coordinated airport, it has enough capacity to meet this requirement. Asturias is an airport located in the North, between A Coruña and Santander airports. Asturias is operating on its own in the catchment area. Consequently, it is highly efficient (70.80%). Leon is located at 163 kilometres and although is highly efficient (68.31%), it is not profitable (i.e. based on AENA's information). Asturias is profitable and also has a higher level of population (225,123 inhabitants) compared to Leon (132,668). Therefore, Leon will be recommended closing and transferring its traffic to Asturias. Asturias would also absorb the losses of Leon (-2,218), becoming the year of the closure not profitable (-1,556), but with a high potential of meeting the break-even point shortly. Asturias is an airport with schedules facilitated. Therefore, there are slight shortfalls in capacity and subsequent conflicts of use.

There are four airports that are highly efficient that could remain open even having a large airport in their catchment area. These are San Sebastian (77.62%); Girona (79.62%); Cordoba (71.36%) and Murcia (75.39%). In this case, San Sebastian would absorb the traffic from Pamplona (at 103 km) and Vitoria (117 km). Both Girona and Murcia are profitable (13,512 and 3,722 respectively) and also airports with schedules facilitated attracting as relevant number of passengers potentially due to their geographical location within the Mediterranean region and closed to popular touristic cities (e.g. Barcelona and Alicante). San Sebastian and Cordoba although not being profitable, are very efficient compared to other airports located in the same geographical area. For example, Cordoba is highly efficient (71.36%) compared to medium airports such as Jerez (63.40%) and Granada (60.26%). Even large airports such as Sevilla located in the same catchment area (69.80%) or Malaga (70%).

The results also show that the diversification of activities help becoming more technically efficient even when having airports nearby, but with other operating main activity or size (Coto-Millan et al., 2016). For example, Zaragoza cargo-oriented airport (86.40%) compared to Vitoria also cargo-oriented, but with a significant number of small airports in the catchment area (69.33%); Sabadell (88.17%) and Madrid Cuatro Vientos (84.22%) general aviation airports or Algeciras (91.03%) and Ceuta (83.60%), both heliports[60]. Madrid Torrejon clearly experiments the impact on efficiency when changing activities from a general aviation airport to become a full military base at the end of January 2013 (58.53%). Similarly, civilian airports with no other airports in the catchment areas are highly efficient for example, Badajoz (85.68%) and El Hierro (74.89%), although with less consistency

[60] Cordoba becomes a general aviation airport since 2015 (71.36%). Although initially, the same analysis would not apply, pre-effects in its efficiency may have happened prior to being fully specialised.

across the years. Both are small airports located in isolated areas with no other airport nearby at 150, 175 or 200 kilometres. This does not apply to La Gomera (61.56%) and Melilla (47.90%) with no other competitors neither, but not that highly-efficient. On the other hand Albacete (61.96%) and Almeria (61.25%) with similar technical efficiency are also small airports, but with one competitor larger in size located at 175 kilometres. With the exception of Melilla (47.90%) and Logroño (53.04%), all the small civilian airports achieve scores between 60% and 86%.

Further analysis may require linking the fixed effects found in the analysis regarding specialised airports and their financial contribution to the system. For example, although the efficiency and catchment area analysis would suggest closing Vitoria, as previously discussed the value of the fixed effects reveal that this airport helps finance the overall labour costs incurred (FE_6=-45%). Based on the catchment area analysis, there is a total of 13 airports recommended being a closure: six small airports (Vitoria; Pamplona; Logroño; Huesca-Pirineos; Leon; Valladolid); six medium (Santander; Reus; Vigo; Santiago; Jerez and Granada) and one large airport (Tenerife South). It is important to remember that the closure of airports is required unless airports' competition is enhanced and/or airports' individual managers are granted with decision power to increase traffic, to make the Spanish market attractive to airlines and passengers.

It is important to bear on mind that closure recommendations are provided due to the current economic regulatory framework of the Spanish airport system. The airports' closure is required unless airports' competition is enhanced. Additionally, unless airports' operators are granted with decision power to increase traffic: to make the Spanish market attractive to airlines and passengers. It could be discussed that the closure of airports creates an issue of lack of capacity if unforeseen increases of demand occur. Consequently, it would imply flight delays and cancellations as well as connectivity pitfalls. Nevertheless, the issue of shortfalls in capacity does not apply to all the Spanish airports. The inexistent competition leads to regional airports with very low traffic, with over-capacity or capacity underused. It is clear that the expansion of infrastructure is essential to meet the demand, essentially for international hubs. Nevertheless, in the short and medium-term is necessary an optimum use of the current infrastructures. Therefore, an optimal slot allocation and rules are required to be implemented to ensure effective competition. Air carriers granted with grandfather rights may decide to cancel flights to the extent that the 80% rule is fulfilled. The consequences of no-shows are slot-loss in coordinated airports that could be used by other airlines. This also applies to seasonality with peaks of demand or bad weather conditions where other airports (for example, with scheduled facilitated) can be used as support for civilian transport. Although new business models such as LCCs have emerged providing traffic growth using secondary airports, the discriminatory increase in airports charges by AENA has pushed LCCs to eliminate routes and to move to other airports[61]. Although LCCs may help reduce seasonality for example, providing leisure travellers during the whole year round, it is clear that LCCs are more likely to change routes or withdraw from an airport in adverse market conditions. On the other hand, airports have to face reducing seasonality by choosing between leisure carriers and LCCs (Farmaki and Papatheodorou, 2015). Consequently, secondary airports have a high risk when operating with a single LCC especially if used as origin or destination in point-to-point routes. Further research will take into consideration these aspects.

[61] Ryanair cancels a significant number of routes in Barcelona and Madrid due to the increase in airport charges in 54% and 50% respectively from 2010 to 2011. These represent 34% of activity in Madrid (11 routes) and 30% in Barcelona (four routes) from November 2012. Additionally, these represent 46 connecting routes (24 in Madrid and 22 in Barcelona). Easyjet was planning to reduce its operations in Madrid by a 20% during the same period.

Cluster	Airports	Size	SFA_2FE	Catchment	EBITDA	Population	Density	Cluster	Airports	Size	SFA_2FE	Catchment	EBITDA	Population	Density
Northern	Bilbao	Large	72.28%	1 Medium, 2 Small	19,348	352,346	8,529	**Centre**	Madrid Barajas	Large	69.89%	2 GAs	330,600	3,246,961	5,360
	Santander	Medium	67.76%	1 Large, 1 Small	-274	179,960	5,177		Burgos	Small	85.34%	3 Small	-2,394	179,159	1,673
	San Sebastian	Small	77.62%	1 Large, 2 Small	-3,348	185,991	3,055		Madrid Cuatro Vientos	Small (GA)	84.22%	1 Large, 1 Military	-5.836	186,793	4,335
	Vitoria	Small	69.33%	1 Large, 1 Medium, 4 Small	-9,948	239,416	865		Leon	Small	68.31%	1 Small	-2,218	132,668	3,399
	Pamplona	Small	60.01%	3 Small	-4,766	197,694	7,833		Salamanca	Small	67.80%	1 Small	-3,236	153,026	3,890
	Logroño	Small	53.64%	3 Small	-4,378	152,773	1,920		Valladolid	Small	66.57%	3 Small	-3,400	313,608	1,587
North-East	Barcelona	Large	55.37%	2 Medium, 1 GA	217,196	1,617,817	16,473		Madrid Torrejon	Small (GA)	58.53%	1 Large, 1 GA	-2,786	121,657	3,730
	Girona	Medium	79.62%	1 Large, 1 GA	13,512	96,727	2,482	**South**	Malaga	Large	70.00%	1 Medium, 1 Heliport, 1 Small (GA)	54,496	568,151	1,438
	Reus	Medium	63.74%	1 Large, 1 Small[1], 1 GA	1,776	106,890	2,018		Sevilla	Large	69.80%	1 Medium, 1 Small (GA)	14,130	702,590	4,972
	Sabadell	Small (GA)	88.17%	1 Large, 2 Medium	-4,684	207,428	5,527		Jerez	Medium	63.40%	1 Large, 1 Heliport	-3,944	210,172	177
	Zaragoza	Small	86.40%	1 GA	-1,522	677,158	695		Granada-Jaen	Medium	60.26%	1 Large	-3,036	238,083	2,705
	Huesca-Pirineus	Small	69.53%	2 Small[1]	-1,744	52,313	1,359		Algeciras	Small (Heliport)	91.03%	1 Large, 1 Medium	-658	116,326	1,356
North-West	A Coruña	Medium	70.80%	2 Medium[2]	-1,274	246,040	6,504		Cordoba	Small (GA 2015)	71.36%	1 Large	-2,576	328,636	262
	Vigo	Medium	69.33%	2 Medium[2]	-2,670	297,106	2,724	**South-East**	Alicante	Large	59.94%	1 Medium	55,304	334,647	1,663
	Santiago	Medium	60.72%	2 Medium	1,315	95,367	433		Murcia	Medium	75.39%	1 Large	3,722	440,004	497
Balearic Islands	Palma de Mallorca	Large	69.58%	1 GA	108,568	403,416	1,934	**Canary Islands**	Tenerife North	Large	66.65%	1 Large	4,814	152,202	1,491
	Son Bonet	Small (GA)	n/a	1 Large	-1,222	34,291	632		Tenerife South	Large	61.10%	1 Large	46,512	41,713	257

Table 4: Catchment areas and average technical efficiency (2009-2013) [1] Huesca-Pirineos and Reus have as competitor Lleida, a small airport managed by *Aeroports de Catalunya.* This airport has not been included in this study. From January 2014 Huesca-Pirineos does not have scheduled services. [2] Vigo is located at 158 km from A Coruña *Airports highly efficient, potentially remaining open.

Airport	Transfer to	Passengers	∆Passengers	Total Passengers	EBITDA (th €)	∆EBITDA	Total EBITDA (th €)
Bilbao	Open	3,912,385	1,531,680	5,444,065	19,348	-8,388	10,960
Santander	Bilbao	1,017,220	-1,017,220	0	-274	274	0
San Sebastian	Bilbao*	271,441	-271,441	0	-3,348	3,348	0
Vitoria	Burgos	28,304	-28,304	0	-9,984	9,984	0
Pamplona	Bilbao	243,019	-243,019	0	-4,766	4,766	0
Logroño	Burgos	21,586	-21,586	0	-4,378	4,378	0
Barcelona	Open	32,278,155	1,279,502	33,557,657	217,196	-1,776	215,420
Girona	Open*	3,748,068		3,748,068	13,512		13,512
Reus	Barcelona	1,279,502	-1,279,502	0	-1,776	1,776	0
Sabadell	Open	719		719	-4,684		-4,684
Zaragoza	Open	578,865	3,300	582,165	-1,522	-1,744	-3,266
Huesca-Pirineos	Zaragoza	3,300	-3,300	0	-1,744	1,744	0
A Coruña	Open	973,624	3,105,897	4,079,520	-1,274	-1,355	-2,629
Vigo	A Coruña	936,092	-936,092	0	-2,670	2,670	0
Santiago	A Coruña	2,169,805	-2,169,805	0	1,315	-1,315	0
Palma de Mallorca	Open	22,096,411		22,096,411	108,568		108,568
Son Bonet	Open	841		841	-1,222		-1,222
Madrid Barajas	Open	46,580,135		46,580,135	330,600		330,600
Burgos	Open	27,344	421,812	449,156	-2,394	-17,762	-20,156
Madrid Cuatro Vientos	Open	1,024		1,024	-5,836		-5,836
Leon	Asturias	71,248	-71,248	0	-2,218	2,218	0
Salamanca	Open	34,414		34,414	-3,236		-3,236
Valladolid	Burgos	371,922	-371,922	0	-3,400	3,400	0
Madrid Torrejon	Open	23,276		23,276	-2,786		-2,786
Malaga	Open	12,403,439	890,821	13,294,260	54,496	-5,612	48,884
Sevilla	Open	4,243,041	976,025	5,219,065	14,130	-3,944	10,186
Jerez	Sevilla	976,025	-976,025	0	-3,944	3,944	0
Granada-Jaen	Malaga	881,107	-881,107	0	-3,036	3,036	0
Algeciras	Open	9,631		9,631	-658		-658
Cordoba	Malaga*	9,714	-9,714	0	-2,576	2,576	0
Alicante	Open	9,386,084		9,386,084	55,304		55,304
Murcia	Open*	1,313,091		1,313,091	3,722		3,722
Tenerife North	Open	3,888,604	8,071,197	11,959,801	4,814	46,512	51,326
Tenerife South	Tenerife North	8,071,197	-8,071,197	0	46,512	-46,512	0
Asturias	Open	1,271,952	71,248	1,343,200	662	-2,218	-1,556
		159,122,585	**0**	**159,122,585**	**802,453**	**0**	**802,453**

Table 5: Catchment Areas: Transfer of Traffic (2009-2013)

6. Conclusions

This study applies a stochastic frontier analysis to estimate the overall efficiency of the Spanish airport-system and to explain potential sources of airports' inefficiencies. The inclusion of exogenous factors and fixed effects are considered since it is assumed having an impact in in the way that airports operate: use of resources and infrastructure (capacity). Although the most important output is the number of passengers, airports require seeking alternative sources of income by enhancing the commercialisation aspect. None of the iterations are relevant except for commercial revenues and passengers highlighting the commercial aspect of the airports, but with the requirement of the aeronautical perspective. Passengers are as important as commercial revenues, but commercial revenues will not be earned without passengers. Airports' specialisation is evidenced helping improving efficiency to the extent that no other airports specialised in the same function are located in the same catchment area. Airports special features must be considered in the production function to avoid models misspecification. The results also show that not only large airports contribute to the financial aspect of the system, but also smaller airports when having a specialised activity. The results show that there is no relation between the size of the airports' infrastructure and traffic. Small and medium airports are highly efficient compared to large airports. Airports with relevant investments and without the increase in traffic accordingly and airports with season effect help with less significance in financing the network.

Although the translog distance function indicates that not all the inefficiency is caused by the management, it has not been possible to conclude the main cause of the overall inefficiency of the Spanish airport-network except for factors directly related to traffic: train facilities and the existence of PSOs. The fact that accessibility increases significantly the network inefficiency, initially suggests that not all the inefficiency is under AENA's control. Other environmental variables such as the existence of PSOs and air traffic control restrictions are clearly not influencing the airports' inefficiency. The PSOs are a requirement even there are not passengers using the routes to connect remote areas (i.e. between islands). Finally, the insignificant impact of catchment areas suggests that airports do not compete for attracting traffic even being located close to each other. Therefore, the traffic from airports technically inefficient could be transferred to the nearby airport with higher efficiency, but with capacity underused. The fact that the number of competitors (catchment areas) is not relevant responds to the strong centralised management. The inexistence of competition between airports questions the adequacy of having more than one airport serving the same area and making the network technically inefficient. The question to address is to what extent the small and medium airports could improve their current technical efficiencies by competing with airports located in the same catchment areas. The results also show a significant improvement in the efficiencies when considering fixed effects. These findings highlight the requirement of carefully analysing each airport's structural characteristics and geographical environment prior to making managerial decisions regarding inputs and outputs. Airports cannot be treated equally in terms of managerial decisions. On this basis, it is questionable if specific environmental variables could be managed by AENA.

From a profitability perspective, the Spanish network is costly to run incurring in significant fixed costs, but a deficit in earning revenues. There is a clear discrepancy between the profitability stated by AENA and the technical inefficiencies of airports. Not always large airports are the most profitable neither the most technically efficient. Overall heliports, general aviation airports, and cargo-oriented airports are highly efficient even being small and having other airports in their respective catchment areas. Additionally, the fixed costs of large infrastructures without the increase in traffic overcome any potential income. The fact that the depreciation is not relevant suggests that the Spanish airports suffer from over-capacity. These results confront the conclusions of the Airports Council International (ACI), at least in the Spanish airport system. The ACI states that only the largest airports in terms of passengers can operate profitably[62]. The depreciation of the assets and interest from borrowings must be still subtracted from the EBITDA values provided by AENA. Additionally, it is necessary converging accounting values of profit with the pure definition of efficiency: airports could be profitable by increasing airport charges, but not for increases in traffic according to their potential capacity (under-used). Further analysis of the catchment areas confirms the requirement of closing a relevant number of airports since these are not efficient and are not required for connectivity purposes. On this basis, unless competition is enhanced and airports' managers are granted to decide commercial policies to attract airlines and passengers, the infrastructure becomes an idle resource for the network and airports underused become a burden for the system. The final discussion refers to confirm if the Spanish Government treats airports as public utilities for social welfare purposes (public employment). Alternatively, politics' interests may be prioritised to the factual industry needs.

[62] Airports with over five million passengers per year have profits; airports with passengers between one and five million per year meet their operating expenses; airports with less than one million of passenger per year are unable to cover their operating costs.

Apart from the limited access to data (i.e. more recent information regarding inputs and outputs) as well as the robustness of the EBITDA indicators, one of the main limitations of the study is the endogeneity issue inherent in stochastic frontier analysis with distance functions (Amsler et al., 2016). A potential solution could be using cost functions rather than production functions. The fact that more than several techniques are used by for example the inclusion of fixed effects, seems to potentially add further difficulties to the model based on the limited access to the data. One solution could be to calculate an aggregate measure of total costs rather than using individual variables. On this basis instead of estimating technical efficiency, the model would estimate allocative efficiency by defining the cost production function as a function of outputs and inputs prices. It is essential then to control the output prices that are externally decided by AENA rather than by the airports' operators. Furthermore, the reliability of future results will depend upon the access to more information and reliable data.

References

Aigner, D.; Lovell, Knox C.A. & Schmidt, P. (1977): 'Formulation and estimation of stochastic frontier production function models' *Journal of Econometrics* 6, 21-37

Amsler, C.; Prokhorov, A. and Schmidt, P. (2016): 'Endogeneity in stochastic frontier models' *Journal of Econometrics* 190, 280-288

Ashford, N., Stanton, H., & Moore, C. (1996): *'Airport Operations'* New York, McGraw-Hill Education (second edition)

Coelli, T.J. and Perelman, S. (1999): 'A comparison of parametric and non-parametric distance functions with application to European railways' *European Journal of Operational Research* 117, 326-339

Coelli, T.J. and Perelman, S. (2000): 'Technical efficiency of European railways: a distance function approach' *Applied Economics* 23, 1967-1976

Coelli, T. J.; Rao, D.S.P.; O'Donnell, C.J. & Battese, G.E. (2005): *'An Introduction to Efficiency and Productivity Analysis'* 2nd Edition. New York: Springer.

Martin-Cejas (2002): 'An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier' *Journal of Air Transport Management* 8, 233-238

Battese, G.E. and Coelli, T. J. (1988): 'Prediction of Firm-level technical efficiencies with a generalized frontier production function and panel data' *Journal of Econometrics* 38, 387-399

Battese, G.E. and Coelli, T. J. (1992): 'Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India'. *Journal of Productivity Analysis* 3, 153-169

Battese, G.E. and Coelli, T. J. (1993): 'A Stochastic Frontier Production Function incorporating a model for technical inefficiency effects' *Working Papers in Econometrics and Applied Statistics* 69, Department of Econometrics. University of New England.

Battese, G.E. and Coelli, T. J. (1995): 'A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data' *Empirical Economics* 20, 325-332

Coelli, T. J. and Perelman, S. (1996): 'Efficiency measurement, multi-output technologies and distance function: with application to European railways' *CREPP Working Paper* 96/05, University of Liege.

Coelli, T. J.; Perelman, S. & Romano, E. (1999): 'Accounting for Environmental Influences in Stochastic Frontier Models: with application to International Airlines' *Journal of Productivity Analysis* 11, 251-273

Coelli, T. J.; Prasada Rao, D.S. & Battese, G.E. (1998): *'An Introduction to Efficiency and Productivity Analysis'* Kluwer Academic Publishers, New York.

Coto-Millan, P.; Carrera-Gomez, G.; Castanedo-Galan, J.; Inglada, V.; Nuñez-Sanchez, R.; Pesquera, M.A.; Sainz, R. (2007): *'Efficiency Stochastic Frontiers: a Panel Data Analysis for Spanish Airports (1992–1994)'* Essays on Transport Economics (chapter 121-126), Physica-Verlag HD

Coto-Millan, P.; Casares-Hontañón, P.; Inglada, V.; Agüeros, M.; Pesquera, M.A.; Badiola, A. (2014): 'Small is beautiful? The impact of economic crisis, low cost carriers, and size on efficiency in Spanish airports (2009–2011)' *Journal of Air Transport Management* 40, 34-41

Coto-Millan, P.; Inglada, V.; Fernandez, X.L.; Inglada-Perez, L. & Pesquera, M.A. (2016): 'The *effect procargo* on technical and scale efficiency at airports: The case of Spanish airports (2009–2011)' *Utilities Policy* 39, 29-35

Cuesta A. and Orea, L. (2002): 'Mergers and technical efficiency in Spanish saving banks: A stochastic distance function approach' *Journal of Banking & Finance* 26 (12), 2231-2247

Cuesta, R. A., Lovell, C. K., Zofío, J. L., (2009): 'Environmental efficiency measurement with translog distance functions: A parametric approach' *Ecological Economics* 68, 2232-2242

Färe, R.; Grosskopf, S.; Lovell, C. A. K. & Yaisawarng, S. (1993), 'Derivation of Shadow Prices of Undesirable Outputs: A Distance Function Approach' *Review of Economics and Statistics* 75(2), 374-380

Färe, R.; Grosskopf, S. & Roos, P. (1997): 'Malmquist productivity indexes: a survey of theory and practice' In *Index Numbers: Essay in Honour of Stern Malmquist,* Kluwer Academic Publisher, Boston.

Farmaki, A. and Papatheodorou, A. (2015): ‘Stakeholder Perceptions of the Role of Low-Cost Carriers in Insular Tourism Destinations: The Case of Cyprus’ *Tourism Planning and Development* 12(4), 412–432

Greene, W. (2003): *‘Econometric Analysis’* Prentice Hall, Englewood Cliffs 5th Edition

Greene, W. (2005): ‘Fixed and Random Effects in Stochastic Frontier Models’ *Journal Productivity Analysis* 23(1), 7-32

Hattory, T. (2002): ‘Relative Performance of U.S. and Japanese Electricity Distribution: an application of Stochastic Frontier Analysis’ *Journal of Productivity Analysis* 18, 269-284

Humphreys, I. (1999): ‘Privatisation and commercialisation Changes in UK airport ownerships patterns’ *Journal of Transport Geography* 7, 121-134

Jondrow, J.; Lovell, C.A.K.; Materov, I.S. & Schmidt, P. (1982): ‘On the estimation of technical inefficiency in stochastic frontier production function model’ *Journal of Econometrics* 19 (2-3), 233-238

Kumbhakar, S.C. (1990): ‘Production frontiers, panel data and time-varying technical inefficiency’ *Journal of Econometrics* 46, 201-2012

Kumbhakar, S.C.; Ghosh, S. & McGuckin, J.T. (1991): ‘A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Frontier Approach for Estimating Determinants of Inefficiency in U.S.Dairy Firms’ *Journal of Business and Economic Statistics* 9, 279-286

Kumbhakar, S.C.; Lien, G. & Hardaker J.B. (2014): ‘Technical efficiency in competing panel data models: a study Norwegian gran farming’ *Journal of Productivity Analysis* 41 (2), 321-337

Kumbhakar, S.C. and Lovell, C.A. (2000): *‘Stochastic Frontier Analysis’* Cambridge University Press, Cambridge, United Kingdom.

Kumbhakar, S., C.; Park, B. U.; L. Simar, Tsionas, E. (2007): ‘Nonparametric Stochastic Frontiers: A Local Maximum Likelihood Approach’. *Journal of Econometrics* 137 (1), 1-27

Lovell, C.A. K.; Richardson, S. Travers, P. & Wood, L.L. (1994): 'Resources and functioning: a new view of inequality in Australia' *Models and measurement of welfare and inequality.* Eds. W. Eichhorn, Springer. Berlin, 787-807

Lozano S. and Gutierrez, E. (2011): 'Slacks-based measure of efficiency of airports with airplanes delays as undesirable outputs' *Journal Computers and Operations Research* 38(1), 131-139

Lozano S.; Gutierrez, E. & Moreno, P. (2013): 'Network DEA approach to airports performance assessment considering undesirable outputs' *Applied Mathematical Modelling* 37, 1665-1676

Martin J.C. and Roman, C. (2001): 'An application of DEA to measure the efficiency of Spanish airports prior to privatization' *Journal of Air Transport Management* 7(3), 149-157

Martin, J. C. and Roman, C. (2006): 'A benchmarking analysis of Spanish commercial airports. A comparison between SMOP and DEA ranking methods' *Networks and Spatial Economics* 6(2), 111-134

Martin J.C.; Roman, C. and Voltes-Dorta, A. (2009): 'A stochastic frontier analysis to estimate the relative efficiency of the Spanish airports' *Journal of Productivity Analysis* 31(3), 163-176

Martin J.C.; Roman, C. and Voltes-Dorta, A. (2011): 'Scale economies and marginal costs in Spanish airports' *Transportation Research Part E* 47, 238-248

Martin-Cejas, R.R. (2002): 'An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier' *Journal of Air Transport Management* 8 (4), 233–238

Murillo-Melchor, C. (1999): 'An Analysis of technical efficiency and productivity changes in Spanish Airports using the Malmquist Index' *International Journal of Transport Economics 26(2), 271-292*

Parker, D. (1999): 'The performance of BAA before and after privatisation' *Journal of Transport Economics and Policy* 33, *133-145*

Pels, E.; Nijkamp, P. & Rietveld, P. (2001): 'Relative Efficiency of European Airports' *Transport Policy* 8 (3), 183-92

Pels, E.; Nijkamp, P. & Rietveld, P. (2003): 'Inefficiencies and scale economies of European airport operations' *Transport Research Part E* 39, 341-361

Pestana, B. C. and Sampaio, A. (2004): 'Technical and allocative efficiency in airports' *International Journal of Transport Economics* 31, 355-377

Reifschneider, D. & Stevenson, R. (1991): 'Systematic Departures from the Frontier: A Framework for the Analysis of Firm Inefficiency' *International Economic Review* 32, 715-723

Ripoll-Zarraga, A.E. and Mar-Molinero, C. (2017): 'Spanish airports: a Visual study of Management Efficiency' *Funcas Working Papers* 791/2017 (September)

Ripoll-Zarraga, A.E.; Portillo, F. and Mar-Molinero, C. (2017): 'The impact of the 2008 Economic Crisis in the efficiency of Spanish airports: A DEA Analysis' *Funcas Working Papers* 794/2017 (December)

Ripoll-Zarraga, A.E. and Raya, J.M. (2018): 'Can airports' inefficiency be determined by tourism variables?' *Funcas Working Papers* 2018 (January)

Salazar de la Cruz, F. (1999): 'Technical, allocative and economic efficiency in transport' *International Journal of Transport Economics* 26(2), 255-270

Schmidt, P. and Sickles, R. (1984): 'Production frontiers and panel data' *Journal of Business and Economics Statistics* 2 (4), 367-374

Tapiador, F.J.; Mateos, A. & Marti-Henneberg, J. (2008): 'The geographical efficiency of Spain's regional airports: a quantitative analysis' *Journal of Air Transport Management* 14(4), 205-212

Tovar, B. and Martin-Cejas, R.R. (2009): 'Are outsourcing and non-aeronautical revenues important drivers in the efficiency of Spanish airports?' *Journal of Air Transport Management* 15(5), 217-220

Tovar, B. and Martin-Cejas, R.R. (2010): 'Technical efficiency and productivity changes in Spanish airports: A parametric distance functions approach' *Transportation Research Part E* 46(5), 249-260

Wang, H. and Schmidt, P. (2001): 'One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels'. *Munich Personal RePec Archive MPRA* 31,075

Zhang, T. and Garvey, E. (2008): 'A comparative analysis of multi-output frontier models' *Journal of Zhejiang University Science A*

Reports

Abertis (2009): *'Ten years that marked an historic era change in the presidency'* Issue 17

ACETA (2011): *'Estudio y análisis sobre el incremento de las tasas aeroportuarias en Aviación General y en la formación de pilotos profesionales'* http://aviaciondigital.com/incremento-de-tasas-aeroportuarias-en-aviacion-general-y-formacion-de-pilotos/

http://www.aviaciondigitalglobal.com/newsFiles/20110622011312-4.pdf

ACI Europe (2010): *'The Ownership of Europe's Airports'*

AECFA (2014): https://www.slotcoordination.es/csee/Satellite/Slots/es/Page/1237545152315/1237544440201/ (last accessed August 2018)

AENA (2018): 'Price Guide 2018. Basic Airport Services' http://www.aena.es/en/airlines/tariffs.html (last accessed March 2018)

Cambra de Comerç de Barcelona (November 2010): *'El modelo de gestión aeroportuaria en España: marco institucional y jurídico y líneas maestras para una propuesta de cambio'*

Comisión Nacional de los Mercados y la Competencia (CNMC, July 2014): *'El Sector Aeroportuario en España: Situación Actual y Recomendaciones de Liberización'*

'Documento de Regulación Aeroportuaria' (DORA 2017-2021, January 2017) https://www.seguridadaerea.gob.es/lang_castellano/aeropuertos_2/dora/default.aspx

ENAIRE https://www.enaire.es/control_de_tr%C3%A1fico_a%C3%A9reo_(atc) (last accessed July 2018)

European Commission European Court of Auditors (2014): *'EU-funded airport infrastructures: poor value for money'* Special Report, 21 http://www.politico.eu/article/eu-wasted-money-on-new-airports-say-auditors/

European Commission Press release (July, 2016): *'State aid: Commission orders Spain to recover incompatible State aid for high speed train test centre from railway operator ADIF'*

http://europa.eu/rapid/press-release_IP-16-2621_en.htm

The International Air Transport Association (IATA) (November 2013): *'Airport Competition. IATA Economic Briefing No. 11'*

International Civil Aviation Organization (ICAO) (March 2013): '*Worldwide Air Transport Conference (ATCONF) Sixth meeting: Airport Competition'* https://www.google.com/maps/d/viewer?mid=zylWTnxRlUJE.kU5cVv1m27wk&hl=en_US

Word Finance (March, 2016): *'Spain's infrastructure woes are more serious than they appear'* http://www.worldfinance.com/infrastructure-investment/government-policy/spains-infrastructure-woes-are-more-serious-than-they-appear

http://www.aci.aero/

http://aeroports.cat/

Chapter seven

Conclusions and Further Research

1. Conclusions and Further Research

As specified in the introduction, the overall research objective of this thesis was to estimate the individual technical efficiency of the Spanish airports, and to determine plausible explanations of the airports' technical inefficiency controllable and not controllable by the airports' management (AENA). At the same time, the use of two differentiated methodological approaches to confirm the robustness of the results in terms of efficiencies and consistency across time. The overall aim has been met by the three specific objectives regarding estimating the individual efficiency levels of the Spanish airports; to conclude potential factors explaining the efficiency scores, and to differ between controllable and non-controllable exogenous variables. The inefficiencies reflect airports' over-capacity since with the current resources the airports could achieve more traffic. These results are aligned with the conclusions of the Court of Auditors of the European Commission (December 2014). On the other hand, the discussion across the different papers and results highlights the inefficiency that could be reduced by AENA (controllable) and the inefficiency due to external factors beyond control.

Regarding the overall outcomes of the five research papers, the individual technical efficiencies show consistency for the most efficient airports (frontier and highly efficient), but there is a discrepancy regarding the less efficient airports depending on the methodology used. Usually, large airports with a significant number of passengers and airports' investments such as Barcelona and Madrid are highly efficient. Additionally, large airports located in touristic popular areas such as the Balearic Islands (Palma de Mallorca and Ibiza) and Canary Islands (Gran Canaria and Lanzarote). Other large airports located in the Mediterranean and the northern coasts, as well as some airports in the islands, show more diversity in their technical efficiency levels. For the rest of the large airports, their efficiency is similar or even lower compared to medium and small airports. The results show activity specialisation having a positive impact in efficiency normally for smaller airports reflecting a better usage of airports' resources including infrastructure. Consequently, the overall results confirm that the system suffers from over-capacity and most of the airports are technically inefficient. The remark to address is regarding the source of inefficiency (due to managerial decisions or external factors) that it may influence the way that airports develop their aeronautical activity.

Methodologies such as centralised DEA and SFA highlight the aeronautical aspect of smaller airports by capturing special features in the way that these airports performed. The results confirm that smaller airports can be technically efficient essentially from a specialisation perspective (for example, general aviation and cargo-oriented activities). These results are confirmed by previous findings with distribution between passengers and cargo influence airports operating efficiency (Coto-Millan et al., 2016). Overall, there are few exogenous factors beyond AENA's managerial control that seem to affect airports' inefficiencies. These have more relevance regarding the geographical location of airports in areas perceived as touristic compared to non-touristic areas. Other environmental variables related to structural characteristics of the airports (e.g. existence of PSOs; airports' capacity) seem not to influence the airports' efficiency. Further analysis is required including other countries with similar networks and government-ownership forms to confirm these research findings. Regarding SFA, when including fixed effects the airports achieve higher technical efficiencies overall. The fixed effects clearly capture individual-firm effects that must be taken into consideration to avoid model misspecifications. For example, the fixed effects analysis shows the requirement of having small airports operating even when are not efficient since they help to the financial aspect of the network. Again, this is supported by airports being specialised rather than performing all the aeronautical activities. Further analysis must be performed to identify other airports that could also have special features not identified at this point. This should be identified by visiting and observing the internal production process of each of the airports and also the physical airports' infrastructure since fixed effects can also be related to the airports' physical aspect.

The DEA results show that when considering one-year framework, large airports tend to be more technically efficient compared to medium and small, but some of the smallest airports perform better than their peers by specialising in other activities rather than civilian transport. These results are also confirmed in a dynamic framework. Large airports located in popular touristic areas are not that highly efficient as it would be expected due to a potential season effect. Other aspects such as punctuality are not evidenced to improve airports efficiency. Usually large airports have more air traffic control restrictions with a higher likelihood of having more delays, but still are technically efficient. Aircraft movements and longest runways are clear drivers of efficiency with a higher impact in larger airports. All the years show the similar relevance of the efficiency and the other factors identified except for punctuality with a significant relevance in 2009; the efficiency dealing with passengers in 2011 and the length of the runways in 2013, where previous significant extensions have been finished during 2012 and are used from 2013. With the exception of some large airports, these results confirm those largest airports have a better usage of their infrastructure thanks to the level of passengers, but not for cargo and general aviation activities. At the same time, smaller airports win from orienting their aeronautical aspect to either cargo or passengers, but not both as previously has been confirmed. The centralised DEA model also confirms these results: large airports being more efficient, but also some of the smallest ones improving from specialisation. The results conclude that not all the inefficient airports must improve the number of passengers to perform better, but cargo or aircraft movements. Although the scaling effects have been taken into consideration by imposing variable returns to scale, the comparison of different sized airports and essentially different environmental features become a limitation of the DEA studies. The requirement of a second-stage DEA should include exogenous features of the airports potentially determined by their physical location. One clear example is the wealth of the region or city where airports are located as well as the geographical location that could enhance more traffic in certain airports compared to other. Potential approaches could be bootstrap DEA

(Simar and Wilson, 2007) or a second-stage DEA regression (McDonald, 2009) to avoid environmental factors being linearly correlated with the efficiency scores (dependent variable). Again, this is essential when not having access to the population, but a sampling distribution is used. Additionally, a second stage procedure allows separating the statistical evidence of the impact of environmental variables on the efficiency scores estimated in the first stage becoming an interesting regulators and policymakers' managerial tool. As previously discussed, another limitation of the DEA studies is the use of ratios (Dyson et al., 2001). At the moment of doing the research, there was no access to further data except for the percentages of flights on time. Delay data have been already collected and used to compare the results obtained in the centralised DEA model. Further references in DEA visualisation will consider these new data.

It is evidenced that airports' specialisation becomes a managerial variable that can help inefficient airports in order to have a better use of their resources and especially their infrastructure that is currently underused. Although this is not a straight option for the Spanish airports' managers airports will increment their efficiency to the extent that AENA allows them to specialise.

The latest two papers show specific external factors not changeable by AENA. The results show that certain airports have advantages by being located in areas and cities considered attractive from a tourist perspective. The geographical location enhances the airports' efficiency for areas having a higher number of hotels. Airports located in areas perceived as touristic, but with other types of accommodation will attract fewer passengers. One clear limitation of this study is the inability to access municipality data and, instead province data were used. Nevertheless, these results were confirmed by the previous findings (paper one to three): airports located in popular tourist destinations such as the Mediterranean and the islands are highly efficient even suffering from a season effect. Exogenous factors more related to the Spanish regulatory framework seem not to affect the level of traffic, except for airports with train facilities to directly access the airports. It seems sensible that most of the passengers would choose them as origin point impacting significantly the overall inefficiency of the rest of airports. Nevertheless, there are currently only five airports with train infrastructure and four of them are large airports potentially offering more routes and choice of prices compared to medium or small airports. Consequently, this could be highlighting an endogeneity matter requiring further research. One of the limitations of the SFA studies when using distance functions are precisely issues of inherent endogeneity. In SFA models the usual assumption made is that inputs are exogenous (Amsler et al., 2016). Although controlling the noise assures reducing the endogeneity effect, it is not clear that distance functions are more appropriate compared to cost functions. The inclusion of fixed effects helps reducing noise, but the inefficiency due to the actual genuine effects (true fixed effects) compared to persistent inefficiency is unknown. On this basis the significant reduction in the overall inefficiency when including fixed effects is expected, but still is not clear if is due to the airports special features. The aims of the SFA performed seem difficult to achieve due to the limited data. Consequently, very sensitive results are expected as shown in the difference in noise parameters and efficiency scores. SFA performs better with higher lambdas, implying lower noise. Therefore, a deterministic approach may be a better option. At the same time significant differences in the value and significance of the rest of the parameters (inputs and outputs) should not be expected. On this basis with the exception of the noise parameters, the results seem consistent when including or excluding fixed effects. The standard procedure used in empirical panel data to discriminate between the fixed and random effects models is the Hausman test (Hausman, 1978)[63]. This test confirms that there are not statistical significant differences in the coefficients of both models (i.e. fixed versus random effects). The idea is to identify if the unobserved heterogeneity is correlated (fixed effects) or uncorrelated (random effects) with the regressors (Greene, 2005). Although the likelihood ratio test has been performed in the SFA studies to determine that the model chosen is closer to the real data than the alternative (Vuong, 1989) and more than several tests to confirm the presence of fixed effects (e.g. STATA commands), further endogeneity tests seems to be required. The alternative option to control and to avoid endogeneity is using a cost function. On this basis, an overall cost value could be used rather than individual costs and to measure allocative efficiency rather than technical efficiency. Nevertheless, the researcher has found a limitation in data as previously discussed since there is no public information about inputs and most of the outputs prices. Additionally, the output prices are externally determined by AENA rather than airports' operators (AENA, 2018). On this basis considering the commercial revenues as one of the outputs could enhance certain airports to be more efficient in detriment than others.

Another limitation of parametric SFA models is the lost in flexibility since the functional form of the production frontier function as well as the distribution of the inefficiency term and noise are specified. The restrictive formulation of stochastic production functions has been criticised as a major deficiency in SFA models (Simar and Wilson, 2015). There are no apparently constraints to choose one distributional form over other (Coelli et al., 1998) however the parametric should assure reflecting the true performance of the units of analysis. On this basis, the truncated normal distribution seems to be the most adequate since most of the airports are expected to have inefficiency different from zero. Additionally, the number of airports operating efficiently across the sample can vary.

As previously stated, the findings when performing the stochastic frontier analysis have revealed that the flatness of the likelihood functions used in SFA made lead to model misspecifications due to providing different values of parameters (solutions) and the difficulties in finding significant effects of the environmental variables due to the low power of test.

[63] This approach is also used by Durbin (1954) and Wu (1973).

As part of additional tests performed include more than several SFA models (Battese and Coelli, 1988, 1992; 1995; Kumbhakar, 1990); different values of depreciation and useful life of the assets (e.g. considering airside and landside assets altogether; separately or using only one of them at time); runways as an usual input and semi-fixed input in the production function (Pels et al., 2003) and testing the exogenous nature of the environmental variables by including them in the production function, and/or the inefficiency term (Coelli et al., 1999). Additionally, different outputs based on a combination of raw data such as workload units (Martin-Cejas, 2002; Martin et al. 2009 and 2011) or aircraft size (Tovar and Marti-Cejas, 2009 and 2010). Finally, certain airports with different production function have been removed from the database (i.e. heliports and general aviation airports) and potential outliers (i.e. Barcelona and Madrid). Beyond the technical constraint of the software, the limitations of the methodological approach are the consequence of the inability of the researcher to access further and updated information.

To sum up, except for certain large airports considered mavericks and the large airports located in popular touristic areas, the overall results confirm that most of the airports are technically inefficient and suffer from overcapacity. The specific second and third objectives are clearly answered by highlighting aeronautical aspects of the Spanish airports that can be changed in order to improve their efficiency. Therefore, these are managerial factors that AENA can influence.

The quality and the reliability of the data is a clear matter. Although the estimated cost of capital used in the studies shows a significantly lower correlation with the operating costs, it is not clear if the labour and capital costs are a fair reflection of the Spanish airports' costs. As previously discussed, there is no information regarding the type of labour being essential to access information in terms of full-time and full-time equivalent employees. Additionally, the latest year with individual financial data refers to 2013. It is evidenced that based on the economic regulatory framework discussed in the introduction, the DORA regulation will enhance a more transparent process in establishing airport charges. Nevertheless, the slot allocation remaining a concern, and the strong centralised management unlikely to change evidence that the results would not change significantly even if more update data were available.

In order to extrapolate the results and essentially to confirm the adequacy of the methodologies uses, it is required comparing the Spanish airports with other similar airports regarding ownership-management forms. This is as long as there is enough information (disclosures) for the data to be converged and to avoid model misspecifications. One potential case is Norway with a significant amount of government-owned airports managed by a government-owned company (AVINOR). Although airports managers seem to have flexibility regarding the decision making process compared to the Spanish airports' operators. On this basis, the impact of a strong centralised management versus a more flexible management could be analysed to provide managerial recommendations in terms of decentralisation.

Regarding new methodological approaches, a network DEA will be considered in future research papers (Färe and Grosskopf, 1996 and 2000). The main idea is to identify diversified airports' operations that may imply different inputs and generate intermediate outputs from time separable dynamic stages (e.g. aircraft movements and aircraft loading). Additionally, more empirical evidence regarding the robustness of the SFA models is required. As previously discussed there are more than several models for panel data, but few empirical cases are considered. Benchmarking with other countries with a similar regulatory framework are to be performed using SFA as the main methodological approach, but controlling endogeneity. For example, current work in progress includes relevant external factors related to airports' operators rather than the physical aspect of the airports. These refer to managerial skills; as well as experience and background of the airports' managers comparing Spanish and Polish airports, and the impact of a different degree of management centralisation.

In this Thesis, exogenous factors have been enclosed under the assumption of not being controlled by AENA. Nevertheless, further external factors relatively changeable should be accounted for. One clear example is the number and type of low cost carriers (LCCs) and their impact on the overall efficiency. Previous studies in the Spanish airports have confirmed the association between low cost carriers and a specific type of efficiency such as scale (Coto-Millan et al., 2014) or with the productivity of the largest British airports (Bottasso et al., 2012). The increasing demand for air traffic due to the presence of low cost carriers could explain the overall efficiency of some of the regional airports (medium and small).

The future research will underpin further managerial and policymakers' recommendations. At this point, the latest paper (work in progress) provides some insights in terms of closure recommendations, but these must be settled considering regional characteristics and individual needs. Airports may have a development impact in the related regional areas sustaining the employment and the economic growth of isolated or remote areas or areas where there are limited sectors as the main source of income. The profitability performance and the technical efficiency as managerial variables to decide closing airports should be carefully considered. Further analysis is essential, but it will depend upon having relevant and reliable information of how airports work: which physical and intangible resources the Spanish airports really have and which are really used from the aeronautical perspective.

References

Abbott, M. and Wu, S. (2002): 'Total Factor Productivity and efficiency of Australian airports' *Australian Economic Review* 35 (3), 244-60

Adler, N. and Berechman, J. (2001): 'Measuring airport quality from the airlines' viewpoint: an application of data envelopment *analysis' Transport Policy* 8, 171-181

Aigner, D.; Lovell, C.A.K. and Schmidt, P. (1977): 'Formulation and estimation of stochastic frontier production models' *Journal of Econometrics* 6 (1), 21-37

Amsler, C.; Prokhorov, A. and Schmidt, P. (2016): 'Endogeneity in stochastic frontier models' *Journal of Econometrics* 190, 280-288

Andreatta, G.; Capanna, L.; De Giovanni, L.; Monaci, M. and Righi, L. (2014): 'Efficiency and robustness in integrated airport apron, a support platform for intelligent airport ground handling' *Journal of Intelligent Transportation Systems,* 18 (1) 121–130

Ashford, N.; Stanton, H. and Moore, C. (1996): *'Airport Operations'* NewYork, McGraw-Hill Education (second edition)

Asmild, M. and Pastor, J. T. (2010): 'Slack free MEA and RDM with comprehensive efficiency measures' *Omega* 38(6), 475–483

Assaf, A. (2010a): 'Bootstrapped scale efficiency measures of UK airports' *Journal of Air Transport Management* 16 (1), 42–44

Assaf, A. (2010b): 'The cost efficiency of Australian airports post privatization: a Bayesian methodology' *Tourism Management* 31 (2), 267–273

Banker, R. D. (1993): 'Maximum Likelihood, consistency and Data Envelopment Analysis: a statistical foundation' *Management Science* 39 (10), 1265 - 1273

Banker, R.D.; Charnes, A. and Cooper, W.W. (1984): 'Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis' *Management Science* (30), 1078 – 1092

Banker, R. D. and Morey, R. C. (1986): 'Efficiency analysis for exogenously fixed inputs and outputs'. *Operations Research* 34, 513-521

Barros, C.P. (2008a): 'Technical change and productivity growth in airports: A case study' *Transportation Research part A* 42, 818-832

Barros, C.P. (2008b): 'Technical efficiency of UK airports' *Journal of Air Transport Management* 14 (4), 175–178

Barros, C.P. (2009): 'The measurement of efficiency of UK airports, using a stochastic latent class frontier model' *Transport Reviews* 29 (4), 479-98

Battese, G.E. and Coelli, T. J. (1988): 'Prediction of Firm-level technical efficiencies with a generalized frontier production function and panel data' *Journal of Econometrics* 38, 387-399

Battese, G.E. and Coelli, T. J. (1992): 'Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India'. *Journal of Productivity Analysis* 3, 153-169

Battese, G.E. and Coelli, T. J. (1993): ‘A Stochastic Frontier Production Function incorporating a model for technical inefficiency effects’ *Working Papers in Econometrics and Applied Statistics* 69, Department of Econometrics, University of New England.

Battese, G.E. and Coelli, T. J. (1995): ‘A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data’ *Empirical Economics* 20, 325-332

Bazargan, M. and Vasigh, B. (2003): ‘Size versus efficiency: a case study of US commercial airports’ *Journal of Air Transport Management* 9, 187-193

Bennell, J. A.; Mesgarpour, M. and Potts, C. N. (2011): ‘Airport runway scheduling’ *Annals of Operations Research* 204, 249–270

Bottasso, A.; Conti, M. and Piga, C. (2012): ‘Low-cost carriers and airports’ performance: empirical evidence from a panel UK airports’ *Industrial and Corporate Change* 22(3), 745-769

Castelli, L.; Pesenti, R. and Ranieri, A. (2011): ‘The design of a market mechanism to allocate Air Traffic Flow Management slots’ *Transportation Research Part C* 19 (5), 931–943

Charnes, A.; Cooper, W. W.; Rhodes, E. (1978): ‘Measuring the efficiency of decision making units’. *European Journal of Operational Research* 2, 429-444

Charnes, A.; Cooper, W. W.; Golany, B.; Seiford, L. & Stutz, J. (1985): ‘Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions’. *Journal of Econometrics* 30, 91-107

Charnes, A., S. Haag, P. Jaska, and J. Semple (1992) 'Sensitivity of efficiency classifications in the additive model of Data Envelopment Analysis' *International Journal of Systems Science* 23, 789-798

Cooper, W. W.; Kyung, S.P. and Pastor, J. T. (1999): ‘RAM: a range adjusted measure of inefficiency for use with additive models, and relations to other models and measures in DEA’. *Journal of Productivity Analysis* 11, 5-42

Cornwell, C.; Schmidt, P. and Sickles, R. (1990): ‘Production frontiers with cross-sectional and time-series variation in efficiency levels’ *Journal of Econometrics* 46, 185-200

Cuesta, R. A., Lovell, C. A. K. and Zofio, J. L., (2009): ‘Environmental efficiency measurement with translog distance functions: A parametric approach’ *Ecological Economics* 68, 2232-2242

D’Ariano, A.; Pistelli, M. and Pacciarelli, D. (2012): ‘Aircraft retiming and rerouting in vicinity of airports’ *IET Intelligent Transport Systems* 6 (4), 433–443

Debreu, (1951): ‘The coefficient of resource utilization’ *Econometrica* 19, 273-292

Durbin, J. (1954): ‘Errors in Variables’ *Review of the International Statistical Institute* 22, 23-32

Dyson, R.G.; Allen, R.; Camanho, A.S.; Podinovski, V.V.; Sarrico, C.S. and Shale, E.A. (2001): ‘Pitfalls and Protocols in DEA’ *European Journal of Operational Research* 132, 245-259

Farrell, M. J. (1957): 'The Measurement of Productive Efficiency' *Journal of Royal Statistical Society* Series A 120(3), 253 – 290

Färe, R. (1991): 'Measuring Farrell efficiency for a firm with intermediate inputs' *Academia Economic Papers*, 329-340

Färe, R. and Grosskopf, S. (1996): 'Productivity and intermediate products: A frontier approach' *Economics Letters* 50, 65-70

Färe, R., Grosskopf, S. (1996): *'Intertemporal Production Frontiers: With Dynamic DEA'* Kluwer Academic Publishers, Boston, London and Dordrecht.

Färe, R. and Grosskopf, S. (2000): 'Network DEA' *Socio-Economic Planning Sciences* 34(1), 35-49

Färe, R. and Lovell, C.A.K. (1978): 'Measuring the Technical Efficiency of Production' *Journal of Economic Theory* 19(1), 150–162

Färe R. and Grosskopf S. (1996): *'Intertemporal Production Frontiers: With Dynamic DEA'* Kluwer Academic Publishers, Boston

Fernandes, E. and Pacheco, R. R. (2002): 'Efficient use of airport capacity' *Transportation Research Part A* 36 (3), 225-38

Fung, M.K.Y.; Wan, K.K. H.; Hui, Y.V. and Law, J.S. (2008): 'Productivity Changes in Chinese Airports 1995-2004' *Transportation Research Part E* 44 (3), 521-542

Gardi, A.; Sabatini, R. and Ramasamy, S. (2016): 'Multi-objective optimisation of aircraft flight trajectories in the ATM and avionics context' *Progress in Aerospace Science* 83 (1), 1–36

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

Greene, W. (2003): *'Econometric Analysis'* Prentice Hall, Englewood Cliffs 5th Edition

Greene, W. (2005) 'Reconsidering heterogeneity in panel data estimators of the stochastic frontier model' *Journal of Econometrics* 126, 269-303

Greene, W. (2005): 'Fixed and Random Effects in Stochastic Frontier Models' *Journal Productivity Analysis* 23(1), 7-32

Gutierrez-Nieto, B.; Serrano-Cinca, C. & Mar-Molinero, C. (2007): 'Microfinance institutions and efficiency' *Omega. The International Journal of Management Science* 35, 131-142

Hausman, J.A. (1978): 'Specification tests in Econometrics' *Econometrica* 46, 1251-1271

Hausman, J.A. and Taylor, W.E. (1981): 'Panel data and unobservable individual effects' *Econometrica* 49, 1377-1398

Humphreys, I. (1999): 'Privatisation and commercialisation Changes in UK airport ownerships patterns' *Journal of Transport Geography* 7, 121-134

Jondrow, J.; Lovell, C.A.K.; Materov, I.S. and Schmidt, P. (1982): 'On the estimation of technical inefficiency in the stochastic frontier production function model' *Journal of Econometrics* 19(2-3), 233-238

Kim, J.; Kroeller, A. and Mitchell, J. (2009): 'Scheduling aircraft to reduce controller workload' doi: 10.4230/OASIcs.ATMOS.2009.2144 (last accessed August 2018)

Koopmans, T.C. (1951): 'Analysis of production as an efficient combination of activities' in Koopmans, T.C. (Ed.): *'Activity Analysis of Production and Allocation'* John Wiley, New York.

Kumbhakar, S.C. (1990): 'Production frontiers, panel data and time varying technical inefficiency' *Journal of Econometrics* 46, 201-2012

Kumbhakar, S.C.; Lien, G. and Hardaker, J.B. (2014): 'Technical efficiency in competing panel data models. A study of Norwegian grain farming' *Journal of Productivity Analysis* 41, 321-337

Kuosmanen, T. (2005): 'Weak Disposability in Nonparametric Production Analysis with Undesirable Outputs' *American Journal of Agricultural Economics* 87(4), 1077-1082

Lee, Y.H. and Schmidt, P. (1993): 'A production frontier model with flexible temporal variation in technical efficiency' in Fried, H.O.; Lovell, C.A.K. and Schmidt, P. (eds.) '*The Measurement of Productive Efficiency: Techniques and Applications'*, New York: Oxford University Press.

Malmquist, S. (1953): 'Index numbers and indifference surfaces' *Trabajos de Estadistica* 4, 209–242

Martin J.C. and Roman, C. (2001): 'An application of DEA to measure the efficiency of Spanish airports prior to privatization' *Journal of Air Transport Management* 7(3), 149-157

Martin, J.C. and Roman, C. (2006): 'Benchmarking analysis of Spanish commercial airports: A comparison between SMOP and DEA ranking methods' *Networks and Spatial Economics* 6 (2), 111-34

Martin, J.C.; Roman, C. and Voltes-Dorta, A. (2009): 'A stochastic frontier analysis to estimate the relative efficiency of Spanish airports' Journal of Productivity Analysis 31, 163–176

Martin-Cejas (2002): 'An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier' *Journal of Air Transport Management* 8, 233-238

Meeusen, W. and van der Broeck, J. (1977): 'Efficiency estimation from Cobb-Douglas production functions with composite error' *International Economic Review* 18, 435-444

McDonald, J. (2009): 'Using least squares and Tobit in second stage DEA efficiency analysis' *European Journal of Operational Research* 197 (2), 792-798

Neyman, J. and Scott, E.L. (1948): 'Consistent estimation from partially consistent observations' *Econometrica* 16, 1-32

Nyshadham, E.A. and Rao, V.K. (2000): 'Assessing Efficiency of European Airports. A Total Factor Productivity Aproach' *Public Works Management and Policy* 5(2), 106-114

Olesen, O.B.; Petersen, N.C. and Podinovski, V.V. (2015): 'Efficiency analysis with ratio measures' *European Journal of Operational Research* 245(2), 446-462

Oum T.H.; Yan, J and Yu Ch. (2008): 'Ownership forms matter for airport efficiency: a stochastic frontier investigation of worldwide airports' J Urban Econ 64, 422–435

Pels, E.; Nijkamp, P. and Rietveld, P. (2001): 'Relative efficiency of European airports' *Transport Policy* 8, 183-192

Pels, E.; Nijkamp, P. and Rietveld, P. (2003): 'Inefficiency and scale economies of European airports operations' *Transportation Research Part E: Logistics and Transportation* 39, 341-361

Pinol, H. and Beasley, J.E. (2006): 'O.R. Applications. Scatter Search and Bionomic Algorithms for the aircraft landing problem' *European Journal of Operational Research* 171, 439-462

Pitt, M. and Lee, L. (1981): 'The measurement and sources of technical inefficiency in Indonesian weaving industry' *Journal of Development Economics* 9, 43–64

Ripoll-Zarraga, A.E. (2017): 'The Spanish airport-system: critical evaluation of the effectiveness of the Spanish government's management of public resources'. *The Public Sphere Journal of Public Policy*, February 2017, 221-254 ISSN 2056-533X (Institute of Public Affairs London School of Economics and Political Science) http://publicspherejournal.com/latest-issue/

Ripoll-Zarraga, A.E. (2018): 'Can airports' inefficiency be determined by tourism variables?' Operational Research Society Journal *Inside O.R.* March/2018

Ripoll-Zarraga, A.E. (2018): 'Airports' productivity and capacity: the case of the Spanish airport system' *Funcas Working Papers* (expected submission April 2018)

Ripoll-Zarraga, A.E. and Mar-Molinero, C. (2017): 'Spanish airports: a visual study of management efficiency' *Funcas Working Papers* 2017/791 (September) Citation: *Boletín de Documentación de Transporte* (October, 2017), 349 Spanish Government http://www.fomento.gob.es/AZ.BBMF.Web/documentacion/pdf/349.pdf

Ripoll-Zarraga, A.E.; Portillo, F. and Mar-Molinero, C. (2017): 'DEA efficiency in Spanish Airports: a time evolution analysis' *Funcas Working Papers* 2017/794 (December)

Ripoll-Zarraga, A.E. and Lozano, S. (2018): 'A centralised DEA approach to resource reallocation in Spanish airports' Working Paper

Ripoll-Zarraga, A. E. and Raya, J.M. (2018): 'Can airports' inefficiency be determined by tourism variables?' *Funcas Working Papers* 2018/795 (January); *Inside O.R.* 2018/567 (March)

Russell, R.R. (1985): 'Measures of technical efficiency' *Journal of Economic Theory* 35, 109-126

Sagarra, M.; Mar-Molinero, C. and Agasisti, T. (2017): 'Exploring the efficiency of Mexican universities: integrating Data Envelopment Analysis and Multidimensional Scaling' *Omega* 67, 123-133

Samà, M.; D'Ariano, A. and Pacciarelli, D. (2013): 'Rolling horizon approach for aircraft scheduling in the terminal control area of busy airports' *Transportation Research Part E* 60 , 140–155

Sarkis, J. and Talluri, S. (2004): 'Performance-Based Clustering for Benchmarking of US Airports' *Transportation Research Part A* 38, 329-346

Serrano-Cinca, C.; Mar-Molinero, C. and Chaparro F. (2004): 'Spanish saving banks: a view of intangibles' *Knowledge Management Research and Practice* 2(2), 103-117

Serrano-Cinca, C.; Mar-Molinero, C. and Fuertes, Y. (2016): 'Input and output search in DEA: the case of financial institutions'. Chapter 3 in *'Handbook of operations analytics using Data Envelopment Analysis'* Hwang, S.N.; Lee, H.S. and Zhu, J. Editors, Springer. New York.

Simar, L. and Wilson, P.W. (1998): 'Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models' *Management Science* 44(1), 49-61

Simar, L. and Wilson, P.W. (2007): 'Estimation and inference in two-stage, semi-parametric models of production processes' *Journal of Econometrics* 136, 31–64

Simar, L. and Wilson, P. W. (2015): 'Statistical approaches for nonparametric frontier models: A guided tour' *International Statistical Review* 83, 77-110

Schmidt, P. and Sickles, R. (1984): 'Production frontiers and panel data' *Journal of Business and Economics Statistics* 2 (4), 367-374

Stevenson, R.E. (1980): 'Likelihood functions for generalized stochastic frontier estimation' *Journal of Econometrics* 13(1), 57-66

Tone, (2001): 'A slacks-based measure of efficiency in Data Envelopment Analysis' *European Journal of Operational Research* 130, 498–509

Von Hirschhausen, C. and Cullmann, A. (2005): 'Questions to Airport Benchmarkers. Some Theoretical and Practical Aspects Learned from Benchmarking Other Sectors' *Efficiency Analysis Working Papers* WP-EA-03 Dresden University of Technology and DREWAG-Chair for Energy Economics

Vuong, Q.H. (1989): 'Likelihood ratio tests for model selection and non-nested hypotheses' *Econometrica* 57(2), 307–333

Wang, H. and Schmidt, P. (2002): 'One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels' *Journal Productivity Analysis* 18, 129-144

Wanke, P.; Barros, C. P. and Nwaogbec, O.R. (2016): 'Assessing productive efficiency in Nigerian airports using Fuzzy-DEA' *Transport Policy* 49, 9–19

Wilson, P. (1995): 'Detecting influential observations in Data Envelopment Analysis' *Journal of Productivity Analysis* 6, 27 – 45.

Wu, D. (1973). 'Alternatives tests of independence between stochastic regressors and disturbances' *Econometrica* 41, 733-750

Yu M.-M.; Chern, Ch.-Ch. and Hsiao, B. (2013): 'Human resource rightsizing using centralized data envelopment analysis: Evidence from Taiwan's Airports' *Omega* 41, 119–130

Zhu, J. (1996) 'Robustness of the efficient DMUs in Data Envelopment Analysis' *European Journal of Operations Research* 90, 451-460

Reports

ACETA (2011): 'Estudio y Analisis sobre el incremento de las tasas aeroportuarias en aviacion general y en la formacion de pilotos profesionales' http://aviaciondigital.com/incremento-de-tasas-aeroportuarias-en-aviacion-general-y-formacion-de-pilotos/

http://www.aviaciondigitalglobal.com/newsFiles/20110622011312-4.pdf

ACI (2018): 'Policy Brief. Creating fertile grounds for private investment in airports' https://aci.aero/about-aci/priorities/economics/documentation/

ACI Europe (2010): 'The Ownership of Europe's Airports'

ACI Europe (2012): 'Economics Report 2012'

ACI Europe (2015): 'ACI Europe Position Paper on Airport Capacity'

AENA (2018): 'Price Guide 2018. Basic Airport Services' http://www.aena.es/en/airlines/tariffs.html (last accessed March 2018)

BAA airports market investigation (CC). Competition Commission https://www.gov.uk/cma-cases/baa-airports-market-investigation-cc

Boletín Oficial del Estado BOE-A-1991-15530 (BOE, 18th of June 1991) https://www.boe.es/buscar/act.php?id=BOE-A-1991-15530

Boletín Oficial del Estado BOE-A-2011-4116 (BOE, 5th of March 2011) https://www.boe.es/buscar/doc.php?id=BOE-A-2011-4116

Boletín Oficial del Estado BOE-A-2011-14221 (BOE, 26th of August 2011) https://www.boe.es/buscar/doc.php?id=BOE-A-2011-14221

Boletín Oficial del Estado BOE-A-2011-9926 (BOE, 7th of June 2011) https://www.boe.es/diario_boe/txt.php?id=BOE-A-2011-9926

Boletín Oficial del Estado BOE-A-2014-10517 (BOE, 15th of October 2014) https://www.boe.es/buscar/act.php?id=BOE-A-2014-10517

Boletín Oficial del Estado BOE-A-2017-2052 (BOE, 20th of February 2017)

https://www.boe.es/buscar/doc.php?id=BOE-A-2017-2052

Boletín Oficial del Estado BOE-A-2013-5940 (BOE, 4th of June 2013) ttps://www.boe.es/buscar/doc.php?id=BOE-A-2013-5940

Boletín Oficial del Estado FOM/1050/2014 (BOE, 17th of June 2014) https://www.boe.es/diario_boe/txt.php?id=BOE-A-2014-6509

Comisión Nacional de los Mercados y la Competencia (CNMC, July 2014): 'El Sector Aeroportuario en España: Situación Actual y Recomendaciones de Liberización'

'Documento de Regulación Aeroportuaria' (DORA 2017-2021, January 2017) https://www.seguridadaerea.gob.es/lang_castellano/aeropuertos_2/dora/default.aspx

Council Regulation (January 1993): 'Regulation EEC 95/93 on common rules for the allocation of slots at Community airports' https://ec.europa.eu/transport/modes/air/airports/slots_en

European Commission (March 2009): 'Directive 2009/12/CE' https://publications.europa.eu/en/publication-detail/-/publication/b3f91d83-d246-449e-888f-4665d194b3f2/language-en

European Commission (April 2004): 'Regulation EC 793/2004 on common rules for the allocation of slots at Community airports' https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32004R0793

European Commission (March 2011): 'Flightpath 2050. Europe's Vision for Aviation' https://ec.europa.eu/transport/sites/transport/.../flightpath2050.pdf

European Commission European Court of Auditors (2014): 'EU-funded airport infrastructures: poor value for money' Special Report, 21 http://www.politico.eu/article/eu-wasted-money-on-new-airports-say-auditors/

European Commission Press release (July 2016): 'State aid: Commission orders Spain to recover incompatible State aid for high speed train test centre from railway operator ADIF' http://europa.eu/rapid/press-release_IP-16-2621_en.htm

Steer Davies Gleave (September 2013): 'Evaluation of Directive 2009/12/EC on airport charges' https://travelsdocbox.com/Air_Travel/73787342-Evaluation-of-directive-2009-12-ec-on-airport-charges.html

IATA https://www.iata.org/policy/Documents/single-till.pdf

IATA (January 2018): 'Worldwide Slot Guidance' (WSG) https://www.iata.org/policy/slots/Pages/slot-guidelines.aspx

International Civil Aviation Organization ICAO (2006): 'Airport Economics Manual' Doc. 9562 https://www.icao.int/sustainability/Documents/Doc9562_en.pdf

International Civil Aviation Organization (ICAO) (March 2013): 'Worldwide Air Transport Conference (ATCONF) Sixth meeting: Airport Competition' https://www.google.com/maps/d/viewer?mid=zylWTnxRlUJE.kU5cVv1m27wk&hl=en_US

Word Finance (March, 2016): 'Spain's infrastructure woes are more serious than they appear' http://www.worldfinance.com/infrastructure-investment/government-policy/spains-infrastructure-woes-are-more-serious-than-they-appear

Conferences; Professional Bodies and Institutional Bodies

http://www.AENA.es/

http://aeroports.cat/

http://www.aceta.es/

http://www.aci.aero/

http://www.atrsworld.org/

https://www.cnmc.es/en

http://www.cost.eu/COST_Actions/tud/TU1408 and https://www.atard-online.com/

http://deazone.com/en/

https://www.eac-conference.com/

https://ec.europa.eu/programmes/horizon2020/h2020-sections

http://ewepa.org/conferences/london2017/

http://www.funcas.es/

www.garsonline.de

ww.gencat.cat

https://www.iata.org/pages/default.aspx

https://www.icao.int/Pages/default.aspx

http://www.theorsociety.com/

Online Newspapers

http://diarigran.cat/

http://www.diariodeleon.es/

http://www.europapress.es/turismo/transportes/aeropuertos/noticia-abalos-no-hay-intencion-interes-privatizar-mas-aena-20180713140608.html

Online Journals

http://www.theorsociety.com/Pages/Publications/InsideOR.aspx

http://publicspherejournal.com/

Journal Citation Lists

2017 Journal Citation Reports (JCR)
http://images.info.science.thomsonreuters.biz/Web/ThomsonReutersScience/%7Bda895e0c-0d4f-44f2-a6d5-6548d983a79f%7D_M151_Crv_JCR_Full_Marketing_List_A4_FA.pdf

2015 The Association of Business Schools (ABS) Academic Journal Quality Guide
http://www.kfs.edu.eg/com/pdf/20820152253917.pdf

2016 SCImago Journal Rank (SJR) http://www.scimagojr.com/journalrank.php

Higher Education Institutions and Research Centres

http://www.aston.ac.uk/aston-business-school/research/departments/oim/

https://www.etsi.us.es/

https://www.hs-bremen.de/internet/en/index.html

https://www.kent.ac.uk/kbs/business/

https://www.tecnocampus.cat/ca/presentacio-eum

http://www.uab.cat/economia-empresa/

https://www.unirioja.es/dptos/dee/index.shtml

Case Studies and Dissemination Articles

Ripoll-Zarraga, A.E. (2017): 'The Spanish airport-system: critical evaluation of the effectiveness of the Spanish government's management of public resources'. The Public Sphere Journal of Public Policy, February 2017, 221-254 ISSN 2056-533X (Institute of Public Affairs London School of Economics and Political Science)

Ripoll-Zarraga, A.E. (2018): 'Can airports' inefficiency be determined by tourism variables?' Operational Research Society Journal Inside O.R. March/2018

Appendix

Table A1 Airports' Codes

Code	Airport
LCG	A Coruña
ABC	Albacete
ALC	Alicante
LEI	Almeria
OVD	Asturias
BJZ	Badajoz
BCN	Barcelona
BIO	Bilbao
RGS	Burgos
JCU	Ceuta
ODB	Cordoba
VDE	El Hierro
FUE	Fuerteventura
GRO	Girona
LPA	Gran Canaria
GRX	Granada-Jaen
HSK	Huesca
IBZ	Ibiza
XRY	Jerez
GMZ	La Gomera
SPC	La Palma
ACE	Lanzarote
LEN	Leon
RJL	Logroño
MAD	Madrid-Barajas
MCV	Madrid-Cuatro-Vientos
TOJ	Madrid-Torrejon
AGP	Malaga
MLN	Melilla
MAH	Menorca
MJV	Murcia
PMI	Palma de Mallorca
PNA	Pamplona
REU	Reus
QSA	Sabadell
SLM	Salamanca
EAS	San Sebastian
SDR	Santander
SCQ	Santiago
SVQ	Sevilla
TFN	Tenerife North
TFS	Tenerife South
VLC	Valencia
VLL	Valladolid
VGO	Vigo
VIT	Vitoria
ZAZ	Zaragoza

Airports	Labour	Operating	PAX	ATM	Cargo	Commer. Revenues	Flights Delayed > 30'	Minutes Delayed
A Coruña	-548.65	0	0	9,618.17	31,779,301	298.18	-20.92	-1,907.30
Almeria	-677.04	-5.57	0	25,742.44	9,707,110	251.11	-15.13	-2,412.26
Asturias	-861.74	0	0	18,057.83	28,104,293	337.19	-1.12	-832.30
El Hierro	-544.82	-403.61	0	914.70	0	209.06	-4.69	-301.09
Girona-Costa Brava	0	0	0	0	34,307,595	0	-26.22	0.00
La Palma	-376.01	-1,183.16	0	9,414.18	42,977,763	768.25	-1.90	-23.79
Leon	-140.17	0.00	4,354	0.00	7,218,515	56.86	-0.02	0.00
Malaga	-783.23	0.00	463,130	0.00	51,116,555	0.00	-134.10	-33,155.82
Menorca	-1,004.31	0.00	0	2,868.38	60,291,590	1,324.45	-11.03	-3,229.89
Pamplona	-480.13	0	0	24,213.37	14,449,657	326.79	-0.11	0.00
Reus	-294.48	0	0	7,941.14	33,490,904	513.31	-11.36	-2,214.00
Santiago	-1,112.61	-881.00	0	24,374.21	8,550,320	0.00	-3.89	0.00
Valencia	0	0	503,471	0	9,176,875	0	0	-2,688.22
Valladolid	0.00	-1,299.99	0	1,016.20	26,368,667	384.45	0	-32.27
Vigo	-793.68	0.00	0	15,380.87	16,780,390	154.50	0	0.00
Sum	**-7,616.81**	**-3,773.34**	**970,955**	**139,541.49**	**374,319,533**	**4,624.14**	**-230.48**	**-46,796.95**
(%)	**(2.54%)**	**(0.00%)**	**(0.52%)**	**(7.79%)**	**(58.58%)**	**(0.73%)**	**(3.73%)**	**(5.26%)**

Table A2 Centralised DEA results without Percentages of Flights on Time