Competition and regulation (when lacking the former) outrank ownership form in generating airport efficiency

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First Draft: 20th November 2010. Please do not quote but comments would be gratefully received.

Abstract

The combined impact of ownership form, economic regulation and competition on airport performance is analyzed using data envelopment analysis in a first stage efficiency measurement and regression analysis in a second stage environmental study. The results of an analysis of European and Australian airports prove to be stable across spatial and robust cluster regression models and show that airports not facing regional or hub competition and partially private airports with a majority public ownership structure should be regulated. However, in a competitive setting, economic regulation inhibits both public and major or fully private airports from operating efficiently. Furthermore, airport productivity has decreased over the past decade, indicating that regulation is repeatedly incorrectly applied.

Keywords: airport efficiency, data envelopment analysis, robust cluster and spatial regression, ownership form, regulation, competition

1 Introduction

Traditionally, airports were mostly deemed state-owned entities and viewed as natural monopolies hence were subject to economic regulation in order to prevent abuse of market power. However, the nature of the airport industry has changed over the last two decades. Moving away from viewing the airport as a public utility, governments are now interested in encouraging the efficient utilization of infrastructure through the development of appropriate market conditions. A number of privatization processes have been actively promoted by governments with the proclaimed intention of reducing government involvement and increasing airport productivity and innovation. However, given the assumed natural behaviour of private companies working in a monopolistic environment, the majority of privatized airports in Europe remain subject to economic regulation. Whilst some studies have analyze the impact of ownership form, regulatory regime and levels of airport competition on efficiency, none have analyzed their joint impact. In other words, the literature has yet to discuss whether the deregulation of the airline industry and changes in airport ownership and management has affected the competitive situation and airport productivity to the extent that the benefits of economic regulation are potentially unnecessary. For example, deregulation has led to increased competition between gateway hubs (e.g. Frankfurt and Amsterdam) and former military airports have opened to serve low cost carriers (e.g. Hahn in Germany), substantially changing the downstream airline market and potentially impacting the airport market too. Furthermore, as a result of increasing commercialization, many airports have augmented their revenues from non-aeronautical sources in order to cross-subsidize aviation charges and attract additional airlines and passengers to their airport (Zhang and Zhang 2010). The aim of this research is therefore to analyze the impact of the structural changes in the aviation markets on airport productivity in order to further our understanding of the most appropriate ownership form and regulatory regime given the competitive market level at a specific airport.

Performance measurement may serve multiple purposes, as outlined by Oum et al. (1992). It may assess the productivity or efficiency of units within or across companies or industries and identify best-practice standards. Furthermore, the availability of panel data permits the measurement of changing levels of productivity over time. Although the instrument of performance measurement was applied in other transport sectors and regulated utilities in the nineteen seventies, it only became of primary importance in the airport industry twenty years later. This may be partly explained by the unique character of the airport systems causing problems of comparability (Forsyth 2000). Graham (2005) argues that the increasing interest in airport benchmarking is a result of the changes in ownership that began in 1987 with the privatization of BAA and the liberalization, commercialization and globalization trends which have influenced airport business growth, complexity and competitiveness.

Three well-documented quantitative methods have been applied to analyze the productivity and efficiency of government and private enterprises. A non-parametric, index number approach has been used to measure total factor productivity (Caves, Christensen and Diewert 1982), however this approach requires input and output prices and quantities which are not always available. Parametric stochastic frontier analysis (SFA) assesses efficiency utilizing regression analysis and disentangles unobservable random error from technical inefficiency (Aigner, Lovell and Schmidt 1977; Meeusen and van den Broeck 1977) based on assumptions as to the distributional forms of the efficiency function and error term. Non-parametric data envelopment analysis (DEA), based on linear programming, categorizes data into efficient and inefficient groups hence produces weaker results than those of SFA, but does not require assumptions with respect to a functional form therefore is chosen for the purposes of this study. Airport studies of efficiency utilizing all three approaches are reviewed in Liebert (2010).

Various environmental variables that, at least in the short-term, are beyond managerial control may contribute to the DEA efficiency estimates. Previous research argues that airport characteristics such as hub status or traffic structure, outsourcing policies, regulatory procedures and institutional settings with respect to ownership structure all may contribute to airport productivity (Gillen and Lall 1997; Oum et al. 2006). Assessing the importance of the environment on the efficiency estimates may be undertaken utilizing either non-parametric Mann-Whitney and Kruskal-Wallis tests or parametric regression. Banker and Natarajan (2008) demonstrate that two-stage procedures in which DEA is applied in the first stage and regression analysis in the second stage provide consistent estimators and outperform parametric one- or two-stage applications. Published airport studies apply the (censored) Tobit regression (e.g. Gillen and Lall 1997; Abbott and Wu 2002), simple ordinary least squares (Chi-Lok and Zhang 2009) and truncated regression (Barros 2008) for this purpose. A recent debate in the literature discusses the most appropriate second stage regression model to be applied when investigating DEA efficiency estimates. Simar and Wilson (2007) argue that truncated regression, combined with bootstrapping as a re-sampling technique, best overcomes the serial correlation complicating the two-stage analysis. Banker and Natarajan (2008) conclude that simple ordinary least squares, maximum likelihood estimation or Tobit regression dominate other alternatives. Combining the arguments of Simar and Wilson (2007) and Banker and Natarajan (2008), we apply robust cluster regression based on ordinary least squares in order to account for the correlation across observations. Furthermore, in order to ensure the robustness of the results, we also apply spatial and truncated regressions.

The second stage analysis of this research considers the impact of ownership form, economic regulation and levels of competition amongst other factors. Several empirical studies to date have assessed the effects of privatization on airport efficiency. Parker (1999), utilizing data envelopment analysis, argues that the privatization of BAA had no effect on subsequent efficiency. Oum et al. (2006), applying variable factor productivity argues that private majority ownership and pure government ownership are equally efficient and both are strictly preferable to government majority ownership or multi-tiered government ownership. Oum et al. (2004) analyze different regulatory regimes and conclude that total factor productivity is maximized under dual till price-caps rather than single till price-caps or rate of return regulation. Chi-Lok and Zhang (2009), utilizing data envelopment analysis on a Chinese airport dataset, reach the conclusion that the intensity of airport competition at the level of the local catchment area or between international gateways encourages greater productivity.

Whereas previous studies analyze the effects of ownership, regulation and competition individually, we support the argument of Button and Weyman-Jones (1992) that all three factors should be accounted for simultaneously as their combined impact is likely to affect airport productivity. Furthermore, such an analysis may contribute to the search for the more desirable combinations. The dataset in this research consists of European and Australian airports in order to include a sufficiently heterogeneous sample with respect to the ownership structure, regulatory mechanism and competitive environment. The empirical results reveal that under monopolistic conditions, airports should be regulated to encourage cost efficiency and dual till price-cap regulation appears to be the most effective form. However, gateway or regional competition replaces the need for any form of economic regulation for both public and major or fully private airports, thereby supporting the argument of Vickers and Yarrow (1991) that competition rather than privatization is the key driver of efficiency.

The paper is organized as follows: the theoretical and empirical literature on ownership, regulation and competition is presented in Section 2; Section 3 introduces the methodology and model specifications, Section 4 discusses the dataset for the two stages of analysis, the results are presented in Section 5 and conclusions and directions for future research are suggested in Section 6.

2 Literature on Competition, Regulation and Ownership

The neoclassical theory of the firm states that competition leads to increased productive and allocative efficiency as a result of lower prices and higher outputs. In the case of indivisibilities, as occurs in the provision of infrastructure based services and utilities, one large firm might be able to produce at lower costs under monopolistic conditions. In this case, in order to encourage efficiency and avoid abuse of market power, a natural monopolist should be subject to economic regulation (Lipczynski et al. 2009). According to Czerny (2006), airports enjoy both economies of scale and market power hence economic regulation is a relevant and necessary instrument. Starkie (2002), on the other hand, argues that there is no evidence that airports exhibit economies of scale for large throughput and that demand complementarities between aeronautical and terminal activities prevents airports from abusing market power. After the deregulation of the airline industry, the traditional role of an airport appears to be shifting. Competition for airport services covers a multiplicity of markets including (1) a shared local catchment area, (2) connecting traffic through regional hubs and international gateways, (3) cargo traffic, (4) destination competition, (5) non-aeronautical services and (6) alternative modes of transport such as high speed rail in the medium distance markets (Tretheway and Kincaid 2010).

In Europe, airport charges have traditionally been regulated according to a rate of return or cost-plus principle (Reinhold et al. 2010). Such regulation permits airports to generate sufficient revenue to cover total expenditures, including the depreciation of capital and an expected rate of return on capital. However, according to Averch and Johnson (1962), this form of regulation may lead to overcapitalization which does not engender productive efficiency. To solve the problem of overinvestment, Littlechild (1983) proposes an incentive based price-cap regulation for the British network utilities. Price-caps are generally set over a regulatory period of five years according to the

RPI-X formula where *RPI* represents the retail price index and *X* is the efficiency improvements that the regulators consider reasonable within the timeframe. If the airport management achieves greater cost reductions over the five year period, the gains are enjoyed by the company hence this type of regulation intends to encourage cost input efficiency. In the case of airports, the single till principle is applied in the UK, in which case both aeronautical and non-aeronautical revenues are constrained. Over the years, price-cap regulation has been emulated by other European authorities however, unlike the UK model, a dual till approach is applied whereby aeronautical revenues alone are subject to regulation (Gillen and Niemeier 2008). Compared to traditional rate of return regulation, a price-cap creates incentives for cost savings hence encourages efficiency, however it equally may lead to underinvestment on the part of firms with heavy infrastructure sunk costs. Consequently, it may be necessary to regulate in order to ensure a reasonable level of quality with respect to the products or services offered.

With the stated aim of reducing government involvement, minimizing costs and maximizing productivity, a wave of airport privatizations began in the late Eighties in the UK. Despite successful initial public offerings and increasing share prices, most European countries only began to partially privatize their airports in the mid Nineties (Gillen and Niemeier 2008). Reviewing the theoretical literature on privatization, its effects seem to be somewhat controversial. Sappington and Stiglitz (1987) argue that the transactions costs of government intervention are lower under public ownership. In a similar vein, Shapiro and Willig (1990) argue that the government is better informed and more capable of regulating state-owned firms. Opponents of this point-of-view sought evidence to demonstrate that state intervention leads to inefficiency. Shleifer and Vishny (1994) assume that the relationship between politicians and managers is governed by incomplete contracts and conclude that political intervention may lead to excessive employment. Boardman and Vining (1989) review the effects of mixed ownership based on theoretical arguments and empirical studies. They conclude that large, industrial, partly privatized and state-owned companies perform in a less productive and profitable manner than their private counterparts, which may be caused by the public and private shareholders' differing objectives. Vickers and Yarrow (1991) argue that privatization is not a universal solution to the agency problem in the public sector and should not be separated from the economics of competition and regulation which are all determinants of corporate incentives. In addition, the emergence of partially privatized models complicates the debate as to the effects of ownership on productivity.

Empirical studies that attempt to assess the effects of ownership on the efficiency of airports are so far rather inconclusive and studies evaluating the effects of regulation and competition are rare. Two different opportunities occur to consider ownership as a potential efficiency driver. Parker (1999) utilizes DEA to estimate the technical efficiency of the BAA airports between 1979 and 1996 covering the period pre and post privatization. No evidence is found that full privatization improves technical efficiency and he concludes that the UK government's golden share limits the impact of capital market pressures. Furthermore, he argues that BAA remained subject to economic regulation hence incentives to operate more efficiently are distorted as a result of government intervention. In contrast, Yokomi (2005) reviews the technical and efficiency change of six BAA airports from 1975 to 2001 utilizing Malmquist DEA. As opposed to Parker, Yokomi find that the BAA airports exhibit positive changes in efficiency and technology as a result of the privatization. It should be noted that commercial growth after privatization was substantial however this activity is not considered in Parker's analysis. Furthermore, changes in ownership form are often accompanied by changes in both regulation and restructuring processes such as outsourcing. Consequently, changes in efficiency may be attributable to multiple explanations in addition to the change in ownership structure.

The effects of ownership on efficiency have been analyzed empirically but the results have not reached clear conclusions. Barros and Dieke (2007) analyze 31 Italian airports from 2001 to 2003 using DEA in the first stage and Mann-Whitney hypothesis testing in the second stage, revealing that private airports operate more efficiently than their partially private counterparts. However, Lin and Hong (2006) find no connection between ownership form and efficiency after analyzing a dataset of worldwide airports for the years 2001 and 2002 utilizing DEA and hypothesis testing. Oum et al. (2006, 2008) distinguish between public airports owned by public corporations and those owned by more than one public shareholder (multilevel). Referring to Charkham (1995), they argue that different ownership and governance structures affect the quality of managerial performance. Oum et al. (2006) assess a sample of 100 airports worldwide covering the years 2001 to 2003 utilizing variable factor productivity. They reach the conclusion that the productivity of a public corporation is not statistically different from that of a major private airport. However, airports with major public shares or multiple government involvement operate significantly less efficiently than other ownership forms. Oum et al. (2008) estimate a heterogeneous translog cost function with stochastic frontier analysis on a similar set of airports as that of Oum et al. (2006), measuring cost efficiency between the years 2001 and 2004. The authors conclude that airports with major private shareholders are more efficient than public airports, particularly those with a major public ownership structure.

To the best of our knowledge, the impact of regulation on efficiency has only been assessed in two papers. Barros and Marques (2008) incorporate a dummy variable defining cost-plus or price-cap regulation in order to assess a worldwide set of airports between the years 2003 and 2004, estimating a heterogeneous cost frontier utilizing stochastic frontier analysis. They conclude that regulatory procedures contribute to cost savings. The study by Oum et al. (2004) collects data on worldwide airports for the years 1999-2000 using gross endogenous-weight total factor productivity. They carefully study various forms of regulation including differences between single till and dual till concepts. The results indicate that airports under the dual till price-cap regulation tend to have higher levels of gross total factor productivity than those with a single till price-cap or those that operate under the single till rate of return regulation. Furthermore, dual till approaches together with rate of return regulation appear to provide incentives to improve efficiency but are very complex to estimate.

The traditional perspective of airports behaving as monopolists has changed as a result of the deregulation of the downstream aviation industry. Amongst the empirical literature, only Chi-Lok and Zhang (2009) examine the effects of regional competition utilizing a Chinese airport dataset for the years 1995 to 2006. After applying DEA in the first stage and ordinary least squares in the second-stage, they conclude that airports operating in a locally competitive environment tend towards efficiency. However, the outcome of a Tobit regression found competition intensity to be insignificant.

Whereas previous research analyzes the individual effects of ownership, regulation and competition on efficiency, the joint impacts may be of great interest as argued in Button and Weyman-Jones (1992, p.440) that *"[t]he degree of competitiveness in a firm's market, the extent to which it is incorporated as part of a public- sector bureaucracy, and the nature of the regulatory regime under which a firm operates are all primary sources of possible X- inefficiency"*. Consequently, our intention is to assess the combined impact of ownership structure and economic regulation (or lack thereof) given relevant levels of local and hub competition. We argue that ownership form and the regulatory procedures are clearly within the bounds of public policy initiatives within the medium term whereas the competitive environment remains more costly to change. Similarly to Oum et al. (2006), we divide privatized airports into categories characterized by minor, major and fully private shares. Further, we include a set of airports that are not ex-ante regulated in order to judge whether regulation is a necessity in a competitive environment. The levels of competition have been defined by regional competition based on catchment area and hub competition.

3 Methodology and Model Specification

The following section presents the unit and translation invariant, non-radial, weighted additive DEA model (Lovell and Pastor 1995) which we apply in the first-stage analysis in order to account for both the desired equi-proportional reductions in all inputs and any remaining slacks. To test for the impact of providing ground handling services in-house on the efficiency estimates, we apply the program evaluation procedure that measures efficiency variation across different groups utilizing the non-parametric Kruskal-Wallis test (Brockett and Golany 1996). We then discuss the second-stage regression specifications in which the logged DEA efficiency estimates are regressed against environmental factors.

3.1 Data Envelopment Analysis

DEA is a non-parametric method of frontier estimation that measures the relative efficiency of decision-making units (DMUs) utilizing multiple inputs and outputs. DEA accounts for multiple objectives simultaneously without attaching ex-ante weights to each indicator and compares each DMU to the efficient set of observations, with similar input and output ratios, and assumes neither a specific functional form for the production function nor the inefficiency distribution. DEA was first published in Charnes et al. (1978) under the assumption of constant returns-to-scale and was extended by Banker et al. (1984) to include variable returns-to-scale. This non-parametric approach solves a linear programming formulation per DMU and the weights assigned to each linear aggregation are the results of the corresponding linear program. The weights are chosen in order to show the specific DMU in as positive a light as possible, under the restriction that no other DMU, analyzed under the same weights, is more than 100% efficient. Consequently, a Pareto frontier is attained, marked by specific DMUs on the boundary envelope of input-output variable space. The frontier is considered a sign of relative efficiency, which has been achieved by at least one DMU. Charnes et al. (1978) described DEA as a "*mathematical programming model applied to observational data [which] provides a new way of obtaining empirical estimates of extremal relations – such as the production functions and/or efficient production possibility surfaces that are a cornerstone of modern economics*".

The weighted additive model (Charnes et al. 1985; Lovell and Pastor 1995), chosen for its units and translation invariance properties, reflects all inefficiencies identified in the inputs. The input oriented model is chosen because we assume that airport managers control operations costs and to a lesser extent capacities, but have less control over traffic volume. By comparing *n* units with *q* outputs denoted by *Y* and *r* inputs denoted by *X*, the efficiency measure for airport *a* is expressed as in model (1).

$$
\begin{aligned}
&\underset{s,\sigma}{Max}\ \ w^t s \\
&s.t.\quad Y\lambda - s = Y^a \\
&\qquad -X\lambda - \sigma = -X^a \\
&\qquad e\lambda = 1 \\
&\qquad \lambda, s, \sigma \geq 0
\end{aligned}
\tag{1}
$$

In (1), λ represents a vector of DMU weights chosen by the linear program, w^t a transposed vector of the reciprocals of the sample standard deviations, e a vector of ones, σ and s vectors of input and output slacks respectively and X^a and Y^a the input and output column vectors for DMU_a respectively. Hence $DMU_{a,}$ the airport under investigation, is efficient if and only if all input slacks equal zero. Variable returns-to-scale is assumed because the sample dataset consists of airports of substantially different sizes ranging, between 0.5 million at Southampton to more than 50 million passengers per annum at London Heathrow and Frankfurt.

In order to determine whether there are distinct efficiency differences across airport groups, we apply the program evaluation procedure outlined in Brockett and Golany (1996) and Sueyoshi and Aoki (2001). Four steps are required to implement the procedure. In the first step, the complete set of DMUs ($j=1,\dots,n$) are split into *k* sub-groups and the DEA model is run separately over each of the *k* groups. In order to obtain efficiency estimates between zero and one for the Kruskal-Wallis test the radial model has been chosen for this purpose instead. Then, for each of the *k* individual groups, the inefficient DMUs are moved to their hypothetical efficient level by projecting them onto the efficient frontier of their relevant group. In the third step, a pooled DEA is run with all *n* DMUs based on their adjusted variables. Finally, a Kruskal-Wallis test is applied to determine if the *k* groups possess the same distribution of efficiency values within the pooled set. If the null hypothesis is correct, we expect to see most of the DMUs rated as efficient in step three. Note that in order to avoid inaccuracy in the nonparametric rank test, the number of observations in each of the *k* subgroups in the first step should be of similar size.

3.2 Second-stage Regression

The inefficiency scores estimated in the first stage may be explained by factors beyond managerial control. In order to conduct hypothesis testing, regression analyses is often applied in a second stage in which the logged DEA efficiency estimate is regressed against a set of potential environmental variables. Banker and Natarajan (2008) and Simar and Wilson (2007) independently review appropriate forms to conduct second-stage regressions of DEA estimates which led them to different conclusions. Based on Monte Carlo simulations, Banker and Natarajan (2008) argue that ordinary least squares, Tobit regression and maximum likelihood estimation in the second-stage outperform one-stage and two-stage parametric methods. Simar and Wilson (2007) argue that the majority of empirical two-stage studies do not properly define the data generating process because the efficiency estimates are serially correlated via the efficiency frontier hence the error term, ε_i, will also be serially correlated, violating the common assumption that the errors are identically and independently distributed. They also state that any bias in the efficiency estimate is ignored and will be automatically included in the error term. Consequently, Simar and Wilson advocate generating an identically and independently distributed pseudo sample through bootstrapping and applying truncated regression in the second stage, which removes the efficient units from the sample. The problem with this approach is that we would then ignore all airports deemed to be lying on the efficient frontier, yet we are searching for the most appropriate form of ownership and regulation given the competitive environment.

Drawing inspiration from both papers, we apply both ordinary least squares and truncated regression, thereby following the Banker and Natarajan (2008) approach. To handle the issues identified in Simar and Wilson (2007), we utilize robust cluster regression. Accounting for heteroscedastic robust standard errors as proposed by White (1980), we construct unbiased t-tests and confidence intervals hence attempt to solve the limitation that the error term is not identically distributed. Furthermore, the sample will be clustered according to the airports in order to overcome the limitation that the error term is not independently distributed. For purposes of sensitivity analysis, we also utilize a spatial error regression model that allows for dependencies across error terms. Instead of spatial dependency across neighbouring locations as in the pioneering work of Anselin (1988) on property crime in Ohio, we apply spatial regression to a pooled sample set where the error terms of a specific airport over multiple years are defined as dependent. The dependency is defined through a spatial weight matrix *W*. For simplicity, we select the contiguity matrix *W* where $w_{i,j} = 1$ if *i* and *j* are the same airport and $w_{i,j} = 0$ otherwise. The regression models applied in this research are presented in Table 1.

Table 1: Regression Analysis

Robust Ordinary Least Squares	Spatial Error Regression	Robust Truncated Regression
$y = X\beta + \varepsilon$ The dependent variable y presents a vector of DEA efficiency estimates; X a matrix of environmental variables, β the parameters to be estimated and ε the error term.	$y = X\beta + \varepsilon$ $\varepsilon = \lambda W\varepsilon + u$ λ is a scalar measuring the spatial correlation in errors; W an nxn spatial weight matrix; ε are spatially correlated residuals and u are iid disturbances. If λ=0 then the model collapses to OLS.	$y = X\beta + \varepsilon$ The dependent variable y is said to be truncated if we observe y*=y for all y≥1.

4 Dataset

In this section we present the airports to be analyzed, the variables collected for the efficiency analysis and then the environmental variables included in the second stage regression. Appendix 1 lists the complete set of airports in the sample, which include 48 European airports of which half are located in Germany and the United Kingdom. To ensure a heterogeneous dataset with respect to the form of ownership, economic regulation and level of competition, we also include three fully privatized Australian airports, Melbourne, Perth and Sydney, which are neither ex-ante regulated nor located in a competitive environment. The pooled data consists of an unbalanced set of 398 observations covering the time period between 1998 and 2007. The size of the airports under review varies considerably between an annual passenger volume of half a million passengers at regional airports such as Southampton to more than 50 million passengers at international gateways such as London Heathrow and Frankfurt.

4.1 Variables in the First-stage Efficiency Analysis

For the first-stage efficiency analysis, three inputs and four outputs are collected as summarized in Table 2. The operating inputs consist of staff costs and other operating costs, including materials and outsourcing. Despite being a smaller airport than London Heathrow in terms of air traffic movements, Frankfurt spends the most on staff costs because it is a highly integrated airport that operates most airport services in-house or through wholly-owned subsidiaries. Consequently, Heathrow spends the most in the other operating costs category, reflecting the high levels of outsourcing undertaken.

It is also necessary to consider capital however this variable is extremely problematic since it is often unreported. If the dataset covers more than one country, the monetary measurement of physical capital creates difficulties due to different national accounting standards and depreciation methods or periods across countries. For example, the airports of the British Airports Authority depreciate their runways over 100 years whereas the airports operated by the Aéroports de Paris apply a 10 to 20 year depreciation rule (Graham 2005). Consequently, physical data such as the number of runways, gates or check-in-counters and terminal size are often collected for cross-border studies as a proxy for capital (Gillen and Lall 1997; Pels et al. 2003). However a simple linear aggregation of these variables is problematic, for example because the number of runways does not include information on the configuration, weather impacts or environmental restrictions. In this study, we include declared runway capacity as a proxy for capital, which is defined as the capacity constraint on the number of departure and arrival movements per hour. Runway capacity is negotiated twice a year in agreement with airport stakeholders and is primarily used to avoid congestion at schedule facilitated airports and to allocate slots at coordinated airports. Compared to the theoretical capacity, declared runway capacity is not only limited by physical runway constraints but also by the air traffic control system, weather impacts and noise and emissions restrictions (IATA 2010). Compared to pure physical information, the capacity measure allows for greater variability since it accounts for bottlenecks that may be solvable in the short to medium term. In the dataset, Amsterdam possesses the highest runway capacity at 110 movements per hour, due in part to the geographical location near the coast which requires additional runways and a special configuration to handle operations consistently irrespective of weather conditions. The smallest airport with respect to runway capacity is Ljubljana with a maximum hourly rate of fifteen movements. Consistent terminal data proved very difficult to collect hence has been excluded in this study, however runway capacity is highly correlated to terminal capacity therefore this omission should not greatly impact the results.

Table 2: Variables in Analysis (DEA)

Variable	Description	Average	Standard Deviation	Maximum	Minimum	Source
Staff costs	Wages and salaries, other staff costs (2000=1 and US$=1)	63,654,765	120,554,070	1,080,756,267	3,655,825	Annual Reports
Other operating costs	Costs of materials, outsourcing and other (2000=1 and US$=1)	84,811,284	117,603,464	725,987,196	3,631,353	Annual Reports
Declared runway capacity	Number of movements per hour	46	20	110	15	IATA (2003) Airport Coordinator
Passengers	Annual passenger volume (only terminal passengers)	11,091,246	12,761,170	67,673,000	480,011	Annual Reports
Cargo	Metric tons (trucking excluded)	580,637	1,943,571	14,214,000	0	Annual Reports
Air transport movements	Number of commercial movements	132,482	109,190	492,569	19,397	Annual Reports
Non-aeronautical revenues	Revenues from concessions own retail and restaurants, rents, utilities and ground handling activities (2000=1 and US$=1)	124,647,578	186,748,031	1,167,377,411	6,194,408	Annual Reports

On the output side, the annual traffic volume is represented by the number of passengers, commercial air transport movements and tons of cargo (trucking was excluded). Freight handling is of differing importance across the airports in the sample set since Dortmund and London-City do not serve cargo operations whereas Leipzig and Cologne-Bonn are the European hubs for DHL and UPS respectively. The fourth output variable captures revenues from the non-aeronautical activities, including concessions, car parking and rent. In addition to the traditional income sources, non-aeronautical revenues also include revenues from labour-intensive ground handling activities. Ignoring this operation on the output side would otherwise bias the results since the input data could not be adjusted to exclude this service. At least theoretically we should be able to compare all three airport models, namely airports who produce ground handling services in-house and have relatively higher employee costs and requisite revenues, those who outsource which appear in the other costs category and their respective revenues and the third case in which airports do not provide the service nor earn revenue beyond perhaps a nominal fee from third party contractors. All financial data is deflated to the year 2000 and adjusted by the purchasing power parity according to the United States dollar in order to ensure comparability across countries. In addition, the data has been normalized by the standard deviation to ensure that all inputs are considered equally within the additive model.

4.2 Variables in the Second-stage Regression

Variables describing ownership structure, economic regulation and the level of competition have been collected for this study in addition to specific airport characteristics and information on managerial strategies. All factors are at least in the short-term beyond managerial control yet may contribute to the inefficiency measurement process. All data is expressed in the form of categorical variables. To further assess efficiency changes over the review period, time-related categorical variables have been included.

Airports frequently attempt to increase revenues from non-aeronautical sources that are not directly related to aviation activities in order to cross-subsidize aviation charges in turn attracting more airlines and passengers to their airport (Zhang and Zhang 2010). Consequently, revenue source diversification that exploits demand complementarities across aeronautical and non-aeronautical services may improve airport efficiency. Oum et al. (2006) find a positive and highly significant relationship between the share of non-aeronautical revenues and the level of efficiency. To compare our results with that of Oum et al. (2006), we compute the percentage share of non-aeronautical revenue ignoring ground handling activities. Airports are split between those that earn less than 50% of their revenues from airside activities and those that exceed this share. The threshold of 50% was chosen such that a rich set of airports exist in the two categories and sensitivity analysis show no change in the results when reducing the threshold to 40% or increasing it to 60%.

Oum and Yu (2004) conclude that a higher share of intercontinental traffic leads to efficiency decreases due to additional service requirements that generate higher costs compared to domestic traffic. We define a threshold of 15% or more of intercontinental traffic to separate the set between hubs such as Frankfurt, Amsterdam and London-Heathrow and airports with predominantly domestic and European destinations.

Odoni and Morisset (2010) argue that the different scheduling practices of airports affect airport capacity and the number of delayed flights consequently contributing to the level of efficiency.

Applying stochastic frontier analysis to a dataset of European airports, Pels et al. (2003) demonstrate that slot-coordinated airports operate less efficiently due to lower declared capacities. Having been unable to obtain sufficient information on scheduling practices for all airports in the sample, this research considers runway utilization which is expected to positively affect efficiency. The variable was calculated based on annual air transport movements divided by estimated annual declared capacity[1]. We define three categories including (1) airports with less than 50% runway utilization indicating under-utilization, (2) airports between 51% and 90% runway utilization and (3) airports achieving more than 90%[2] runway utilization indicating congestion.

Pathomsiri et al. (2008) consider the impact of delay on productivity by incorporating the number of delayed flights and time delays (min) as a negative output in their non-parametric model analyzing a sample of US airports. Perhaps unsurprisingly, they conclude that ignoring delays leads to an overestimation of airport efficiency. For the European market we were not able to collect non-weather related delays per movement for the first stage analysis hence have collected a categorical variable based on the ranking of the most delayed airports (departure and arrival) as reported by the European air traffic control. Over the review period Amsterdam, the London airports Heathrow, Gatwick and Luton and Manchester are consistently ranked as the European airports with the greatest levels of delay with Zurich listed up until 2005 (Eurocontrol 1999-2008). An airport appearing on the list of the Top 50 delayed airports in Europe was categorized accordingly[3].

According to Kamp et al. (2007), analyzing airports without considering the degree of outsourcing is likely to bias the efficiency results particularly with regard to labour-intensive ground handling services. In our dataset, airports located in Austria, Germany and Italy traditionally operate ground handling activities in-house whereas in the UK and Switzerland these operations are provided by the airlines themselves or via independent third party providers. In order to test whether ground handling operations in-house affects the efficiency estimates of airports despite considering all salient variables, we include a categorical variable with regard to the provision of this activity. Unfortunately, ground-handling provision must be analyzed separately because of the high correlation with regulation (0.65), ownership (0.55) and the share of non-aeronautical revenues (0.40).

Ownership form is defined according to (1) fully public airports, (2) public-private airports with minor private shares (less than 50%), (3) public-private airports with major private shares (above 50%) and (4) fully private airports. The form of economic regulation has been categorized according to (1) no ex-ante regulation[4], (2) single till cost-plus regulated, (3) dual till cost-plus regulated, (4) single till price-cap regulated and (5) dual till price-cap regulated airports. Unfortunately, this level of refinement is not possible in the combined model due to an insufficient level of data hence we aggregated the classification to ex-ante unregulated and regulated airports in the combined impact

[1] The annual capacity has been estimated from the declared hourly capacity obtained from the airport coordinator.
[2] Note that the theoretical runway capacity normally exceeds the declared runway capacity hence the runway utilization with respect to the theoretical value is somewhat lower than 90%.
[3] Australian airports are included in the group of non-delayed airports for lack of further information.
[4] For simplicity we refer to airports subject to ex-post standard anti-trust regulation as unregulated airports.

modelling approach. Regional competition has been defined as the number of operating commercial airports within a catchment area of 90 km around the airport[5]. In addition, competition between gateway airports is considered. Consequently, weak competition is defined as competition at the regional or hub level of no more than a single airport and strong competition as a location with at least two competitors. Table 3 presents the combinations and the number of observations that belong to the different groups in the combined model.

Table 3: Combination of environmental variables analyzed

		Weak competition	Strong competition
		number of observations per category	
Public	**No regulation**	37	36
	Regulation	59	60
Minor private	**No regulation**	0	8
	Regulation	13	24
Major private	**No regulation**	2	19
	Regulation	9	15
Fully private	**No regulation**	33	53
	Regulation	6	24

5 Empirical Results

In the following section we first discuss the DEA efficiency results including the outcome of the program evaluation procedure testing efficiency differences between in-house ground handling provision and outsourced airports. The complete set of DEA efficiency scores is listed in Appendix 2. The second part of this section discusses the results of the regression analyses, initially discussing the individual impacts and followed by the combined environmental regression approach.

5.1 Efficiency Scores from Data Envelopment Analysis

The average efficiency score of the dataset obtained from the input-oriented additive DEA model is 0.62 (after normalization) with 14% of all airports categorized as relatively efficient. The majority of airports exhibit an efficiency decrease over time which proved significant according to the paired sample Wilcoxon sign rank test (p-value = 0.000). As a result of the general economic downturn and the attacks on the world trade centre in New York in 2001, the majority of airports experienced stable or even declining traffic rates with disproportional increases in staff and other operating costs. Increased security measures for baggage screening require additional training and the recruitment of specialized workers, expenses which have been covered at least partially by the airports (Vienna International Airport 2004). Hence one could argue that the additional costs provide an increased quality with respect to safety related to passenger traffic.

Consistently efficient airports include Ljubljana and Malta that represent the smaller airports in the dataset, many of the Australian airports, as well as the largest operators, Frankfurt and London

[5] According to an unpublished research study by the German Aerospace Center (DLR), 95% of an airport's relevant catchment area in Germany is within 90 km of the airport.

Heathrow. Australian airports do not provide the labour-intensive ground handling services and domestic terminals are often operated by incumbent airlines under long-term leases, thereby lowering maintenance and staff costs (Hooper et al. 2000). In 2002, both Melbourne and Perth experienced above average increases in staff costs and other operating costs which resulted in efficiency drops of 20% and 30% respectively. Costs remained relatively consistent thereafter enabling Melbourne to achieve relative efficiency by 2004 and Perth two years later, as a result of both traffic and revenue increases. These efficiency decreases could be explained partially by the aftermath of 2001, however given that the efficiency reduction is substantially higher than that of other airports in the sample, we also assume that the change from ex-ante incentive regulation to an ex-post monitoring process in 2002 partly affected the results. Frankfurt and London-Heathrow obtain reasonably high cost efficiency estimates over time. It should be noted that both airports are severely congested and require airside capacity expansions. Whereas Frankfurt has long been fighting for the construction of a fourth runway which is now expected to open in 2011, Heathrow was denied the right to construct a third runway in May 2010 by the new UK government (BBC News 2010; Fraport 2009). Both airports place great emphasis on cost efficiency with London-Heathrow attempting to minimize staff costs and Frankfurt tending to reduce other operating costs. The diverse strategies are not surprising given the different levels of outsourcing including ground handling provision. Whereas Frankfurt provides ground handling services in-house, this operation has long been outsourced to airlines and third-party providers at London-Heathrow.

The airports in Amsterdam, Brussels, Copenhagen, Dortmund, Dusseldorf, Leeds-Bradford, London-Gatwick and Nice operated on the Pareto frontier at the beginning of their respective review periods but all experience substantial decreases over time. Basel-Mulhouse, Bratislava, Marseille, Tallinn and Zurich were inefficient throughout the timeframe and show further efficiency declines over time. Many of these airports both increased their costs and served lower traffic throughput which explains the decreasing efficiency scores. In addition, Basel-Mulhouse and Bratislava suffer from heavy reductions in their cargo operations which are not fully compensated by passenger growth rates. An increase in runway capacity at Zurich decreased their relative efficient score from 2005 by 14%. On the other hand, the average delay per movement dropped from 10.35 to 5.75 minutes between 2005 and 2007[6], mainly due to a reduction in the length of the departure queues, which we have been unable to consider in this analysis due to a lack of comparable data.

At Brussels and Dortmund, efficiency estimates dropped from 1.00 to 0.42 over time. Brussels suffered heavily from the bankruptcy of the home carrier Sabena in 2001, with a substantial decrease in traffic whilst concurrently increasing staff and other operating costs. Compared to their benchmark in Nice, Brussels ought to lower costs in order to achieve relative efficiency. Dortmund completed large and expensive capacity expansions on the terminal and airside yet is located in a highly competitive corridor with Dusseldorf, Munster-Osnabrueck and Paderborn airports within a 90 km

[6] Eurocontrol (2006-2008).

radius as well as alternative transport modes, hence may find it difficult to fill excess capacity even in the medium term. Furthermore, Dortmund airport report operating losses in all years under review.

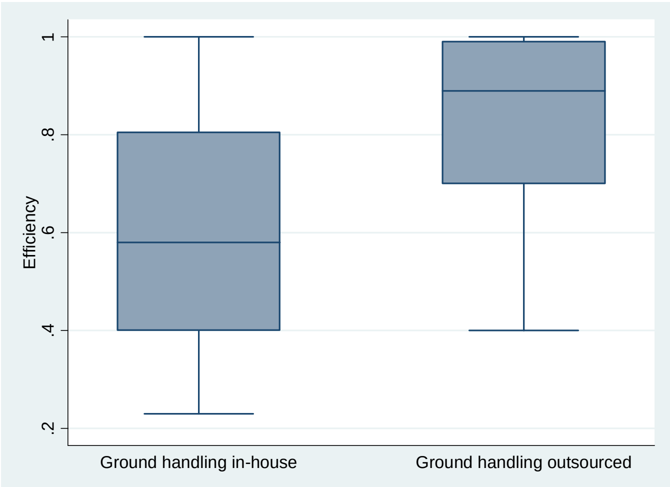
Except for Sydney, no airport consistently improved their relative efficiency scores over time. Between 2003 and 2007, Sydney increased its score from 0.56 to 1.00 which is mainly attributable to a large increase in non-aeronautical revenues with fairly constant cost inputs. This indicates that the complete privatization process that was completed in 2002 may have led to an increasing commercial focus and a change in managerial productivity incentives. Southampton airport reached an efficiency peak in 2003 after a substantial increase in cargo operations. However, a reduction in non-aeronautical revenues in 2004 decreased their efficiency estimates compared to that of Leeds-Bradford and Ljubljana, their reference peers.

Average efficiency scores are achieved by most of the small to medium sized airports with less than 10 million passengers per year and this proved to be reasonably consistent over the review period. The airports of Budapest, Cologne-Bonn, Hanover, Leipzig, Lyon, Manchester, Munich and Vienna appear to be the least relatively cost efficient airports in the sample. Vienna, for example, has higher staff and other operating costs compared to its benchmarks, including London-Gatwick, Nice and Sydney. Manchester airport is also more expensive than its benchmarks, including London-Gatwick, Ljubljana and Melbourne. Athens underwent substantial capacity expansions and a new green-field location hence capacity utilization is low in comparison to reference airports such as London-Gatwick and Nice. Furthermore, the German airports of Cologne-Bonn and Leipzig suffer from excess airside capacities despite the extensive cargo operations resulting from their positions as the European hubs for UPS and DHL respectively. Hanover also suffers from excessively low capacity utilization and concentrates on non-airport related activities in order to improve performance. Furthermore, Hanover airport also exhibits relatively high operating costs compared to its benchmarks. However, as service quality indicators such as congestion and delay are not included in the first stage analysis, the inefficiency may be somewhat overestimated.

The dataset consists of airport producing ground-handling in-house hence employ a larger number of workers than those who purely outsource the service but whom also earn additional revenues which are included in the output revenue variable. Airports that outsource this activity to airlines or third party contractors do not show this process on their books thus have lower inputs and outputs. In order to test whether the two sets of airports lie within the same production possibility set, we apply the program evaluation procedure first outlines in Section 3.1. The results of the non-parametric procedure reveal that airports providing ground handling in-house operate on average 30% less efficiently than their counterparts who outsourced this activity, as shown in Figure 2. Ljubljana and Frankfurt represent the only ground-handling providers that lie on the Pareto frontier. Munich, a major German hub, announced in 2009 that their ground handling services department has suffered losses ever since this activity underwent liberalization in 1996. Munich airport management argue that salaries are paid based on public tariffs which are on average 20% higher than the private sector and strong labour unions in Germany make it difficult to either adjust the compensation or to outsource this segment (Hutter 2009). It should be noted, however, that it may be in the interests of the airport to cross-subsidize the ground-handling operations with alternative revenues in order to remain competitive in the competitive market (Barbot 2010). Nevertheless, it is clear that the two sets of airports operate on different cost frontiers and this is considered in the second stage environmental analysis.

Figure 2: Kruskal-Wallis program evaluation of ground-handling activity

Group	Obs	Rank Sum	Chi-square	
Ground handling in-house	160	22082.00	**Chi-square**	76.441
Ground handling outsourced	238	57319.00	**Df**	1
			Pr > Chi-Square	0.0001



5.2 Regression Results

In this section we analyze the impact of environmental variables on the DEA cost efficiency scores in addition to the ground-handling and time considerations identified in Section 5.1. Tables 4 and 5 present the results obtained from the three regression models introduced in Section 3 with the former presenting the results of the modelling approach in which the environmental impacts are analyzed individually and the latter presenting the joint effects. All three models, although based on substantially different underlying assumptions, clearly highlight general trends, despite the fact that the truncated regression removes all efficient observations from the analysis. The base case for Table 4 is defined as a monopolistic unregulated public airport with less than 50% non-aeronautical revenues, no heavy delays, intercontinental traffic of less than 15% and capacity utilization below 50%. Due to the high correlation between the ground handling dummy and ownership form, it was not possible to include both sets of variables in a single model hence we report both sets of results per regression.

Table 4: Second-stage regression results from the individual model

	Robust Cluster OLS Regression		Spatial Error Regression		Robust Cluster Truncated Regression	
Dependent Variable	DEA Efficiency Scores (log)		DEA Efficiency Scores (log)		DEA Efficiency Scores (log)	
a) Airport Characteristics and Management Strategies						
Ground handling operation	-	-0.215 (0.077)***	-	-0.167 (0.075)***	-	-0.230 (0.081)***
Share of non-aviation revenues >50%	0.109 (0.061)*	-	0.103 (0.032)***	-	0.072 (0.063)	-
Share of intercontinental traffic > 15%	-0.006 (0.065)	-	0.083 (0.055)	-	-0.091 (0.079)	-
Heavy delays	-0.253 (0.063)***	-0.322 (0.072)***	-0.100 (0.035)***	-0.075 (0.038)**	-0.203 (0.072)***	-0.251 (0.076)***
Runway capacity utilization between 50-90%	0.138 (0.060)***	0.066 (0.069)	0.129 (0.026)***	0.133 (0.026)***	0.102 (0.064)	0.001 (0.074)
Runway capacity utilization > 90%	0.712 (0.123)***	0.646 (0.112)***	0.493 (0.093)***	0.454 (0.081)***	0.842 (0.100)***	0.787 (0.103)***
b) Ownership, Regulation and Competition						
Minor private airport	-0.251 (0.072)***	-	-0.195 (0.088)***	-	-0.240 (0.080)***	-
Major private airport	0.210 (0.088)***	-	0.109 (0.097)	-	0.091 (0.087)	-
Fully private airport	0.030 (0.075)	-	0.074 (0.077)	-	0.074 (0.085)	-
Strong competition	0.027 (0.060)	0.060 (0.073)	0.004 (0.062)	0.002 (0.075)	0.004 (0.067)	0.042 (0.076)***
Cost-plus regulation, single till	-0.272 (0.077)***	-	-0.307 (0.108)***	-	-0.269 (0.074)***	-
Cost-plus regulation, dual till	-0.275 (0.070)***	-	-0.207 (0.089)***	-	-0.279 (0.080)***	-
Price-cap regulation, single till	-0.206 (0.083)***	-	-0.241 (0.080)***	-	-0.141 (0.087)	-
Price-cap regulation, dual till	0.026 (0.089)	-	-0.052 (0.078)	-	-0.100 (0.081)	-
C) Time Trend						
Year 1999	-0.022 (0.029)	-0.005 (0.034)	-0.012 (0.050)	-0.013 (0.049)	0.016 (0.030)	0.024 (0.032)
Year 2000	-0.057 (0.042)	-0.027 (0.048)	-0.043 (0.049)	-0.047 (0.048)	-0.030 (0.042)	-0.010 (0.049)
Year 2001	-0.134 (0.049)***	-0.103 (0.052)**	-0.123 (0.044)***	-0.126 (0.043)***	-0.025 (0.049)	-0.027 (0.053)
Year 2002	-0.160 (0.057)***	-0.133 (0.058)***	-0.180 (0.044)***	-0.188 (0.043)***	-0.058 (0.046)	-0.057 (0.055)
Year 2003	-0.221 (0.061)***	-0.190 (0.061)***	-0.234 (0.046)***	-0.247 (0.045)***	-0.124 (0.045)***	-0.117 (0.055)***
Year 2004	-0.192 (0.061)***	-0.161 (0.061)***	-0.212 (0.046)***	-0.227 (0.045)***	-0.104 (0.045)***	-0.094 (0.057)*
Year 2005	-0.234 (0.060)***	-0.209 (0.059)***	-0.264 (0.045)***	-0.267 (0.044)***	-0.163 (0.043)***	-0.163 (0.050)***
Year 2006	-0.263 (0.065)***	-0.245 (0.065)***	-0.292 (0.046)***	-0.281 (0.046)***	-0.175 (0.048)***	-0.201 (0.058)***
Year 2007	-0.279 (0.079)***	-0.266 (0.079)***	-0.299 (0.051)***	-0.279 (0.052)***	-0.213 (0.063)***	-0.239 (0.071)***
Intercept	-0.226 (0.084)***	-0.198 (0.090)***	-0.319 (0.082)***	-0.310 (0.081)***	-0.313 (0.085)***	-0.386 (0.093)***
Lambda	-	-	0.720 (0.042)***	0.786 (0.030)***	-	-
Sigma	-	-	-	-	0.218 (0.017)***	0.266 (0.021)***
R^2	0.5626	0.3586	0.4869	0.2096	0.5059	0.3330
Observations (n)	398	398	398	398	342	342

Note: *, **, *** indicate the level of significance at 10%, 5% and 1% respectively. Standard errors in parentheses, OLS and truncated regression are expressed in robust standard errors. OLS and truncated regression clustered at airport level.

All time trend data prove increasingly negative and statistically significant, supporting the results of the Wilcoxon sign rank test that indicate cost efficiency decreases over time. The dummy defining airports that earn more than 50% of their revenues from non-aeronautical sources prove weakly positively significant, supporting the results of Oum et al. (2006) and indicating a marginal contribution to cost efficiency of approximately 10% as occurred at Sydney airport after privatization. A substantial relative share of intercontinental traffic proves statistically insignificant across all regressions. On the other hand, delay and congestion have a statistically significant impact on airport cost efficiency, as discussed in Pathomsiri et al. (2008). Delay impacts cost efficiency negatively in the region of 10 to 28%, however congestion (proxied by capacity utilization above 90%) has an even larger positive impact ranging from 45% to 80% increases in airport efficiency compared to underutilized airports. From this perspective, it would appear unlikely that airports will be encouraged to reduce delay in order to improve airline performance. This would indicate the need for service quality indicators written into contracts between airlines and airports or internalization through compensation to airlines and passengers for airport related delays.

Across the board, airports with less that 50% of shares traded privately prove to be significantly less efficient than other ownership forms, a group which includes Athens, Hanover and Vienna. Fully private airports do not prove to be statistically significantly different in terms of cost efficiency than their fully public counterparts, in line with Oum et al. (2006). Unregulated airports generally dominate their regulated counterparts, such as Ljubljana and a number of Australian and British airports. Cost-plus regulation appears to be the least appropriate form of economic regulation whether single or dual till, reducing efficiency by 20% to 30%. Single till price-caps also appear to be dominated by dual till price-caps and standard ex-post anti-trust monitoring. The importance of competition is not statistically significant in the models including ownership form and regulation, in part due to a correlation across the variables. In the ground-handling models, competition is statistically significant in one out of the three models whereby greater competition has a slightly positive impact on cost efficiency.

Table 5 presents the results of the combined model in which the monopolistic, minor private, regulated airport defines the base case. Under weak competitive conditions, defined as at most one airport within the catchment area, privatized airports with at least 50% of the shares in private hands are the most efficient ownership form. In comparison to minor private airports, the major or fully privatized airports are 60% more efficient given the same form of regulation. However, after an airport is privatized in a weakly competitive market, economic regulation is necessary to ensure cost efficiency. Referring back to the individual regression model results presented in Table 4, dual till price-cap regulation would be the most preferable instrument. The unregulated major and fully private airports Aberdeen, Bratislava, Melbourne (from 2002), Perth (from 2002) and Sydney perform on average less efficiently than their regulated counterparts Copenhagen, Melbourne (until 2002), Malta and Perth (until 2002).

Purely public airports are also strictly preferable to minor private ones and almost of a similar magnitude as the major or fully private concerns. Furthermore, publicly owned and regulated airports perform on average 10% less efficiently than their unregulated counterparts. This indicates that managers of public airports behave as welfare maximizers and additional economic regulation decreases relative cost efficiency. However, it should be noted that ground-handling may also explain this result because the unregulated public airports in this category mostly outsource ground handling (Basel-Mulhouse, Budapest, Lyon and Geneva) whereas the regulated public airports operate the activity in-house (Dresden, Leipzig, Nuremberg, Salzburg, Stuttgart and Tallinn). Due to correlation, it is not possible to include the ground-handling dummy in these regressions in order to separate the impact.

Table 5: Second-stage regression results from the combined model

			Robust Cluster OLS Regression	Spatial Error Regression	Robust Cluster Truncated Regression
Dependent Variable				DEA Efficiency Scores (log)	
a) Airport Characteristics and Management Strategies					
Share of non-aviation revenues >50%			0.095 (0.055)*	0.102 (0.030)***	0.049 (0.055)
Heavy delays			-0.278 (0.066)***	-0.103 (0.036)***	-0.220 (0.069)***
Runway capacity utilization between 50-90%			0.141 (0.054)***	0.128 (0.026)***	0.084 (0.053)
Runway capacity utilization > 90%			0.733 (0.164)***	0.550 (0.109)***	0.718 (0.109)***
b) Competition, Ownership and Regulation					
weak competition	public ownership	no ex-ante regulation	0.436 (0.112)***	0.457 (0.102)***	0.453 (0.123)***
		ex-ante regulation	0.296 (0.120)***	0.385 (0.091)***	0.333 (0.123)***
	major private ownership	no ex-ante regulation	0.379 (0.103)***	0.307 (0.114)***	0.419 (0.114)***
		ex-ante regulation	0.785 (0.134)***	0.874 (0.195)***	0.538 (0.104)***
	fully private ownership	no ex-ante regulation	0.378 (0.147)***	0.565 (0.115)***	0.345 (0.137)***
		ex-ante regulation	0.580 (0.151)***	0.566 (0.122)***	0.958 (0.331)***
strong competition	public ownership	no ex-ante regulation	0.662 (0.087)***	0.648 (0.097)***	0.687 (0.099)***
		ex-ante regulation	0.112 (0.104)	0.166 (0.120)	0.095 (0.119)
	minor private ownership	no ex-ante regulation	0.268 (0.107)***	0.443 (0.175)***	0.282 (0.113)***
		ex-ante regulation	0.154 (0.119)	0.189 (0.101)*	0.096 (0.105)
	major private ownership	no ex-ante regulation	0.661 (0.151)***	0.722 (0.122)***	0.495 (0.090)***
		ex-ante regulation	0.518 (0.097)***	0.506 (0.216)***	0.418 (0.122)***
	fully private ownership	no ex-ante regulation	0.581 (0.106)***	0.648 (0.093)***	0.603 (0.114)***
		ex-ante regulation	0.406 (0.131)***	0.448 (0.119)***	0.573 (0.114)***
C) Time Trend					
Year 1999			-0.028 (0.028)	-0.014 (0.051)	0.007 (0.031)
Year 2000			-0.068 (0.041)	-0.049 (0.051)	-0.042 (0.041)
Year 2001			-0.146 (0.049)***	-0.126 (0.045)***	-0.070 (0.043)
Year 2002			-0.165 (0.058)***	-0.183 (0.045)***	-0.087 (0.042)***
Year 2003			-0.220 (0.062)***	-0.241 (0.047)***	-0.143 (0.044)***
Year 2004			-0.192 (0.061)***	-0.217 (0.047)***	-0.123 (0.043)***
Year 2005			-0.226 (0.059)***	-0.264 (0.046)***	-0.178 (0.042)***
Year 2006			-0.251 (0.064)***	-0.278 (0.047)***	-0.191 (0.047)***
Year 2007			-0.236 (0.072)***	-0.278 (0.052)***	-0.195 (0.057)***
Intercept			-0.695 (0.115)***	-0.836 (0.097)***	-0.786 (0.122)***
Lambda			-	0.682 (0.042)***	-
Sigma			-	-	0.185 (0.014)
R-squared			0.6333	0.5720	0.5738
Observations (n)			398	398	342

Note: *, **, *** indicate the level of significance at 10%, 5% and 1% respectively. Standard errors in parentheses, OLS and truncated regression are expressed in robust standard errors. OLS and truncated regression clustered at airport level.

In a competitive environment, purely public airports (Leeds-Bradford, Marseille and Nice) and major or fully privatised airports (Edinburgh, Glasgow and London-Stansted) are equally cost efficient. It is clear that such airports do not require economic regulation to maintain cost efficiency as compared to airports operating in a weakly competitive environment. Only the minor private airports require regulation when operating in a competitive environment and this result proved consistent across all regression models. Irrespective of ownership form, airports located in a competitive environment generally operate more efficiently than those operating in weakly competitive surroundings. Among the unregulated private airports, Aberdeen and Belfast located in uncompetitive environments operate significantly less efficiently than the competitive Edinburgh, Glasgow, London-City and Southampton examples. Among the regulated public airports, Nuremberg, Stuttgart and

Salzburg located in weakly competitive environments are substantially more cost efficient than the competitive Cologne-Bonn, Dortmund and Munich examples. Consequently, government intervention would appear to incur high transaction costs and is required to emulate the competitive environment when missing but is very expensive when such conditions already exist in the market. Hence, the results clearly show that competition replaces the need for economic regulation irrespective of ownership form (with the exception of minor private airports which would appear to be the least efficient ownership form).

The time trend dummies prove to be statistically significant across all regressions from 2002. Hence, after accounting for the efficiency decreases over time, we conclude that ownership form, competition and regulation play an important role in explaining efficiency differences across airports both individually and in combination. In summary, minor private airports appear to be the least efficient ownership form and require economic regulation irrespective of the competitive environment. Under weakly competitive conditions, dual till price cap economic regulation is the most appropriate. However, under competitive market conditions, regulation is not effective irrespective of whether the airport is purely public or major or fully private. According to this empirical analysis, there would not appear to be a most efficient ownership structure which supports the theoretical arguments of Vickers and Yarrow (1991) that competition is more important than ownership form with respect to efficiency. Finally, since the level of competition is an exogenous factor at least in the short term, economic regulation is an effective tool to engender cost efficiency when market conditions are poor.

6 Conclusions and Future Research

The inefficiency of airports may be explained not only by input excess and output shortfalls but also by exogenous factors over which management have little to no control. A number of empirical studies have assessed the impact of ownership structure, economic regulation and levels of competition on efficiency however the effects were always considered separately. The aim of this paper was to combine the environmental variables in order to assess the most efficient ownership and regulatory forms given the level of regional and hub competition.

The two-stage analysis combined DEA in the first stage and regression analysis in the second stage. The non-radial additive input-oriented DEA model has been chosen to identify all relative inefficiencies of the input. Following the recent debate on the most appropriate second-stage regression model, Banker and Natarajan (2008) and Simar and Wilson (2007) propose standard OLS and truncated regression respectively. Due to issues of heteroscedasticity in the error terms, we applied robust clustering to each of these forms and also included a spatial error regression to ensure that the results are robust. The regression results proved robust since the outcomes of the robust cluster ordinary least squares and spatial error regressions were very close and the general directions were clear across all three modelling approaches.

Despite including ground-handling related revenues in the output variables for airports undertaking the activity in-house, the results of the program evaluation procedure reveal that ground handling provision leads to on average a 30% reduction in cost efficiency. Hence, the results of the second-stage regression will clearly be affected by this issue. It was not possible to analyze ground-handling provision and the environmental variables jointly due to high correlation, which leaves us with a qualitative understanding. For example, the regression analyses suggest that publicly owned airports located in weakly competitive conditions do not require regulation in order to be efficient, as opposed to all other forms of ownership. Since the unregulated public airports in this category outsource ground handling whereas the regulated public airports all operate the activity in-house, it is more likely that the ground-handling issue is driving this specific result. Consequently, we would suggest that all airports located in a weakly competitive market should be regulated irrespective of ownership form.

Data availability remains a serious issue and the attempt to include all combinations of institutional settings proved difficult. However, the results do provide additional information beyond that of the individual regression models. The results suggest that ex-ante regulation at public and major or fully private airports located in a competitive environment is unnecessary and generates x-inefficiency of the order of 15% (this is substantially higher at purely public airports). On the other hand, airports enjoying a monopolistic position require economic regulation in order to encourage cost efficiency and dual till, price-cap regulation would appear to be the most efficient form. In addition, whilst heavy delays impact cost efficiency negatively, high runway utilization increased efficiency by more than double the negative impact of delay. This would suggest that airports striving for cost efficiency may also need contracts to include service quality indicators or penalties in order to internalize the delay externalities suffered by airlines and passengers alike.

Future research would require substantially more data to permit an improved analysis of all the categories described here. Finer distinctions with respect to ownership form and regulation might better highlight the most efficient institutional setting given alternative levels of competition. Additional environmental variables, including delays, noise and air pollution, would enable the development of a social welfare analysis of airports and the trade-off across the different stakeholders.

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Appendix

Appendix 1: List of Airports

Code	Airport	Country	Time Period	Ownership	Regulation	Competition	Ground Handling
ABZ	Aberdeen	UK	99-05	fully private	no ex-ante regulation	weak	not provided
AMS	Amsterdam	NL	98-06 2007	public	cost-plus incentive	heavy	not provided
ATH	Athens	GR	05-07	minor private	cost-plus	weak	not provided
BFS	Belfast	UK	99-07	fully private	no ex-ante regulation	weak	not provided
BHX	Birmingham	UK	98-07	major private	no ex-ante regulation	heavy	not provided
BLQ	Bologna	IT	00-05	public	no ex-ante regulation	heavy	provided
BRE	Bremen	DE	98-07	public	cost-plus	heavy	provided
BRU	Brussels	BE	99-04	major private	cost-plus	heavy	not provided
BTS	Bratislava	SK	03-05 06-07	public major private	no ex-ante regulation	weak	provided
BUD	Budapest	HU	00-01	public	no ex-ante regulation	weak	not provided
CGN	Cologne Bonn	DE	98-07	public	cost-plus	heavy	provided
CPH	Copenhagen	DK	01-04	major private	incentive	weak	not provided
DRS	Dresden	DE	98-06	public	cost-plus	weak	provided
DTM	Dortmund	DE	98-07	public	cost-plus	heavy	provided
DUB	Dublin	IE	06-07	public	incentive	weak	not provided
DUS	Dusseldorf	DE	99-07	major private	cost-plus	heavy	provided
EDI	Edinburgh	UK	98-07	fully private	no ex-ante regulation	heavy	not provided
EMA	East Midlands	UK	98-06	fully private	no ex-ante regulation	heavy	not provided
FRA	Frankfurt	DE	02-07	minor private	incentive	heavy	provided
GLA	Glasgow	UK	98-06	fully private	no ex-ante regulation	heavy	not provided
GVA	Geneva	CH	98-07	public	no ex-ante regulation	weak	not provided
HAJ	Hanover	DE	98-07	minor private	cost-plus	weak	provided
HAM	Hamburg	DE	98-99 00-07	public minor private	cost-plus incentive	heavy	provided
LBA	Leeds Bradford	UK	98-02, 06-07	public	no ex-ante regulation	heavy	not provided
LCY	London City	UK	99-07	fully private	no ex-ante regulation	heavy	not provided
LEJ	Leipzig	DE	98-06	public	cost-plus	weak	provided
LGW	London Gatwick	UK	98-05	fully private	incentive	heavy	not provided
LHR	London Heathrow	UK	98-05	fully private	incentive	heavy	not provided
LJU	Ljubljana	SI	98-06	major private	no ex-ante regulation	heavy	provided
LTN	London Luton	UK	00-07	fully private	no ex-ante regulation	heavy	not provided
LYS	Lyon	FR	98-06	public	no ex-ante regulation	weak	not provided
MAN	Manchester	UK	98-07	public	incentive	heavy	not provided
MEL	Melbourne	AU	99-01 02-07	fully private	incentive no ex-ante regulation	weak	not provided
MLA	Malta	MT	02-06	major private	incentive	weak	not provided
MLH	Basel Mulhouse	FR	98-07	public	no ex-ante regulation	weak	not provided
MRS	Marseille	FR	98-06	public	no ex-ante regulation	heavy	not provided
MUC	Munich	DE	98-05	public	cost-plus	heavy	provided
NCE	Nice	FR	98-06	public	no ex-ante regulation	heavy	not provided
NUE	Nuremberg	DE	98-07	public	cost-plus	weak	provided
OSL	Oslo	NO	99-03 04-07	public	cost-plus incentive	weak	not provided
PER	Perth	AU	99-01 02-07	fully private	incentive no ex-ante regulation	weak	not provided
RIX	Riga	LV	04-06	public	no ex-ante regulation	weak	provided
SOU	Southhampton	UK	99-05	fully private	no ex-ante regulation	heavy	not provided
STN	London Stansted	UK	98-06	fully private	incentive	heavy	not provided
STR	Stuttgart	DE	98-07	public	cost-plus	weak	provided
SYD	Sydney	AU	03-07	fully private	no ex-ante regulation	weak	not provided
SZG	Salzburg	AT	2004 05-07	public	cost-plus incentive	weak	provided
TLL	Tallinn	EE	02-07	public	cost-plus	weak	provided
VCE	Venice	IT	00-04 2005	public minor private	no ex-ante regulation	heavy	not provided
VIE	Vienna	AT	98-07	minor private	incentive	heavy	provided
ZRH	Zurich	CH	01-07	minor private	no ex-ante regulation	heavy	not provided

Appendix 2: DEA Efficiency Scores

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ABZ	-	0,579	0,599	0,546	0,522	0,505	0,515	0,536	-	-
AMS	1,000	1,000	1,000	0,496	0,309	0,249	0,253	0,297	0,259	0,280
ATH	-	-	-	-	-	-	-	0,421	0,432	0,450
BFS	-	0,512	0,489	0,487	0,480	0,485	0,575	0,502	0,500	0,502
BHX	0,549	0,577	0,598	0,582	0,568	0,583	0,535	0,530	0,514	0,481
BLQ	-	-	0,755	0,715	0,710	0,733	0,698	0,740	-	-
BRE	0,587	0,648	0,602	0,589	0,585	0,568	0,575	0,568	0,562	0,562
BRU	-	1,000	1,000	0,653	0,455	0,417	0,431	-	-	-
BTS	-	-	-	-	-	0,854	0,732	0,575	0,579	0,563
BUD	-	-	0,357	0,336	-	-	-	-	-	-
CGN	0,390	0,410	0,390	0,417	0,409	0,388	0,361	0,350	0,337	0,323
CPH	-	-	-	1,000	0,617	0,562	0,635	-	-	-
DRS	0,639	0,588	0,575	0,547	0,559	0,574	0,548	0,538	0,532	-
DTM	1,000	0,843	0,732	0,472	0,433	0,418	0,408	0,410	0,410	0,408
DUB	-	-	-	-	-	-	-	-	0,504	0,475
DUS	-	1,000	1,000	0,605	0,682	0,472	0,588	0,531	0,508	0,574
EDI	0,664	0,712	0,714	0,702	0,713	0,718	0,738	0,711	0,620	0,661
EMA	0,637	0,628	0,629	0,606	0,629	0,640	0,637	0,584	0,558	-
FRA	-	-	-	-	1,000	1,000	1,000	1,000	0,732	1,000
GLA	0,702	0,712	0,714	0,705	0,693	0,685	0,697	0,703	0,692	-
GVA	0,635	0,660	0,791	0,720	0,709	0,700	0,676	0,638	0,645	0,687
HAJ	0,313	0,319	0,331	0,316	0,314	0,310	0,308	0,301	0,302	0,297
HAM	0,535	0,524	0,426	0,394	0,399	0,381	0,420	0,404	0,406	0,414
LBA	1,000	1,000	0,901	0,830	0,842	0,881	0,888	-	-	-
LCY	-	1,000	1,000	0,933	0,887	0,867	0,799	0,744	0,888	1,000
LEJ	0,571	0,570	0,392	0,382	0,374	0,369	0,367	0,337	0,359	-
LGW	1,000	0,861	1,000	0,744	0,682	0,619	0,658	0,537	-	-
LHR	1,000	1,000	1,000	0,907	1,000	0,852	1,000	1,000	-	-
LJU	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	-
LTN	-	0,584	0,518	0,525	0,513	0,520	0,564	0,511	0,529	0,473
LYS	0,487	0,504	0,525	0,509	0,459	0,443	0,448	0,414	0,417	-
MAN	0,477	0,425	0,407	0,334	0,352	0,434	0,504	0,442	0,434	0,397
MEL	-	0,862	1,000	1,000	0,815	0,760	0,903	1,000	1,000	1,000
MLA	-	-	-	-	1,000	1,000	1,000	1,000	1,000	-
MLH	0,887	0,821	0,670	0,542	0,502	0,439	0,432	0,438	0,414	0,413
MRS	0,832	0,844	0,932	0,808	0,621	0,586	0,597	0,600	0,588	-
MUC	0,335	0,338	0,355	0,353	0,332	0,263	0,264	0,234	-	-
NCE	1,000	1,000	1,000	0,857	0,684	0,612	0,543	0,526	0,538	-
NUE	0,628	0,613	0,636	0,619	0,596	0,574	0,578	0,570	0,568	0,564
OSL	-	0,555	0,517	0,515	0,440	0,479	0,441	0,458	0,494	0,543
PER	-	1,000	1,000	0,972	0,790	0,689	0,678	0,673	0,703	1,000
RIX	-	-	-	-	-	-	0,547	0,558	0,563	-
SOU	0,847	0,919	0,943	0,720	0,617	1,000	0,751	-	-	-
STN	0,670	0,770	0,651	0,595	0,723	0,707	0,661	0,635	-	-
STR	0,561	0,564	0,559	0,534	0,513	0,505	0,462	0,516	0,513	0,519
SYD	-	-	-	-	-	0,563	0,748	1,000	1,000	1,000
SZG	-	-	-	-	-	-	0,733	0,716	0,722	0,723
TLL	-	-	-	-	0,904	0,690	0,628	0,522	0,516	0,513
VCE	-	-	0,625	0,599	0,627	0,671	0,682	0,545	-	-
VIE	0,428	0,456	0,471	0,396	0,365	0,338	0,338	0,325	0,320	0,310
ZRH	-	-	-	0,656	0,532	0,516	0,481	0,342	0,315	0,306