Efficiency of German Airports and Influencing Factors

Diploma for the degree Master of Science (MSc)
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LIST OF ABBREVIATIONS

ACI	Airports Council International
ADV	German Association of Commercial Airports (Arbeitsgemeinschaft Deutscher Verkehrsflughäfen)
AENA	Spanish Airports and Air Navigation (Aeropuertos Españoles y Navegación Aérea)
ANA	Airport Authority of Portugal (Aeroportos de Portugal)
ATC	Air Traffic Control
ATM	Air Transport Movement
ATRS	Air Transport Research Society
BAA	British Aviation Authority
CAA	Civil Aviation Authority
CC	Competition Commission
DEA	Data Envelopment Analysis
DGP	Data Generating Process
DMU	Decision Making Unit
EC	European Commission
EU	European Union
EW-TFP	Endogenous Weighted Total Factor Productivity
GAP	German Airport Performance
GmbH	Limited Company (Gesellschaft mit beschränkter Haftung)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
KPI	Key Performance Indicator
LCC	Low Cost Carrier
MLE	Maximum Likelihood Estimation
NERA	National Economic Research Associates
OLS	Ordinary Least Squares
PAX	Passengers
PFP	Partial Factor Productivity
SFA	Stochastic Frontier Analysis
SH&E	Simat Helliesen & Eichner
SMOP	Surface Measure of Overall Performance
TFP	Total Factor Productivity
TRL	Transport Research Laboratory
WLU	Work Load Unit

LIST OF AIRPORTS AND AIRPORT GROUPS

IATA	Airport	Country		IATA	Airport	Country
ABZ	Aberdeen	UK		LBA	Leeds/Bradford	UK
ADM	Milan Airport Group	Italy		LBC	Lübeck	Germany
ADP	Paris Airport Group	France		LCY	London City	UK
ADR	Rome Airport Group	Italy		LEJ	Leipzig	Germany
AHO	Alghero	Italy		LGW	London Gatwick	UK
AMS	Amsterdam	Netherlands		LHR	London Heathrow	UK
AOI	Ancona	Italy		LPL	Liverpool	UK
ATH	Athens	Greece		LTN	London Luton	UK
BER	Berlin Airport Group	Germany		MAD	Madrid Barajas	Spain
BFS	Belfast Int.	UK		MAN	Manchester	UK
BGY	Bergamo	Italy		MRS	Marseilles	France
BHX	Birmingham	UK		MUC	Munich	Germany
BLQ	Bologna	Italy		NAP	Naples	Italy
BRE	Bremen	Germany		NCL	Newcastle	UK
BRS	Bristol	UK		NRN	Düsseldorf-Weeze	Germany
BRU	Brussels	Belgium		NUE	Nuremberg	Germany
CAG	Cagliari	Italy		OLB	Olbia	Italy
CDG	Paris Charles de Gaulle	France		OSL	Oslo	Norway
CGN	Cologne-Bonn	Germany		PAD	Paderborn/Lippstadt	Germany
CPH	Copenhagen	Denmark		PMO	Palermo	Italy
CTA	Catania	Italy		PSA	Pisa	Italy
CWL	Cardiff Int.	UK		PSR	Pescara	Italy
DAA	Dublin Airport Authority	UK		REG	Reggio di Calabria	Italy
DRS	Dresden	Germany		RMI	Rimini	Italy
DTM	Dortmund	Germany		SCN	Saarbrucken	Germany
DUS	Düsseldorf	Germany		SOU	Southampton	UK
EDI	Edinburgh	UK		STN	London Stansted	UK
ERF	Erfurt	Germany		STR	Stuttgart	Germany
FDH	Friedrichshafen	Germany		SUF	Lamezia	Italy
FKB	Karlsruhe/Baden-Baden	Germany		SXF	Berlin Schönefeld	Germany
FLR	Florence	Italy		THF	Berlin Tempelhof	Germany
FMO	Münster Osnabrück	Germany		TPS	Trapani	Italy
FRA	Frankfurt Main	Germany		TRN	Turin	Italy
FRL	Forio	Italy		TRS	Trieste	Italy
GLA	Glasgow	UK		TXL	Berlin Tegel	Germany
GOA	Genoa	Italy		VCE	Venice	Italy
HAJ	Hanover	Germany		VIE	Vienna	Austria
HAM	Hamburg	Germany		ZRH	Zurich	Switzerland
HHN	Frankfurt Hahn	Germany				

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1 Introduction

Although it has been supported by many researchers that each airport has its own characteristics in terms of technical, operational, environmental and financial variables and comparisons might lead to misleading results, airports have intensively and continuously been subject to benchmarking analyses which aim at airport rankings according to their efficiency scores. Airports can be regarded as firms, which use multiple inputs to produce multiple outputs in a complex production system. In this complex production process, generally more than one player, such as airlines, ground handling service providers, terminal operators or airport owners take place with a tight interrelation with each other. These, together with the fact that, airports are traditionally considered as natural monopolies, make the issue of airport benchmarking complicated. The question why airports has attracted so much attention in terms of benchmarking and efficiency measurements in the last decades can be answered with a focus on a number of different aspects.

1.1 What Leads to Airport Benchmarking and Efficiency Measurements?

First of all, airports were challenged by a more competitive environment as a result of liberalization and deregulation process in air transport markets. Following this, changes in the ownership structures due to different privatization processes, have raised questions whether privatization leads to a better performance –due to better management– of airports. Different ownership structures have been mentioned almost in every analysis, which aimed to compare the efficiency of airports. (Parker, 1999; Haririan, Vasigh, 2003; Graham, Vogel, 2006)

Second, regulation of airport charges is considered to be one of the main determinants of efficiency of an airport, especially in case of larger airports with capacity constraints and high congestion levels. In European airport industry, there are mainly three types of charges regulation which have been used (Starkie, 2005). One of them is traditional rate-of-return regulation, which is considered to lose its relevance in airport regulation (Piacentino, 2006). With this type of regulation, the regulator allows airports a pre-determined rate of return on capital by setting the price to be charged accordingly. It takes into consideration, in what quantity the marginal cost of capital changes. Hence, in case of uncertainty it leads to the well-known Averch-Johnson effect which implies that the airports adopt a higher level of capital than its efficient level (Averch and Johnson, 1962). Because of some problems with implementation in airport industry, including the one mentioned above, there has been a tendency towards using incentive regulation, which most of the time takes the form of price-cap. This type of regulation allows airports to increase its prices, by taking the level of inflation and technological change into account and it is considered to be more efficient than the former. Besides, there are different implementations of this type of regulation in different airports, resulting from specific agreements between airports and the regulator. The last and the least used type of regulation is the conduct regulation[1], which is implemented ex-post.

Besides type of regulation, relationship between regulation and the efficient use of airport resources has been subject to economic research, because this is one of the two mechanisms to allocate the resources together with slot allocation according to IATA procedure guide (Niemeier, 2002a). This phenomenon has not been as popular as privatization, regarding the determinants of efficiency in benchmarking analyses, but it has been investigated separately.

Naturally, in determination and implementation of the regulation type, there is a close link to the level of competition to find out the monopolistic power of an airport. In narrow sense, airport competition is determined by the number of airports in an overlapping catchment area. Moreover, several definitions of airport competition and the existence of different players in the picture as airports, airlines and service providers make the analysis of airport competition even harder. For example, there is no consensus on which airport services are competitive and on which are monopolistic. Barrett (2000) points out that low degree of airline competition in the past was the main determinant of low degree of airport competition in Europe. However, this situation has changed first with the deregulation of airline industry, forcing airports to use more attractive

[1] It is not a commonly used type of regulation.

strategies for incumbent airlines as well as new entrants, and second with the development in low-cost-carrier market. Airports with excess capacity used low-cost-carriers for extra passengers, which can create extra revenue sources.

Hence, increasing level of competition and battle for the market power gave rise to the desire for the determination of "best practices" among airports which are competing with each other, in order to get support in developing new strategies to survive or to gain more power.

1.2 Which Players in the Industry are Interested in Benchmarking Results?

Airport benchmarking mainly aims to shed a light to the following two questions: 1- Which airports are more efficient than the others, what is the ranking? 2- What are the factors behind being more efficient?

Efficiency of an airport is determined in a combined way by first the environmental factors, which cannot be influenced by the managerial control and second by other factors, which come to presence with strategic decisions of the management. In order to implement the second set of factors in an effective way, airport managers are willing to get evidence of the situation within the sector, i.e. information about their own airports in comparison to other airports. Nevertheless, there is no consensus between airports what is the best management tool for acquiring this kind of information. Besides, different airports follow various strategies to reach different goals, which in turn reduce the probability that a benchmarking study has the same value for each airport. For example, more and more airports have been following a more business and commercially oriented approach during the last years. This, together with the fact that, more airports have been privatized recently and are being subject to pressure from private investors for a better and more efficient management , gave lead to the acceptance of airport benchmarking as an important tool for the airport management on decision process (Graham,2005).

Recently, more airports started to consult to benchmarking reports in order to evaluate their relative efficiency and to see how they can improve the way they manage. Francis et.al (2002) uses a questionnaire survey and interviews with the world's top 200 airports to specify how often the benchmarking practices are used for efficiency comparison and improvement. Table1 shows that almost half of the airports rely on Best Practice Benchmarking in comparison to other methodologies.

TABLE 1: PERFORMANCE MANAGEMENT TECHNIQUES

Technique	Percentage use by respondents*
Best Practice Benchmarking	46
Total Quality Management (TQM)	41
Activity Based Costing	36
Environmental Management Systems (eg ISO14000)	27
Balanced Scorecard	25
Business Process Reengineering	23
Quality Management Systems (eg ISO9000/BS5750or similar)	23
Business Excellence Model / EFQM	12
Value Based Management	9
Malcolm Baldridge Award	5

*Note that respondents could use more than one method

SOURCE: Francis et. al, 2002

In a regulated environment, together with the management of airport, the regulator also pays a special attention to the efficiency, as there is a direct link between the type of regulation and the efficiency of airport, as mentioned before. In order to steer airports on using the most efficient price mechanism, regulators aim to compare the airport of interest within a good and reasonable sample of airports. Regulators also believe that, benchmarking helps for choosing the correct type of regulation, so that airports will be able to have right investment incentives. Regulators' desire to consult to benchmarking stems from the fact that there is an information asymmetry between the regulator and the airport subject to regulation, which can be exploited by airports (CAA, 2000b).

After explaining the reasons why owners and/or operators and regulators would be interested in benchmarking airports, we can turn our attention to the customers. There are mainly two interrelated groups of customers of an airport. Initial customer is the airlines, which then help provision of the secondary group, namely passengers (NERA, 2001). Airlines' concerns on choosing an airport as operation node can be classified into different categories. Most important one is the demand coming from passenger side. In some cities airport creates its own demand, due to the characteristics of city. These characteristics refer to financial, cultural or touristic attractions of the city. However, in some cases, airlines and airports are together able to create demand or manipulate the supply & demand game by using passenger characteristics, independent of characteristics of the location (city). In recent years, we can see this in the form of low cost carrier airports, where the ultimate destination is in fact not where airport is located.

Despite the fact that airport charges constitute a small part of an airline's costs[2] (Wit, 1999), it remains one of the most important factors that influences an airline's decision on choice of airport, as airlines need to rely on long term strategies. One good example is the network of an airline by using hub and spoke system, which can be the most critical decision affecting an airline's overall performance. Charges can mainly be divided into two parts, first being related to landing and starting of an airplane and second to processing of passengers, i.e. ground handling services. Naturally airports are not free to determine their charges and they face some limitations. As instance, in Europe, the EU directive on airport charges was implemented in March 2009 and it aims to build up a uniform charges system within Europe, which directly affects the way airports, airlines and regulators interact with each other. These are the reasons why a large number of attempts has been made in order to benchmark airport charges, the users of these reports can be provided with a detailed comparison.

Two more points are worth mentioning, when the topic related to airport benchmarking is discussed. One of them is the average delay time of an aircraft in airports, which both concerns airlines and passengers. Overall efficiency of an airline is negatively influenced by the delays, which not only increase the costs due to network effects but also decrease the demand from passengers in medium or long term due to bad reputation. Delay in an airport is closely related to capacity of airport and reliability of ATC[3] system (Adler, Berechman, 2001).

Second factor is the quality of service in airports. This includes both the service offered to airlines and different facilities supplied for passengers. As in case of delays, quality of ground handling services also plays an important role on efficiency of airlines. It should also be kept in mind that delays do not only stem

[2] For large, international airlines around 5%, for smaller, short-haul airlines up to 15%

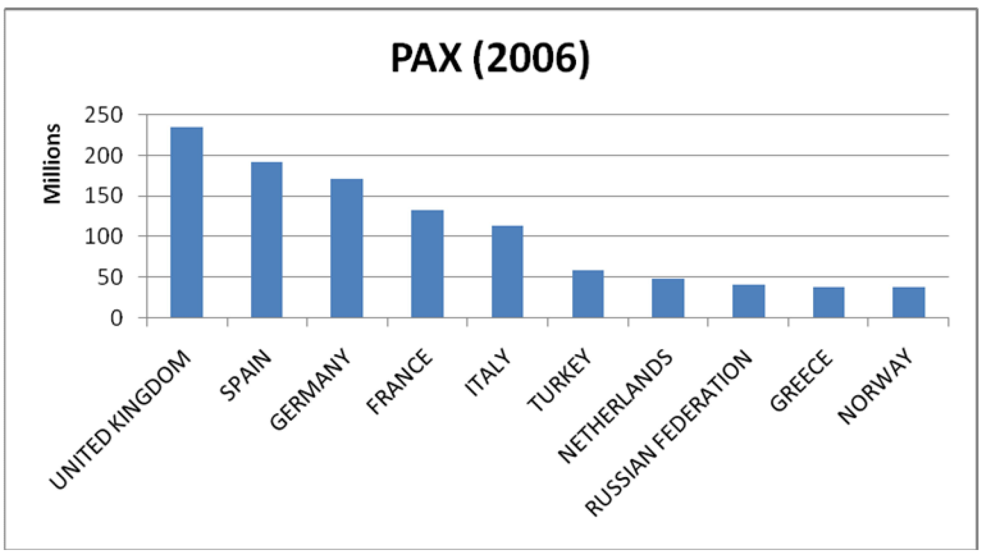
[3] Airport Traffic Control coordinates the landing and starting of aircraft in an airport.

from the bottlenecks on the runway system, but sometimes also from the poor service level on ground. Moreover, airports try to attract passengers by means of a better service and by offering various facilities. Surveys from internal airport sources and independent institutions are continuously used to find out passengers' view on the quality of airports.

1.3 Why are We Interested in Efficiency of German Airports?

Following the United Kingdom and Spain, Germany is the third biggest market in air transport industry in Europe with around 172 million passengers in 2006. Figure 1 shows the biggest ten countries in Europe, measured by number of passengers (PAX). Moreover the size of market in Germany, again measured by number of passengers, increased by more than 30% in the last 10 years. In addition to demand, supply also increased by either adding a new airport to the system or by increasing the capacity of existing airports, which resulted in a stronger competition among German airports.

FIGURE 1: NUMBER OF PASSENGERS IN EUROPA



SOURCE: ACI World Airport Traffic Report, 2006

Nevertheless, despite the importance of Germany in air transport market in Europe, lack of research in national and international level as far as benchmarking is considered is remarkable. International benchmarking studies did not pay enough attention to German airports; they just included some of the largest airports in the sample. Due to lack of consistent data, international benchmarking studies have concentrated on details with respect to technical and traffic data rather than financial strengths or weaknesses. On the other hand, there are couple of studies which also depict the financial performance of airports; however they only use unsatisfactory and heavily criticized analyses such as key performance indicators (KPI) (TRL, 2000; ATRS, 2003). Moreover, on a national scale, there has been an ongoing research within the scope of German Airport Performance (GAP) Project to compare German airports with each other, but complex analyses were again used to investigate technical side and partial analyses were mainly used for financial variables.

Furthermore, these international benchmarking studies concluded that German airports operate not as efficient as their European counterparts, which are in fact their strongest competitors. Müller et.al (2009) points out, that these inefficiencies might stem from incomparability issues between countries or airports. It is also suggested that the data should be used with special care when comparing airports from different countries in order to have consistent results.

In addition, mixed ownership structure of German airports[4] have not only been a main subject in academic world, but also questioned and discussed by authorities who have an active role in airport industry. Moreover, topics such as government subsidies, regulatory institutions and competition have been subject to deep investigations. For example, as public airports got subsidies from local or federal government, it is considered to distort the competitive environment by influencing the level of charges (Petzold, 2003).

All these facts explained above gave rise to the idea that German airports should be benchmarked in order to find answers for a number of questions. The first question, and the most important, deals with the financial efficiency of German airports in order to determine "best practice airport(s)". This can allow

[4] In Germany, there are public, private and public-private airports. For details, please see Chapter 6.

for a comparison of the best performing airport in Germany with international airports from other countries. With the help of these results, the second question can be answered, which investigates the reasons for different efficiency levels.

Time dimension is another subject, which requires attention while investigating the efficiency of German airports. The efficiency against itself in time horizon is also a challenge for an airport, as well as that against other airports. As stated before, benchmarking analyses have been conducted for a relatively long time and they tried to make policy implications about how to increase efficiency. Hence, by using a reasonable time series the changes in efficiency over time could be observed and it can be judged whether the airports have learned lessons from those analyses, which were conducted internally by themselves or externally by independent parties. In addition, German airports have undertaken some capacity expansions in last decade in order to comply with increasing demand. Thus, a dynamic efficiency analysis can be used to remark how effective the investments have been utilized and how good they were reflected in the financial performance.

This master thesis is structured as follows. In Chapter 2 efficiency concept will be explained, with a special focus on airport efficiency. Chapter 3 will focus on explaining the methodologies used to assess airport efficiency. Chapter 4 will have a detailed look at the literature review of airport benchmarking. In Chapter 5 the economic factors on airports efficiency will be presented. Chapter 6 will give a detailed overview of airport industry in Germany. In Chapter 7, data and methodology will be introduced and empirical results will be presented. Chapter 8 will contain the discussion on empirical results. Finally, Chapter 9 will draw the conclusions.

2 Efficiency

2.1 Efficiency vs. Productivity

The terms *efficiency* and *productivity* are mostly used interchangeably, although the underlying meanings of these two terms are not identical. The main difference between *efficiency* and *productivity* lies in concept of maximum attainable outputs. More detailed, *efficiency* does take the maximum output into account, which can be produced with the available inputs, while *productivity* does not.

On the one hand, *productivity* simply calculates the ratio of inputs used in production to the outputs obtained for a production unit (firm). Then, relative productivity can be calculated using the ratios from different production units[5] (Ray, 2004). In order to measure the *efficiency* of a firm, on the other hand, the maximum output a firm can produce by using its inputs should be first calculated. There are two ways of calculating the maximum attainable output. One way is to put the inputs into production function, when information about production technology (function) is available. If there is no information available, then a sample of production units must be constructed and with the help of inputs and outputs from this sample the maximum attainable output should be calculated. [6] Once this is calculated using one of these ways, the ratio of "actual output" to "maximum attainable output" gives the *efficiency* of this firm. If this ratio equals to one, it can be concluded that the firm produces efficiently.

The above explained measure of *efficiency* is output-oriented, where outputs are maximized with a given level of inputs. With same logic, one can also focus on the minimum input(s) to produce a given level of output(s), in order to calculate input-oriented *efficiency*.

2.2 Economic Efficiency

In different fields of economics, it is possible to find different definitions of economic efficiency. For example, Barros and Sampaio (2004) defines it as *"the relative productivity over time or space, or both".* For Bazargan and Vasigh (2003), on the other hand, economic efficiency means *"the firm is using resources in such combinations that the cost per unit of output for that rate of output is the*

[5] If Xa is the input, Ya is the output of firm A and Xb is the input and Yb is the output of firm B, productivity of A is Pa=Ya/Xa, of B is Pb=Yb/Xb and relative productivity of A relative to B is Pa/Pb.

[6] This is the main idea behind Data Envelopment Analysis, which uses a sample of production units in order to construct the representative technology. It will be explained later in detail.

least". The key fact in first definition most probably relates to "relativity". According to that, economic efficiency can be measured only if there is an available sample to compare a production unit, either with other production units, or with itself over a period. In contradiction, second one does not necessarily use a sample; it only considers the cost of production. These examples show that, *"efficiency"* can be used with various meanings according to the goal of analysis.

2.3 Airport Efficiency

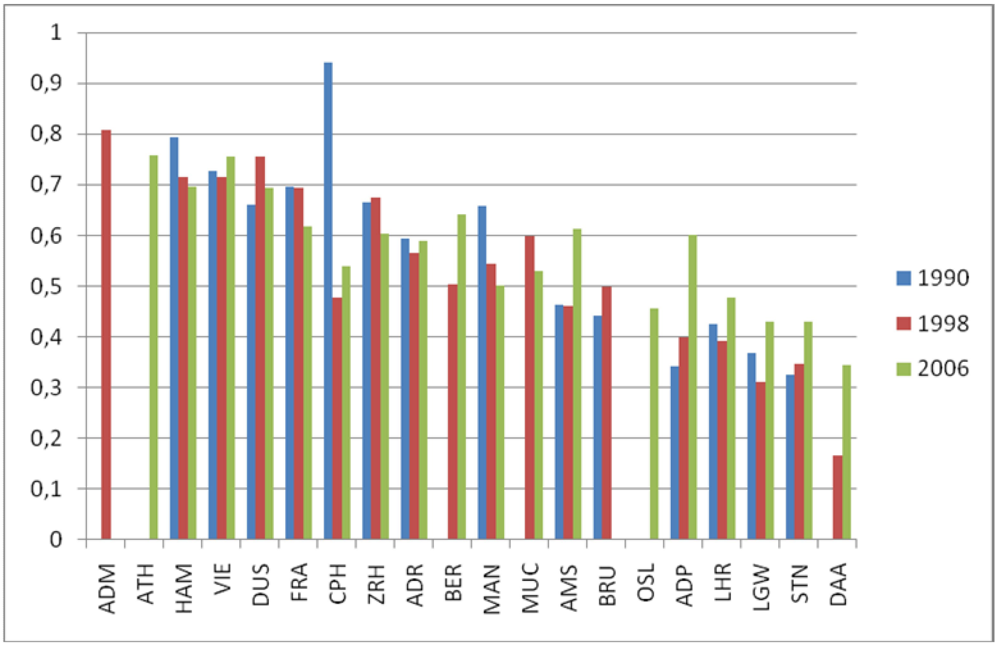
Airports produce multiple outputs by using multiple inputs, which are not as concrete as in case of other industries. Furthermore, production process in airports is segmented and each segment has a qualitatively different approach. For this reason, there is no consensus, both in academic world and in industry, on defining the inputs and outputs of airports.

2.3.1 Financial Efficiency

Terms used in airport efficiency analyses do differ from general terminology of efficiency measurements. For instance, "economic efficiency" generally represents the financial efficiency of an airport. An airport has mainly two different sources of revenues. One of them is the aeronautical revenues and it refers to the landing, passengers, parking, central infrastructure, ground handling, apron and cargo fees. Furthermore airports rely on the non-aeronautical revenues, which are not related to airports' main service. These revenues are composed of duty free sales, retail store and restaurant sales, rents, car parking fees and advertising revenues. The ratio of aeronautical revenues to non-aeronautical revenues is affected by different factors such as type of the airport (international hub, regional hub, low cost carrier, touristic etc.), passenger profile, and competitiveness of the airport or the regulation type and structure. As instance, Park (2003) assumes that a more competitive airport has a higher percentage of non-aeronautical revenues, as they are under pressure of airlines to lower their charges. The same argument applies to the low cost carrier airports regarding charges. However, the passenger profile of such airports is composed of leisure travelers, whose willingness to pay for different goods and services is also low.

Hence, the situation is ambiguous regarding these kinds of airports. Figure 2 shows the share of aeronautical revenues in total operating revenues of selected European airports to give an idea of the situation from 1990 to 2006.

FIGURE2: PERCENTAGE OF AERONAUTICAL REVENUES TO TOTAL REVENUES IN SELECTED EUROPEAN AIRPORTS



SOURCE: GAP-Database from Annual Reports

Financial efficiency uses typical variables, which are published in annual reports of airports. These variables include "the operational costs", which represent costs for labor, or other operating costs; "the assets" divided into current and non-current assets and "the operational revenues" divided into aeronautical and non-aeronautical revenues. To specify the financial efficiency of airports, these variables can be used for constructing the conventional financial ratios such as basic earnings power, operating profit margin, return on capital employed and asset turnover. These variables can also be used together with traffic data to construct Key Performance Indicators such as total costs per passengers, total revenues per passengers or total aeronautical revenues per aircraft movement.

2.3.2 Operational Efficiency

2.3.2.1 Airfield

Airfield efficiency refers to the core business of airports; namely the air transportation. It is a complex system of runways, apron and terminal together. The capacity on airfield is determined by number of air transport movements (ATM) and the type of aircraft (Competition Commission, 2007). Naturally the most important part of this system is the runways. Number of runways in an airport is the most decisive variable which determines and restricts the overall capacity. As in case of financial efficiency, some studies have developed Key Performance Indicators by combining traffic data with number of runways. Most common KPI used was number of aircraft movements per number of runways. However, number of runways alone gives misleading conclusions, especially in terms of efficiency comparisons. Taking into account that the length and width of a runway determines the served aircraft type, some researchers turned their attention to total length or total area of runways as a next step in their analyses, which was supposed to give more reasonable results than using number of runways. Yet these two variables do not give satisfying conclusions for capacity measurements; since configuration of runways plays also an important role by determination of total capacity, for the case when there are more than one runway. For a consistent comparison, ICAO has classified different runway configurations and also specified the number of ATMs to be handled in an hour with each configuration, in case there are no additional limitations. Appendix 1 shows this classification in details. This is also called “design capacity” of a runway system.

In addition to runways, taxiway system[7] is also crucial for the capacity of airfield, i.e. number of ATMs to be handled. Thus, the operator should aim to channel the aircraft in such a way that it leaves the runway as fast as possible and arrives at the terminal (or parking position) as effective and safe as possible. By doing so, free capacity is created on runway for the operation of next aircraft.

The last but not the least determinant of airfield capacity is the number, position and size of aircraft parking positions. These can be located either next to

[7] Taxiway is the path used by aircraft to reach the apron or terminal.

the terminal, where passengers are transferred via bridges, or they can be located far from terminal, where passengers approach the terminal by busses or by walking. If there is not enough space for aircraft parking, the capacity of runway loses its importance, as it will be occupied by another aircraft for longer time.

Aside from the infrastructural specifications in airport, which have been explained above, the size, type and weight of the aircraft also play an important role in determination of airfield capacity. For this reason data for different fleet mixes has become more and more important in assessment of airfield capacity and in efficiency analyses.

Table 2 below summarizes the factors which influence the efficiency of airfield. The underlying purpose of explaining airfield efficiency is to highlight the following fact: Efficiency and benchmarking analyses which only use the number of runways or the number of aircraft parking positions in order to compare airports are not sufficient for evaluating the system as a whole, but they are just considering one aspect of this complex system. As a result, conclusions of these simple analyses lead to misleading interpretations. However, the literature on airport efficiency and benchmarking still suffers from the lack of a satisfactory methodology and analysis, which considers the system with its all determinants.

TABLE 2: DETERMINANTS OF AIRFIELD EFFICIENCY

Airport Infrastructure	**Aircraft**
Number of Runways	Aircraft Type
Length and Width of Runways	Aircraft Size
Configuration of Runways	Aircraft Weight
Taxiway System	
Number and Size of Aircraft Parking Positions	

Another concept, called “declared capacity”, has also been used in order to measure the runway capacity of an airport. The difference to the “design capacity”, however, lies in the fact that declared capacity considers different factors, such as noise, air traffic control (ATC), apron and terminal considerations, in order to determine the maximum number of ATMs which can be handled in an hour. Even so, some problems have not been solved, because different airports use different considerations while declaring the runway capacity of airport. Moreover, there are many other definitions of runway (or airfield) capacity, which have been sometimes used interchangeably. These factors create obstacles for the so-called “apples to apples” comparison for airports. For more details of these problems, different definitions of airfield capacity and a benchmarking analysis of runway efficiency, see Ülkü (2009).

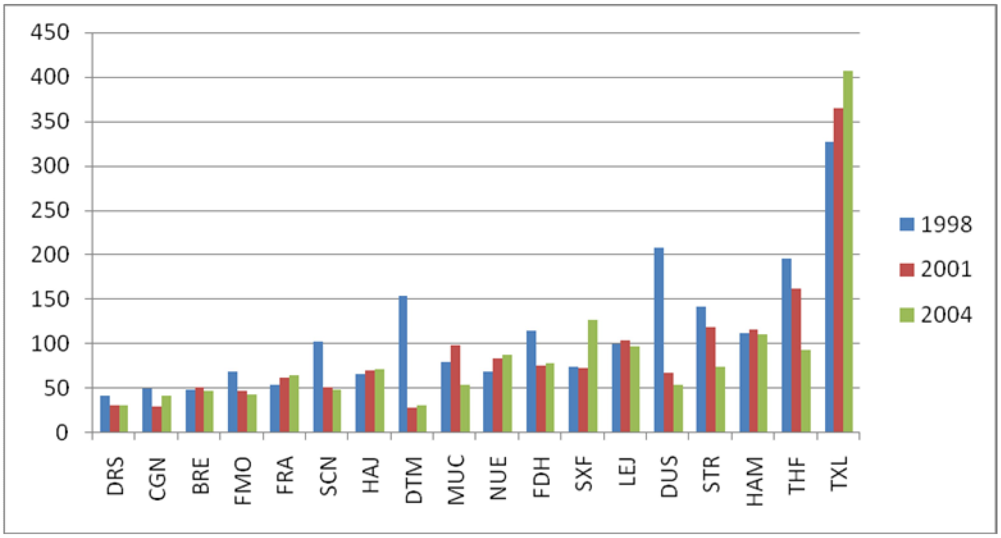
2.3.2.2 Terminal

Terminal efficiency traditionally refers to the number of passengers processed relative to the variables defined by the terminal infrastructure. Airports allocate terminal space to two different facilities. First group relates to the aviation purposes and consists of number of loading bridges, gates, security units, baggage claim units and check-in desks. Car parking lots can also be considered to belong to this group, which has a direct effect on terminal efficiency.

Second group, on the other hand, deals with the concession and includes the facilities such as restaurants and retail stores. In last years, airports have been giving more attention to implement the best combination for these fields in order to create additional revenue sources from non-aeronautical fields and thus maximizing profits.

Analyses, which have targeted to measure terminal efficiency, mostly applied KPIs and econometrical models by using variables in the first group related to aviation purposes mentioned above. In addition to these, terminal area was also considered to be an important input. Researchers often used passengers per number of gates, per number of check-in counters and per terminal area as indicators of capital efficiency on terminal side. Figure 3 presents one of the KPIs explained for German airports.

FIGURE 3: PAX / Total Terminal Area in sqm



SOURCE: Own Calculations using GAP-Database

Although these variables are not as problematic as their counterparts in airfield, it is again difficult to conclude that they show very robust results. One main criticism, as instance, questions the variable "terminal area". Despite giving an insight about the scale of terminal, it does not reflect the capacity level totally. For example, two airports with terminals of equal size do not necessarily supply the same level of capacity due to different structures of aviation and non-aviation facilities. In addition, terminal buildings are lump-sum investments, which are built by considering a higher future demand, in order to prevent a more costly capacity expansion. This influences the current terminal efficiency. Figure 3 shows that Tegel airport is producing almost four times as passenger than Leipzig, although they have almost the same terminal size. This, most probably, is due to Tegel's high volume of passengers in combination with its special terminal structure. Other facts affecting this result are the airport's hub status and the importance of transfer passengers. Frankfurt, as instance, has dramatically lower figures than Tegel because of its huge terminal in order to be able to handle transfer passengers. Thus, a comparison, which uses such KPIs, should be interpreted with a special care, by considering each individual characteristic of an airport.

2.3.2.3 Ground Handling

Ground handling services include both airfield and terminal side. The airfield side includes any service regarding the aircraft, starting with its landing until it leaves the airport. Activities such as ramping services[8], on-board services, flight planning and aircraft weight balancing belong to this group. On the terminal side, check-in, security, baggage handling and ticketing are some of the tasks of ground handler.

Ground handling, at first instance, seems to be very capital intensive. Especially services regarding the aircraft require specific and high technology equipment. However, from an operational perspective, labor also plays an important role on efficiency or quality of the service. First of all, labor needs to be task-oriented, because ground handling can be divided into a variety of services. For instance, aircraft needs to be loaded or unloaded with passengers, baggage, cargo and fuel. Other facilities of aircraft such as electricity, water or cleaning demand a qualitatively different service. Second, the flexibility of workers plays an important role in efficiency as "delays" is an important fact, which should be kept in mind. In this case, allocation of labor can be problematic and the priorities should be given correctly for an efficient service. This shows the importance of ground handling services management on efficiency.

Economic implication of ground handling services on efficiency has also been discussed in aviation industry. This is an issue of competition within the airport, which directly affects efficiency. Ground handling can be provided either by airline, airport or independent ground handling company. Formerly the airports could decide if they can outsource these activities (totally or partly) or not. Some airlines also prefer to do the ground handling by themselves under efficiency concerns. In order to overcome these questions and regulate the ground handling market in Europe, the European Union undertook the "Council Directive 96/97/EC" in 1996. The objectives were mainly to promote the liberalization of market, improve the quality and decrease the costs for these services. The

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[8] It mainly refers to the loading and unloading of aircraft, and passenger, baggage and cargo transferring to the terminals.

Directive determines the restrictions or freedoms on choosing the service providers.

These directives and corresponding changes have been subject to recent research. Schmiedberger et al. (2009) investigates the efficiency of ground handling services in European hub airports and finds differences in terms of employee structures. Another conclusion in this study is that outsourcing these services brings cost efficiency. For more details on ground handling services and liberalization, see SH&E (2002), Fuhr and Beckers (2006) and Templin (2007).

3 Methodologies Used to Measure Airport Efficiency

Different mathematical and statistical methodologies have been used in the airport industry to assess the efficiency of airports with various goals. While some of these methodologies have disadvantages in terms of their general properties, others have been criticized because of being inappropriate for the airport sector. A couple of criteria play a role on choosing the methodology used. One of them relates to the way, efficiency is being questioned. For instance, for airfield efficiency some methodologies could give totally inconsistent results, because a research on this field is a combination of economics, engineering and logistics. On the other hand, in order to ascertain financial efficiency, one should rely on specific methodologies. Second criterion on methodology choice is the availability of data. Some methodologies require particular data, which might not be easy to access for each airport, others could utilize data, which is easy to collect for any single airport.

In this chapter, different methodologies will be explained briefly, their characteristics are going to be defined and their advantages and drawbacks will be presented. Then, in the next chapter, the literature, which applies these methodologies to the airports, will be reviewed.

3.1 Partial Factor Productivity (PFP)

Partial factor productivity deals with the ratio of one output to the ratio of one input, in order to assess efficiency, with respect to a specific field and it does not give any conclusions on overall efficiency. Generally, three variables are considered as outputs of an airport in the literature. These are the number of passengers and ATMs and the volume of cargo. In addition to these, a term called Work Load Unit (WLU) was developed, which combines passengers and cargo into one figure. 1 WLU, therefore, equals 1 passenger or 100 kilograms of cargo. Partial factor productivity indicators focus on the labor and capital productivity as well as the financial productivity.

In order to measure the labor productivity; one of the outputs mentioned above is divided by number of employees according to the focus of the analysis. But it should be determined in advance what one means with number of employees. Concerning the airports, one possibility is using the number of employees, which are employed by the operator, which raises problems due to single-multiple airports operated by the operating company and also due to outsourcing (Pels, 2001). The operating company may provide all services by itself at the airports or contract these out to other parties. Second possibility is the use of total number of workers in the airport, which is more consistent in terms of productivity comparison.

Capital productivity, on the other hand, is measured by looking at the ratio of outputs to terminal or airfield inputs, such as number of gates and number of runways. However as explained in sections 2.3.2.1 and 2.3.2.2, these are considered to reflect a misleading comparison between airports.

The most common financial productivity indicators have been shown in section 2.3.1 and will not be explained here in detail.

The reason why the partial factor productivity indicators are used despite being often criticized is its simplicity both in terms of data collection and methodology. They give simple and easy to be interpreted (but only limited) results.

3.2 Total Factor Productivity (TFP)

In contrast to the partial productivity indicators, non-parametric total factor productivity aims at drawing conclusions on the overall efficiency of airports. To this end, it weights inputs and outputs according to their importance in production process and builds up an index for the end result. Inputs and outputs are generally weighted according to their cost and revenue shares, respectively. This index is the ratio of combined weighted outputs to combined weighted inputs. Hence, an airport with poor performance on capital productivity, for example, can still be better than others thanks to its good performance on other areas. As in case of partial factor productivity, this approach does not require specific information on data and production function, either.

Besides this simple, index based, non-parametric total factor productivity methodology, the endogenous weight TFP approach was developed in order to be able to implement a more efficient analysis. This approach, in contrast, assumes a specific production function for the airport, either with single or multiple input and output combinations.

3.3 Stochastic Frontier Analysis (SFA)

It is a parametric technique, which makes use of the production function of an airport and constructs a frontier using a sample, in order to calculate the relative efficiency of airports. First step of this analysis is to specify a production or a cost function, according to the focus of the analysis. A general production function used in SFA takes the following form:

$$\begin{aligned} y_{j,t} &= x'_{j,t}\beta + e_{j,t} \\ e_{j,t} &= v_{j,t} - u_{j,t} \end{aligned} \qquad (1)$$

where $y_{j,t}$ is the output vector of airport j in period t, and $x_{j,t}$ is the input vector of the same airport in same period. Error term $e_{j,t}$ is divided into two parts: i- the part which represents the inefficiency of airport $(v_{j,t})$, ii- the part which arises from statistical noise, measurement error and other factors which cannot be controlled $(u_{j,t})$. The specification of error term, however, can take different forms according to the econometrical assumptions. (Pels et al, 2001; Cullinane et.al, 2006).

On the other hand, a general cost function takes the following form:

$$C_{nt} = C(P_{ht}, y_{it}) \cdot e^{V_{nt}+U_{nt}}, \qquad \text{i = 1,2,…,N; t = 1,2,…,N} \qquad (2)$$

where C_{nt} represents the costs of n airports in period t; P_{ht} is the prices of inputs and y_{it} is the outputs produced by the production unit. Error term as in the previous case again composes of the two parts.

These functions can be represented in terms of production units, as in equations (1), or in logarithms, as in equation (2). After the production function is specified, either maximum likelihood estimation (MLE) or ordinary least squares (OLS) is used to build up the frontier. Inefficiency of a production unit can then be estimated by comparing the actual outputs produced with the maximum attainable outputs, which could be observed with the specified production function. For equation (1), the mathematical form for inefficiency derived from the frontier is as follows:

$$h_j{}^f = \frac{E(y_{j,t} | U_j, x_{j,t})}{E(y_{j,t} | U_j = 0, x_{j,t})} \qquad (3)$$

Nonetheless, application of this methodology suffers from the fact that the airports are complex production units. For this reason, inputs and outputs cannot be easily determined. Besides, although there have been many attempts, there is still no consensus on the statistical form of the production (or cost) function of an airport, regarding the specification and assumptions on error terms.

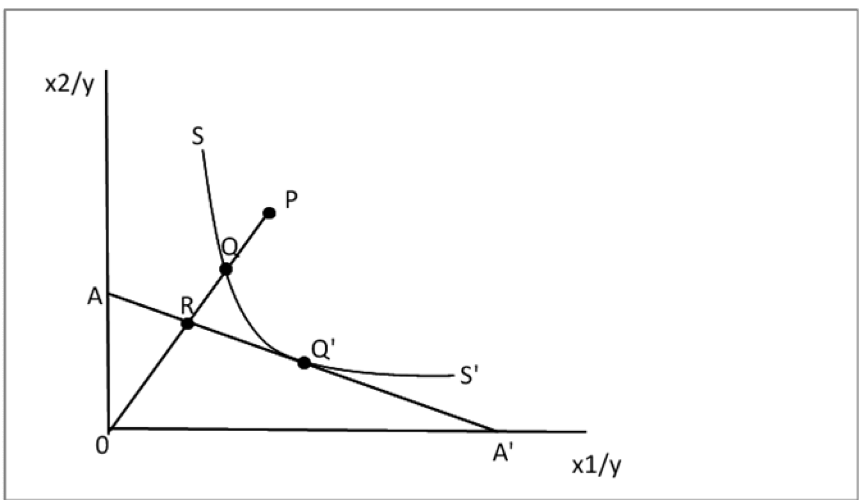
Main advantage of this methodology, in comparison to the non-parametric methods, is that it allows for statistical tests to identify the significance of the variables chosen and the results.

3.4 Data Envelopment Analysis (DEA)

DEA is the most frequently used econometrical methodology on efficiency in airport industry. The main advantage of DEA is that it does not require specification of a production or cost function. Using multiple inputs and multiple outputs, a linear programming approach is implemented, thus the best practicing airports in the sample construct an envelope. This envelope can be interpreted as a maximized implicit production function.[9] The inefficiency scores then can be calculated by measuring the distances from this envelope, i.e. the difference from the best practicing airport(s).

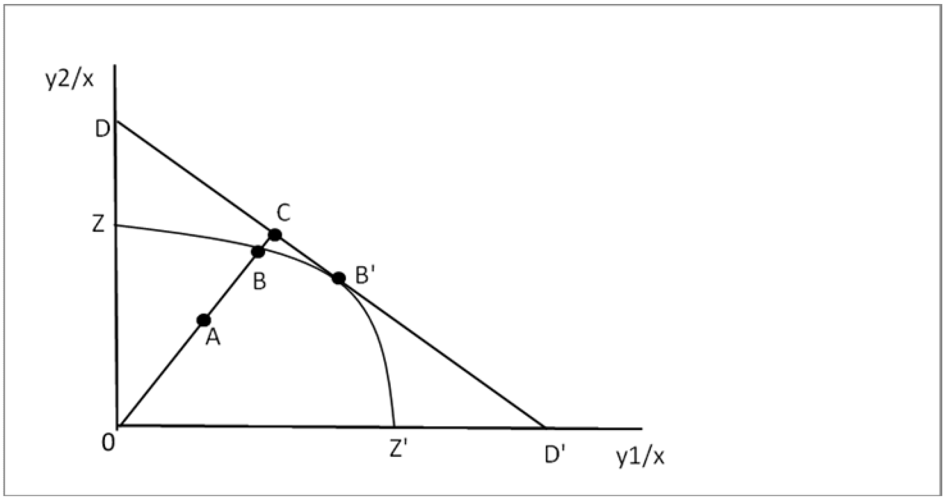
Different DEA models can be implemented for assuming constant or variable returns to scale. Also, for each of these models, DEA can be conducted either by using an input or output oriented method. Input oriented model tries to find out the minimum inputs for producing a given level of output, whereas output oriented model deals with maximization of outputs with given levels of inputs. With DEA model, first used by Farrell (1957), the technical efficiency and allocative efficiency of the production units can be assessed. For the allocative efficiency, however, information on input prices should be available, additional to the inputs and outputs. Figure 4a and 4b show the graphical representation of technical and allocative efficiency in the existence of 2 inputs (*x1* and *x2*) and 1 output (*y*), for input and output orientations, respectively.

FIGURE 4a: INPUT ORIENTED DEA



[9] Since the production function of the best airport is not known, this gives us the estimate of the function.

FIGURE 4b: OUTPUT ORIENTED DEA



SOURCE: Coelli, 1996

In figure 4a, SS´ represents the most efficient production isoquant. Hence, if we assume that a production unit produces at point P, the distance QP gives the technical inefficiency, as this unit could actually produce the same amount of output (y) by using fewer amounts of inputs. The relative technical inefficiency of this unit then can be measured by the ratio 0P/0Q. In addition, if the input prices are also known and represented by the line AA´, allocative efficiency of an airport can also be calculated. Following this, overall economic efficiency can be calculated by multiplying technical and allocative efficiency scores. Analogously, Figure 4b shows the output oriented efficiency of the production unit. Point A is assumed to be where the production unit is producing and ZZ´ is the isoquant for the most efficient production unit. Thus, the distance AB refers to the technical inefficiency of the unit and the ratio 0A/0B gives the relative technical inefficiency.

The mathematical form of the linear programming, which estimates the constant returns to scale output-oriented efficiency scores, is as follows:

$$
\begin{aligned}
&\max_{u,v}(u'y_i / v'x_i)\,, \\
&\text{s.t. } u'y_j / v'x_j \leq 1,\ j = 1,2,...,N, \\
&v'x_i = 1 \\
&u, v \geq 0 \qquad (4)
\end{aligned}
$$

This formulation maximizes the ratio of outputs to inputs (y and x respectively) with corresponding weights *u* and *v*. The restriction $v'x_i = 1$ is used to prevent infinite number of solutions to the maximization.[10] Input oriented method follows a similar approach. Variable returns to scale efficiency scores are then obtained by adding a convexity constraint to this maximization problem.

On the other hand, in addition to Farrell type DEA, Shephard (1970) introduces somewhat different specification of DEA. However, Coelli (1996) shows that technical efficiency results from two different specifications are the same and can be interpreted identically.

Malmquist-DEA

DEA can also be used to construct the Malmquist index to determine the efficiency changes on time. With the help of this index, changes in productivity can be separated into changes in technical efficiency and technological change. Färe et al. (1994) assumes, the solution to simple DEA maximization process in (4) can be shown as $d^T(x^t, y^t)$, where *t* represents the period. Then, index of efficiency change between two periods is the following ratio:

$$d^T(x^{t+1}, y^{t+1}) / d^T(x^t, y^t) \qquad (5)$$

Malmquist index is then measured as the geometric mean of these indices, incorporating the technologies available in periods t and t+1:

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{d^t(x^{t+1}, y^{t+1})}{d^t(x^t, y^t)} . \frac{d^{t+1}(x^{t+1}, y^{t+1})}{d^{t+1}(x^t, y^t)} \right]^{1/2} \qquad (6)$$

A further decomposition of Malmquist index by Färe et al. (1994) divides the changes in efficiency into i- change in technical efficiency -the term outside the brackets in (7)- and ii- change in technology – the term in the brackets in (7). With this decomposition, one can find out the underlying factors of inefficiency.

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[10] For more details on DEA, see Coelli (1996), Färe et al. (1994) and Charnes et al. (1995)

$$M(x^{t+1}, y^{t+1}, x^t, y^t)$$
$$= \frac{d^{t+1}(x^{t+1}, y^{t+1})}{d^t(x^t, y^t)} \times \left[\frac{d^t(x^{t+1}, y^{t+1})}{d^{t+1}(x^{t+1}, y^{t+1})} \frac{d^t(x^t, y^t)}{d^{t+1}(x^t, y^t)} \right]^{1/2} \quad (7)$$

Bootstrapping DEA

Nevertheless, DEA is restricted, as it is a non-parametric approach. As mentioned above, it uses an estimate of the implicit production function, hence it does not allow for statistical significance of the efficiency scores. In order to overcome this problem, Simar and Wilson (1998) proposed a bootstrapping methodology. In this methodology, *"Bootstrapping is based on the idea of repeatedly simulating the data- generating process (DGP), usually through re-sampling, and applying the original estimator to each simulated sample so that resulting estimates mimic the sampling distribution of the original estimator."* Thanks to this methodology, bias corrected efficiency scores can be calculated and confidence intervals can be constructed. Bootstrapping can be applied both to normal DEA and Malmquist-DEA. Bootstrapping DEA is implemented in the empirical part of this thesis and the details will be mentioned in the corresponding chapter.

4 Literature Review

Airport efficiency has been subject of individual researchers, as well as governmental and non-governmental organizations. While some researchers have focused on a specific methodology, some others have implemented more than one to same dataset, expecting to get more detailed and comparable results. Besides, the orientation has also been different in different researches. For example, there are analyses, which just aim to get a comparison of airports by calculating relative efficiency scores, on the other hand, there are analyses, which first investigate efficiencies and then aim to find out the underlying factors. Another point, where there are differences in analyses is the choice of country. Some research focus on airports from a specific country to construct the sample in order to investigate the industry in the framework of country characteristics, while others consider different airports from various countries, using the international characteristic of airport industry in order to assess the country specific aspects. On the other hand, some of them have not been interested in specific airports, but in the sample, to draw more general conclusions. Last but not least, the choice of variables used in the analysis has also varied.

4.1 Literature from Governmental Organizations

Governmental organizations undertake an intensive analysis of airports including capacity problems, financial performance and legislative issues. They aim to understand it better for their interactions with airports, how the airports operate and how they cope with the complete system. In some cases they specifically need a deep analysis of airport efficiency due to the factors, which were explained in Section 1.2.

The Civil Aviation Authority in the United Kingdom, for instance, published a consultation report in order to advise London and Manchester airports and also the Competition Commission (CC) about how airport benchmarking can be used in the process of regulation (CAA, 2000b). In this report, the relationships between benchmarking and economic regulation of airports were first stated. Then different methodologies of benchmarking were explained and difficulties with the comparisons were illustrated.

Besides, despite not directly aiming at benchmarking, the Competition Commission in the UK also published a working paper in 2007, again in order to state its view on the regulation of BAA (British Aviation Authority)[11] airports. This paper focused on the technical efficiency and made use of some basic comparisons between some airports in the UK.

4.2 Literature from Research Organizations

In addition to the state authorities there is a number of non-governmental organizations, which were founded with the purpose of investigating the aviation

[11] BAA is the largest airport operator in the UK, which was privatized in 1987. Currently they own 7 airports in the UK, including the 3 largest London airports. See, http://www.baa.com

industry. The Air Transport Research Society (ATRS)[12] was founded in 1995 and since then is the most influencing organization in air transport industry. The main goal of this organization is to stimulate the researchers in any related topic to air transport industry. ATRS published several "Global Airport Benchmarking Report"s and tried to determine the best airports according to a variety of criteria. Objective of these reports is *"to do a comprehensive, unbiased assessment of airport performance, including productivity and efficiency, unit cost and quality of service."* To this end, the analysis starts with partial factor productivity indicators and continues with gross total factor productivity and residual variable factor productivity measures. Finally, factors affecting the gross TFP are specified. Oum et al. (2004) presents the results of 2003 ATRS global benchmarking report in detail, which is conducted by using 2001 data. It states that the factors which affect the efficiency of airports (measured by gross TFP) can be divided into two categories. First category includes the factors, which are not controlled by management in short and medium term and these include airport size, percentage of international traffic, average aircraft size, percentage of cargo traffic and capacity constraints. On the other hand, factors, which are under the control of management, are percentage of non-aviation revenues, a dummy variable for airport operator (especially terminal operator) and the level of service quality.

Similar to ATRS, Transport Research Laboratory (TRL)[13], which is based in the United Kingdom, publishes the *"Airport Performance Indicators"* every year. As the name says, this publishing focuses on partial factor productivity methodology in costs, revenues and operations. Unlike ATRS, it considers the comparability issues of airports such as outsourcing, ownership, accounting practices, subsidies or traffic mix and adjusts the raw financial and operational data, so that only the core activities of the airports are compared in the analysis.

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[12] *www.**atrs**world.org*

[13] *www.**trl**.co.uk*

4.3 Literature on Methodologies

Some work only concentrates on explaining and comparing different methodologies and reviewed the literature. Graham and Vogel (2006) treats this issue from European perspective, illustrates the different methodologies and uses 31 airports and 4 airports groups in the empirical analysis. Morrison (2009) on the other hand, questions the appropriability of these methodologies on airport benchmarking. First the methodologies are briefly discussed and then reasons are presented why these methodologies can lead to misleading conclusions. It is concluded that benchmarking airports is sensitive to the choice of variables, model structure, assumptions and methodology.

4.4 Literature on PFP, TFP and SFA

Doganis et.al (1995) uses partial productivity indicators with a focus on financial variables to ascertain the economic performance of European airports. Vasigh and Haririan (2003) aims to identify, if private airports perform better than public ones and uses PFP indicators and regressions on financial and operational performance. They take advantage of the fact that most British airports are privatized and the US airports are public, in order to make a comparison between these 2 countries. They obtain mixed results for different indicators.

Because of the fact that PFP considers only one aspect of performance, Hooper and Hensher (1997) applies TFP to 5 Australian airports for accounting years between 1988/89 and 1991/92 by using operating costs, capital costs and other costs as inputs; aeronautical revenues and non-aeronautical revenues as outputs. Firstly the gross TFP is used, where revenues weight the index. Then, the results from gross TFP are compared to output-adjusted TFP, where a simple regression is used with output as independent variable and TFP scores as dependent variables. In conclusion, further research with at least 10 years of data and association of TFP scores to influencing factors are suggested for a more reasonable application of this methodology. Nyshadham and Rao (2000) assesses the efficiency of 25 European airports by also using TFP. The rankings from TFP scores are then compared to the rankings from PFP indicators by using ordinary and Spearman Rank correlations in order to find out if two methodologies deliver consistent results. It is concluded that the rankings provided by PFP indicators are significantly different than those provided by TFP. Windle and Dresner (1992) also discusses the strengths and weaknesses of PFP and TFP, compare two methodologies and apply them to various airlines worldwide for the years between 1970 and 1983. The conclusion is that the variables measuring labor productivity with PFP gives the closest results to TFP. It is also shown that a combination of PFP scores can be used as an estimate of TFP. In comparison, Yoshida (2004) assumes that physical outputs in addition to financial outputs (revenues) should also be considered when efficiency of airports is estimated. He introduces the endogenous-weighted TFP (EW-TFP), where a flexible production function is estimated to determine the relative inefficiencies. It is shown that this methodology is stronger than TFP. On the one hand, it does not require any detailed financial data and it can be conducted only by using technical data, on the other hand, it is not as sensitive as DEA. He applies this methodology to 30 Japanese airports and shows the strengths of this methodology with Monte-Carlo experiments.

As explained in Section 3.3, SFA (or also cost or revenue function approaches) is used by parametrically defining a production function. Pels et al. (2001) applies SFA (and also DEA) to explain terminal and airfield activities separately by using data of 33 European airports from 1995 to 1997. To explain the terminal activities, number of passengers is used as the only output with number of baggage claims, number of parking positions at the terminal and number of remote parking positions as inputs in the corresponding production function. On the other hand, for the airfield activities, number of air transport movements is used as output and number of runways replaces the baggage claims in the previous model for inputs. After calculating efficiency scores by SFA and DEA, it is concluded that the results are compatible with each other. Pels et al. (2003) applies the same methodologies to same data by adding more inputs to the production function and concludes that European airports are operating inefficiently. Martin-Cejas (2002) applies a slightly different methodology to 31 Spanish airports and uses a trans-log joint cost function to determine the relationship between the inefficiency and size of airports. Small and large airports tend to present larger inefficiency scores, in comparison to their mid-sized counterparts. Oum et al. (2008) applies SFA to find out the relationship between the ownership structure and cost efficiency. 109 airports worldwide are used with labor costs, non-labor costs, number of runways and terminal size as inputs; PAX, ATM and non-aeronautical revenues as inputs. The results show that the airports owned and controlled by private companies operate more efficiently than public ones. Barros (2008a) observes efficiency scores and technical changes of 10 Portuguese airports with SFA. In addition to labor and capital as inputs, sales to planes, sales to passengers and non-aeronautical revenues are used as financial inputs. Barros (2008b) implements Stochastic Cost Econometric Frontier, where the costs are used as dependent and input prices and outputs as independent variables in the regression to assess technical efficiency of 27 UK airports.

4.5 Literature on DEA

Research on airport efficiency, which implements the DEA, can be divided into 3 groups regarding the methodology and into 4 groups as far as the input-output variables are concerned. ***Traditional DEA*** is used to determine the technical efficiency scores of the airports (Referred as DEA). In some cases, where data for prices of inputs are available, allocative efficiency scores are also calculated. DEA is also used to calculate ***Malmquist indices*** in some research to find out the efficiency change between two periods (referred as Malmquist-DEA). Finally, ***Bootstrap-DEA*** is conducted to quantify the bias corrected efficiency estimates and to construct confidence intervals. On the other hand, input-output variables can be classified as operational, financial, mixed and innovative. The following table shows the matrix for possible combinations of methodology and variable decision.

TABLE 3: LITERATURE REVIEW CLASSIFICATION ON DEA

Methods/Variables	**Operational**	**Financial**	**Mixed**	**Innovative**
DEA	A1	A2	A3	A4
Malmquist-DEA	B1	B2	B3	-
Bootstrap-DEA	C1	-	-	-

4.5.1 DEA

GROUP A1- DEA with Operational Variables: First group includes the analysis on operational efficiency, which uses technical data as inputs and traffic data as output variables.

Gillen and Lall (2001) applies output-oriented DEA to 21 US airports for the years 1989 to 1993 by separating terminal activities from airside activities of airports. For terminal efficiency, PAX and Cargo are used as outputs and number of runways, gates, employees, baggage claim belts, car parking and terminal area as inputs. For airside efficiency, ATM and commuter movements are used as outputs; airport area, number of runways, runway area and employee numbers as inputs. A second stage Tobit regression is conducted, with several regressors and DEA efficiency scores as dependent variable, in order to determine the reasons behind efficiency.

Pels et al. (2001, 2003) follows a similar methodology and separates airport activities into two parts. As explained in the previous section, the results are compared to SFA to show the inefficiency of European airports.

Malighetti et al. (2008) applies the same approach with terminal and airside to 57 European airports for 2005 and 2006 to determine the efficiency rankings. Then, a second stage Tobit regression is conducted to show that efficiency is related to the network connectivity and to competitive pressure.

Unlike these research, Lin and Hong (2006) treats airports as a connected system and uses number of employees, check-in-counters, runways, parking spaces, baggage claim belts, aprons, gates and terminal size as inputs with outputs PAX, ATM and cargo. 20 major airports worldwide are used for DEA and afterwards for hypothesis testing to find out whether different characteristics relate to efficiency. While ownership and size are found to be insignificant, hub-status, location and economic condition of country are shown to be significant determinants of efficiency.

Pacheco and Fernandes (2002) uses apron area, departure lounge, number of check-in-counters, curb frontage, car parking and baggage claim area as inputs which produce the single output PAX to assess the efficiency of 35 Brazilian airports for 1998. The main focus is the timing of capacity expansion with the help of additional information on passenger demand forecast.

GROUP A2- DEA with Financial Variables: Research in this group use financial variables exclusively as inputs and make use of traffic data as outputs.

Parker (1999) focuses on the BAA airports in the UK with objective of investigating efficiency effects of privatization. DEA is used to assess efficiency of 22 airports with data from 1979/80 to 1995/96. Number of employees, capital costs and total operating costs are used as inputs; PAX and cargo are the outputs. In another analysis turnover is used as single output. Results show that privatization of BAA influenced the technical efficiency of these airports in a positive way.

Martin and Roman (2001) aims to shed a light to the situation in airport market in Spain, because of the expected privatization process. Expenses on labor, material and capital are used to produce PAX, ATM and cargo from 1997 in the DEA model to determine technical efficiency scores. Whether the airports produce with increasing or decreasing returns to scale is also estimated. Martin and Roman (2006) also uses the same methodology and same input-output combinations, to compare it with the results of Surface Measure of Overall Performance (SMOP) analysis.

Pacheco and Fernandes (2003) combines financial variables (operating, commercial and other revenues) to traffic variables (domestic PAX and cargo) for outputs and uses number of employees, payroll and operating costs as inputs. By doing so, the managerial efficiency of 35 Brazilian airports is measured.

Barros and Sampaio (2004) estimates the price of labor and capital to find out the allocative efficiency of 10 Portuguese airports between 1990 and 2000 in addition to the technical efficiency by using DEA. PAX, ATM, cargo and sales to passengers are used as outputs. In a “second stage censored Tobit regression”, the following 6 regressors are used for explaining the efficiency scores: Market share, time trend, share of regional governments, location, population of area and cost structure. It is concluded that, the management seems to have an effect on efficiency, whereas scale does not play an important role.

GROUP A3- DEA with Mixed Variables: The analyses which incorporate financial variables to technical variables as inputs belong to this group. Traffic and financial data are used as outputs as in the previous case.

Sarkis (2000) combines the operating costs, number of employees, number of runways and gates as inputs in order to cover all the areas of an airport operation to find out the efficiency of 43 US airports between 1990 and 1994 by using DEA. Then, the Mann-Whitney U-test is conducted to see if being a hub, belonging to a multiple airport system and being in snowbelt influence efficiency.

Bazargan and Vasigh (2003) also applies DEA with mixed input variables: operating costs, non-operating costs, number of runways and gates. PAX, ATM, commuter movements, aeronautical revenues, non-aeronautical revenues and on-time flights belong to outputs. By using 45 US airports in 1997 and with the help of several statistical tests, inefficiencies are explained by hub structures of airports.

GROUP A4- DEA with Innovative Variables: These papers introduce innovative ideas to the conventional input-output combinations, while applying DEA to airport efficiency.

Yoshida and Fujimoto (2004) tries to identify the effects of airport location for Japan on efficiency by introducing monetary and time access costs to the airport as inputs, in addition to number of employees, total runway length and terminal size. A Tobit regression then identifies if being in mainland for the regional airports and starting operation in 90s influences efficiency.

In a recent publishing, Pathomsiri et al. (2008) divides outputs of an airport into 2 categories as desired and undesired outputs in order to assess the operational efficiency. Undesired outputs are in this sense innovative and include number of delayed flights and time delays. Desired outputs, on the other hand, are non-delayed flights, PAX and cargo. Airport area, number of runways and runway area belong to inputs. 56 US airports are used from 2000 to 2003 and results are compared to the model without undesired outputs. It is shown that, with undesired outputs, large and congested airports operate less efficiently.

4.5.2 Malmquist-DEA

GROUP B1- Malmquist-DEA with Operational Variables: Gillen and Lall (2001) replaced their methodology used in Gillen and Lall (1997) with Malmquist-DEA by retaining the same inputs-outputs and the same sample of US airports. Kamp et al (2004) applies the same methodology and same input-output combinations as Gillen and Lall (2001) to 17 of 18 international German airports for the years between 1998 and 2002 and concludes that the efficiency decreased due to 9/11 terrorist attacks but also because of capacity expansions.

GROUP B2- Malmquist-DEA with Financial Variables: Murillo-Melchor (1999) aims to identify the efficiency changes of 33 Spanish airports for the period 1992-1994 by using Malmquist-DEA. It is assumed that the single output PAX is produced by the following financial inputs; number of employees, accumulated capital stock and intermediate expenses. Mixed results for 2 periods (1992-1993 and 1993-1994) are found in terms of technical efficiency, technological and total factor productivity changes. Barros and Weber (2009) uses 27 UK airports for period between 2000-2005 to determine the total factor productivity by applying Malmquist-DEA. Labor costs, capital invested and operational costs construct the input matrix, whereas PAX, ATM and cargo belong to outputs. Results are presented in the form of efficiency changes, technological changes and total factor productivity changes.

GROUP B3- Malmquist-DEA with Mixed Variables: Abbott and Wu (2002), in comparison, mixes the financial inputs with technical inputs and uses employees, capital stock and runway length as inputs to implement Malmquist-DEA for 12 Australian airports from 1999 to 1999. A second stage Tobit regression tries to find out which of the following variables influence the efficiency changes: rate on return, capital/labor ratio, aircraft standing area, total asset growth rate and ownership.

4.5.3 Bootstrap DEA

GROUP C1- Bootstrap DEA with Operational Variables: Barros (2008c) follows a two-stage approach to assess the efficiency of 27 airports from Argentina. In the first stage, DEA is conducted to get the efficiency scores and bootstrapped by Simar and Wilson (2007) approach for bias correction. In the second stage a truncated bootstrapped two-stage regression is conducted to test whether airport size and being a hub influences the efficiency of airports. By using a truncated bootstrapped two-stage regression, the conventional Tobit regression is out-dated, which is considered inappropriate for explaining DEA results (Simar and Wilson, 2007). Focus is on operational efficiency with number of employees, number of runways, airport ramp and terminal area being inputs for producing PAX, ATM and cargo. Barros and Dieke (2008) uses the same two-stage approach for 31 Italian airports. Input-output combination is changes slightly; revenues are considered as outputs besides traffic variables. Assaf (2009) uses data from 29 UK airports from 2007 and applies the same methodology to find out whether airports operate under increasing, decreasing or constant returns to scale.

In addition to these groups, Adler and Berechman (2001) uses DEA with Principal Components Analysis, where number of outputs are suppressed to a lower number as in form of principal components, but as much as information is kept in the analysis. In this analysis, airlines' point of view on determining efficiency of an airport is taken into account.

5 Economic Factors on Airport Efficiency

In Chapter 2, technical and operational factors influencing airport efficiency have been explained in detail. Besides, a brief introduction to economic factors has also been given. As main focus of this research is to determine the economic efficiency of German airports in terms of financial variables such as costs and revenues, this chapter is dedicated to explain the economic factors, which influence efficiency. Specific characteristics of German airports corresponding to these factors will then be presented in the next chapter.

5.1 Airport Charges and Regulation

5.1.1 Airport Charges

As discussed in chapter 2, airport charges constitute the aeronautical revenues of airports, which together with commercial revenues sum up to total revenues. Level of airport charges has been a debate for the last decades, since it is theoretically supposed to reflect the costs of an airport. In general sense, these costs are made up of operational costs. However, the costs for major investments should also be financed by airport charges. Keeping these facts in mind, airport charges reflect both the present and the future.

In a static analysis, which only considers one year of operation for an airport, it can be seen that operational costs play a major role in total expenses of an airport. Hence, revenues from charges is an important factor on the profitability of an airport, which directly influences the financial, thus overall efficiency.

However, level of charges in Europe is regarded not to cover the operational costs for most of the airports.[14] In order to overcome this problem, generally two different sources are available. Before the liberalization of markets, airports enjoyed high public subsidies from the governments, who at the same time owned the airports, in order to subsidize their losses on operations. Currently many regional airports are still supported by local or federal governments. European Union, however, implemented directives to restrict government support to prevent unfair competition. With more and more airports being privatized and more restrictions implemented on acquiring public funds, airports were forced to innovate new ways to solve problem of cost subsidizing. For this reason airports started to give more attention to their commercial activities. Revenues from these activities such as car parking fees, rents from stores or advertising have been intensively used to cross subsidize the losses from operations.

Zhang (1997) uses the economic theory and explains the role of commercial revenues in determination of airport charges. The social welfare effects are also investigated. It is proven that, with some additional assumptions, in order to maximize social welfare; commercial revenues should be used to

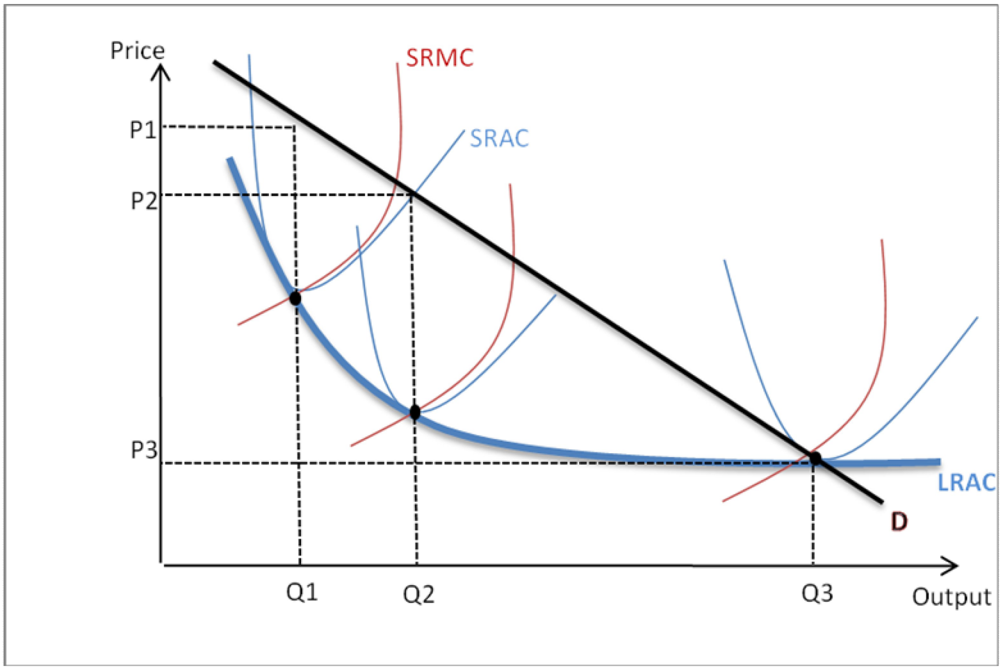
[14] Airport Charges in Europe, ACI Europe, 2003

subsidize the operational costs, airports should be allowed to make profit from concessions and the level of airport charges should be equal to social marginal costs.

When we turn our attention to a long-term analysis, large investments corresponding from capacity bottlenecks due to the increasing traffic demand, place a heavy burden with a large amount of expenses on airports. These expenses are then reflected in the amount of airport charges and passed to the airlines and ultimately to the end-users, i.e. passengers, in the form of higher prices. The fact that capacity is one of the most important factors influencing efficiency of an airport, the level of charges then indirectly (and in long-term) plays a decisive role on efficiency.

As in any field in production economics, optimal pricing of airport charges has also been subject of academic work. Niemeier (2004) argues that capacity is the main driving force of optimal pricing. It is stated that *"According to Button and Stough (2000, p. 191) the "generally accepted position" assumes that the airport industry has a modified L-shaped average cost curve with initially decreasing cost and economies of scale and density flattening out after a certain level."* Then it is shown that the capacity expansion takes place to increase supply along the short run marginal cost curve until the long-term equilibrium is reached. In Figure 5, it can be seen that the equilibrium point is where supply and demand equals with the long-run average cost crossing short-run marginal cost curve. However, Niemeier concludes that the price mechanism in airport industry is working inefficiently, due to the defiance in slot-allocation and regulation procedures.

FIGURE 5: CAPACITY EXPANSION



SOURCE: Niemeier (2000a)

5.1.2 Charges Regulation

Different types of airport regulation have been explained in Section 1.1. As already mentioned, price-cap regulation tends to replace traditional rate of return regulation in the last years. However, implementation of price-cap also creates questions, which has been debated recently. In the application of price-cap, the controversy about using a single-till or a double-till approach has also been the subject of many scientific researches, as well as being an important topic within the industry (Czerny, 2006; CAA, 2000a). Single-till approach observes aeronautical and non-aeronautical revenues of an airport together to calculate the level of charges allowed. On the other hand, dual-till approach considers only the aeronautical revenues. The main principle on the difference between single and dual-till approaches is their point of view, if non-aviation section is independent of the aviation section. Supporters of single-till advocate that non-aeronautical revenues are created thanks to passengers brought to the airport for aviation purposes. Airlines are the main advocator of this approach, as it does not allow airports to set the charges as high as in case of dual-till. In practice, however, cross subsidization of aeronautical and non-aeronautical revenues, as mentioned in previous section, makes it more difficult to assess, which approach should be used as a regulatory basis.

Airport charges are regulated, because airports are regarded as natural monopolies due to their large and fixed capital infrastructure, which leads to a high market power. In addition, bargaining power of airlines is considered to be low. Liberalization and commercialization process of airports accelerated in the last decades, which in turn led people to question if airports are really natural monopolies. In addition, there has been an ongoing debate if non-aviation activities of airports can also be considered as monopolistic. These are the underlying factors behind the deregulation process in airport industry. As a result, researchers started to focus on the question under which conditions the regulation would be unnecessary. The importance of increasing revenue share from non-core activities lead airports to be more passenger and commercial oriented. Following this, Beesley (1999) and Starkie (2001) state, airports with sufficient commercial activities would have an incentive to decrease airport charges to attract more traffic, which would stimulate the commercial sales. Furthermore, importance of commercial services is not the only argument on the deregulation of airport charges. Martin and Socorro (2009), for instance, claims that there would be no need to price regulation when the level of capacity chosen by an airport is relevant to demand.

Many airports regard regulation as a burden for their financial and operational structure; however supporters believe that it is a mechanism, which leads to the efficient use of inputs with minimum costs. In this context, IATA (2007)[15] differentiates between 3 types of efficiency; Productive, Allocative and Dynamic. Productive efficiency deals with cost minimization for producing a level of output. The price-cap regulation is discussed to be very effective to increase productive efficiency via cost savings. On the other hand, rate-of-return regulation is short of giving incentives for cost minimization. Allocative efficiency looks at the relationship between prices and the corresponding costs and is assumed to be negatively influenced by regulation in the airports with

[15] Economic Regulation, International Air Transport Association, 2007

capacity constraints, because of the low level of costs. Finally, dynamic efficiency considers the time horizon, thus the investments. While rate of return regulation results in over-investment, price-cap regulation is considered to give incentives for investing less than the efficient level. Oum et al. (2003) implements capital input and total factor productivity and confirms the above-mentioned efficiency effects of different types of regulation.

Although these statements are generally accepted, type and implication of regulation would not be appropriate for each country, airport or airport system. European Commission's well-known directive proposal on airport charges on 1997 aimed to create a common base for member states. The main arguments were cost relatedness, transparency and non-discrimination (ACI, 2003). However, it had to be withdrawn in 2001, as it did not get enough support. Marques and Brochado (2008) supports using regulatory benchmarking for a new directive for EU states, which could lead airports to operate more efficiently at the end. Forsyth (1997), Tretheway (2001), Gillen and Morrison (2001), Kunz and Niemeier (2000) and Niemeier (2002b) also investigate the implementations, effects and problems of different regulation types for different countries.

5.2 Airport Competition

In the previous section, regulation of airport charges were explained, which arises from the lack of airport competition. Airport competition in broad sense refers to the competition for attracting airlines, which are free to choose from or to which airport to operate. Passengers then choose the airport according to the routes, which are determined by the airlines.

First and most straightforward form of competition applies to the airports with overlapping catchment areas. The main determinant is the location of the airport. Unlike in the other –and simpler– industries, airports face more rigidities on the location, as they require huge land and large fixed capital investments. Catchment area is defined in different, but somewhat similar, ways in various sources. On the one hand, some refer to number of people, who live in the geographical area which is determined by a particular distance (measured generally by radius) to the airport, on the other hand some refer to the number of people, who live in the geographical area, from which access (by means of car, train etc.) takes a particular time (measured generally by hours or minutes) to the airport. A good example of this kind of competition from Germany is the one between airports Cologne-Bonn (CGN), Düsseldorf (DUS) and Dortmund (DTM).

Another field where airports compete for attracting traffic is the transfer activities. This is called hub-competition and is independent (within some limits, naturally) from how close the airports are located to each other. A hub airport serves as a connecting point, collects the traffic from main routes and distributes it to the so-called spokes (the ultimate destination). London Heathrow (LHR), Paris Charles de Gaulle (CDG), Frankfurt-Main (FRA), Madrid Barajas (MAD) and Amsterdam Schipol (AMS) airports, for example, are the biggest 5 airports in Europe and serve a high number of intercontinental traffic, leaving them in a strong competition.

In the last decades, so called secondary airports increased their importance. The main reason is the developments in the Low Cost Carrier (LCC) airline market. Some airports only focused on the traffic from these carriers and have been able to increase their traffic dramatically (Frankfurt-Hahn (HHN), for instance, from around 30 thousand passengers in 1998 to around 4 millions in 2007). In addition to that, competition for cargo traffic is also another type, where airports need to supply qualitatively different services than passenger handling.

The means to develop strategies in a competitive environment to attract traffic for an airport vary. Tretheway and Kincaid (2005) explains these with the "four P's of marketing". The first way for an airport to operate in a competitive environment is to determine the *product*. Despite being theoretically subject to a high level of competition (e.g. same catchment areas), an airport can offer different products, for example different routes, destinations, infrastructure, facilities in airport, to overcome the possible demand losses because of strong competition, or in order to attract more demand. Secondly, *price* plays an important role for airlines and passengers to select the airport. Naturally level of aeronautical charges is the most crucial determinant of price competition. Thirdly, *promotion* includes the reputation of airport and the service quality. Finally *physical distribution* deals with the pure marketing strategies, which aims to let the end-users to be well-informed about the airport.

Nevertheless, competition is limited by the market power of airports. Starkie (2002) mentions the entry barriers as being the most important source of market power of an airport, due to the fact that an airport industry faces a scarcity on the input, namely land, and due to the related high sunk costs. Another source of market power is the comparative advantage which stems from the network connectivity, which hub airports are able to enjoy due to their specific system.

5.3 Airport Ownership and Privatization

Public utilities, including airports, have been considered to operate inefficiently, when they are owned and managed by the governments. The main argumentation points out the various interests of governments, which do not coincide with the best strategies for an efficient operation. Hence, privatizing airports is seen to be a step towards a more efficient airport management. Private companies are considered to be more business and profit oriented. In addition, having shares held by private investors via stock markets, increases the pressure on airports for performing in an efficient manner.

Airports around the world were solely owned by local or federal governments until the 1980s. Privatization of airports in different forms started to take place and accelerated on time. In Europe privatization process started in the UK, when the airports, which belong to BAA (British Aviation Authority), were converted to private ownership following the Airports Act in 1986 (Müller et al. 2009). This constituted an example for the continental Europe and countries started privatizing airports, as in case of Copenhagen (CPH), Vienna (VIE), Zurich (ZRH) and Frankfurt (FRA). On the other hand, in some countries governments still own and manage a large number of airports. Furthermore, some governments keep owning and managing the whole airport system via state airport authorities, as in Spain with AENA and in Portugal with ANA.

As mentioned above, privatization of an airport can take different forms. Different privatization techniques are used, reflecting the interest of authorities of the companies, which were interested in the airports. Vasigh and Haririan (2003) mentions five airport privatization techniques: Contracting out, contract management, long-term lease, build-operate-transfer and full divesture and sale of shares. Each of these techniques leads to a different structure on the ownership and management characteristic. Oum et al (2006) classifies these characteristics as follows: *"(a) government agency or department operating an airport directly; (b) mixed private–government ownership with a private majority; (c) mixed government–private ownership with a government majority; (d) government ownership but contracted out to a management authority under a long-term lease; (e) multi-level governments form an authority to own/operate one or more airports in the region; (f) 100% government corporation ownership/operation."*

Furthermore, in most cases, privatization changes the structure of the regulation applied to the specific airport, in order to steer the effects of privatization on efficiency.

Ownership structures have been profoundly investigated in the airport sector in its relation to financial, operational or overall efficiency. Parker (1999) finds no evidence that privatization of BAA leads to efficiency. Vasigh and Haririan (2003) observes also no significant effect of different ownership structures in the UK and US on financial performance. Holvad and Graham (2003)'s findings confirm the previous results. Oum et al. (2006) concludes that airports with mixed public-private ownership/management structure perform worse than fully public counterparts. On the other hand, findings of Oum et al. (2008) contradict the previous research and conclude that airports owned or controlled by private firms are more efficient than the public ones. Besides, Vogel (2006) finds evidence on the cost efficiency of private airports against the public ones. Contradicting results on the effects of ownership structure on efficiency emphasize the importance of a detailed analysis, where other factors, such as country specific effects or size issues, together with the ownership structure should be investigated case by case.

6 Airport Sector in Germany

Currently 24 airports are classified as international in Germany according to ADV (German Association of Commercial Airports) statistics.[16] 5 of these airports belong to this category only since 2008, with the increasing traffic within

[16] Berlin-Tempelhof has been closed down in 2008, however it is still counted.

Europe thanks to low cost carriers. These 24 airports produced almost 190 million passengers in 2008, more than 2 million commercial aircraft movements and almost 4 million metric tons of Cargo. A list of these airports, ranked according to their corresponding passenger numbers in 2008, is given in Table 4. With this volume, Germany is the third largest market in Europe after the United Kingdom and Spain. In addition to the international airports, there are 29 regional commercial airports and these airports produced around 5.8 million passengers[17] (Source: ADV).

As mentioned before, international German airports experienced a 30% increase in passenger traffic between 1998 and 2008. Hence, capacity expansions were inevitable in order to meet the increasing demand. Additional necessary capacity was added either by introducing new airports to the system or by expanding the existing airport infrastructure, or both simultaneously.

Introducing new airports to the system was mostly undertaken by converting military or regional airports into commercial international airports. Karlsruhe/Baden-Baden (FKB), Düsseldorf-Weeze (NRN) and Paderborn/Lippstadt (PAD) are examples of these airports, which achieved 1 million passengers level during the last years.

TABLE 4: INTERNATIONAL GERMAN AIRPORTS AND PASSENGER NUMBERS (2008)

Airport	IATA Code	Passengers (2008)
Frankfurt	FRA	53.467.450
Munich	MUC	34.530.593
Düsseldorf	DUS	18.151.252
Berlin-Tegel	TXL	14.486.610
Hamburg	HAM	12.838.350
Cologne/Bonn	CGN	10.342.931
Stuttgart	STR	9.924.697
Berlin-Schönefeld	SXF	6.638.162
Hanover	HAJ	5.637.517
Nuremberg	NUE	4.269.606

[17] Data from 2007

Hahn	HHN	3.940.159
Bremen	BRE	2.486.337
Leipzig/Halle	LEJ	2.457.077
Dortmund	DTM	2.329.440
Dresden	DRS	1.856.390
Münster/Osnabrück	FMO	1.570.506
Weeze	NRN	1.523.990
Karlsruhe/Baden-Baden	FKB	1.141.070
Paderborn/Lippstadt	PAD	1.137.043
Friedrichshafen	FDH	649.646
Lübeck	LBC	534.509
Saarbrucken	SCN	518.283
Erfurt	ERF	308.226
Berlin-Tempelhof	THF	278.555

SOURCE: ADV Statistics

On the other hand, terminal and runway expansions continuously took place on the existing international airports. Cologne-Bonn (CGN) opened its Terminal 2 in 2000. Dortmund (DTM) expanded its runway in 1997 and also in 2000, complementing it with a new terminal in 2000. Hanover (HAJ) also built a new terminal which was opened in 1998. Stuttgart (STR), on the other hand, completed the expansion of its runway in 1996, followed by two new terminals in 2000 and 2004. Hamburg (HAM) undertook an extensive expansion and modernization program under the name "HAM21", which was the largest in its history. The whole process continued from 2001 to 2008, which included a new terminal, a passenger-pier, parking lot, access road and an airport plaza, which cost around 350 million euro. Düsseldorf (DUS) faced a big fire in 1996 in its two terminals, which were totally destructed and this, as a result, made building a new terminal inevitable. In 1996 the renewed Terminal C started to be used and the new Terminal B was opened in 2001. Munich (MUC) and Nuremberg (NUE) also opened new terminals in 2003 and 2006, respectively. Furthermore, a new airport in Berlin, on the side of Schönefeld (SXF) airport is being constructed to replace the multiple airport system of Tempelhof, Tegel and Schönefeld with a single airport. The new airport is called Berlin-Brandenburg-International airport.

Tempelhof has already been closed in 2008 and Tegel will be closed when the new airport is opened for traffic at the end of 2011. Frankfurt also solved the juristic problems with the government and started to build a fourth runway in order to solve its congestion problems on the airfield.

Airports in Germany have been owned and managed by public authorities until the end of 1990s. Characteristics of Germany's independent state system are reflected in the ownership structures of airports. Federal government of Germany, local governments and cities hold shares in the public airports with different proportions. Besides this interesting, and still dominant, mixed-public ownership formation, number of partially privatized airports has been continuously increasing. Privatization of airports in Germany followed two different methodologies. Some public owners sold their shares to the private companies. Frankfurt airport, on the other hand, decided to go into stock exchange by initial public offerings. In addition to the changes in ownership structures, partial privatization in terms of outsourcing activities such as ground handling services or terminal operations also took place.

Düsseldorf was the first German airport whose shares were sold to a private company. As stated above, the airport needed to undertake major investments on terminals following the fire catastrophe in 1996. Nonetheless, governments were not eager to finance these by themselves. As a result, Airport Partners GmbH, which is a consortium of *Hochtief Airport GmbH* (40 %), *Hochtief Airport Capital KGaA* (20 %) and *AirRianta plc.* (40%), acquired 50 percent of the shares in 1997. City of Düsseldorf owns the other 50 percent of shares.

Hamburg airport followed a similar methodology with the privatization process. According to the agreement between city-state of Hamburg, federal government of Germany, state of Schleswig-Holstein, which shared the ownership of the airport, and Airport Partners GmbH, a two-stage process was implemented. Airport Partners GmbH acquired 36 percent of the shares in 2000 and raised this to 49 percent in 2002. In contrary to the Düsseldorf case, Air Rianta plc did not take place in the consortium. As a result of the privatization process, shares of federal government and state of Schleswig-Holstein were completely transferred. Currently, city-state Hamburg retains 51 percent of the shares.

Unlike Düsseldorf and Hamburg, Frankfurt airport sold 29 percent of its shares in an initial public offering at the stock exchange market in 2001. With this process, the legal status of the airport was changed to a limited stock company "Fraport AG". Currently, Julius Bär Holding AG (which is a private Swiss bank) and Lufthansa belong to the biggest stake owners of the company in addition to the State of Hessen and city of Frankfurt. Fraport AG followed an expansionary policy to be an international airport operation company by taking shares in different airports in various countries. In Germany, they acquired 65 percent of shares of Hahn airport and 51 percent of Saarbrucken, but these shares were given back later on. They also invested in Hanover airport by acquiring 30 percent of shares. Fraport AG engaged in ownership or management contracts worldwide recently, including airports in Egypt, India, Turkey, Saudi-Arabia, Bulgaria, Peru and China.

Nevertheless, airport privatization has not always been successful in Germany. Construction of new Berlin-Brandenburg-International airport was planned to be completed with a private consortium involvement. Privatization process began in 1997 but stopped in 2003, as the consortium declared that they are not interested in cooperation anymore. For this reason city-state of Berlin, state of Brandenburg and federal government keep their shares and share the costs of new airport.[18]

In addition to transfer of ownership, some large arrangements were also implemented between airport owners (public authorities) and private companies in different fields of airport operations. Berlin airports, for instance, outsourced its ground handling activities to Globe Ground Berlin. Furthermore, Munich airport and Lufthansa constructed the Terminal 2 and currently operate it together in the form of a joint venture.

As in case of ownership characteristics, Germany's decentralized political structure shows its effects on the regulation. As opposed to other network industries in Germany, such as telecommunications, electricity, railway and gas, where there is a single regulatory body, airports in Germany are subject to

[18] To see a full list of shareholders of international German airports, see: http://www.adv.aero/fileadmin/pdf/Wirtschaft_u_Recht/Gesellschafter_und_Beteiligungsverhaeltnisse_der_Flughaefen_01.pdf

regulation under the authorities of corresponding federal state. Having different authorities as regulatory bodies, leads to questioning the efficiency of regulation process because it is supported that these authorities suffer from a lack of experience and expertise. In addition, independency of regulation is also open to criticism, as the (partial) owners of the airports are also responsible for the regulation.

Regulation process in Germany follows the principles, dictated by §43 of the Air Transport Licensing Agreement of federal government. Although the states follow these laws, different states apply different implementations. Because this law only states that airport charges must be approved by the local state authorities before being applied, but it does not mention or dictate why and in which way these charges should be implemented (Müller et al, 2008).

Charges regulation of German airports followed entirely the rate of return approach until the end of 1990s. This approach was usually supplemented by a dual-till procedure, where only aeronautical revenues, but not non-aeronautical revenues were considered in the calculation of airport charges. This contradicts the position of IATA and some economic research, which favor the use of single-till procedure, which is considered to be more appropriate and efficient for airports. Berlin Tegel, Munich, Stuttgart and Cologne-Bonn are still subject to rate of return type of regulation.

These kinds of problems, followed by strong criticism, led to the implementation of different types of incentive regulation. Incentive regulation is based on private framework agreements between airports, airlines and the regulators. It was used for the airports which were partially privatized. Some airports started to negotiate it even during the privatization process and implemented it right after the transfer of shares.

Incentive regulation used in German airports differs from the traditional price-cap regulations in terms of its specific sliding scale mechanism. This mechanism does not only adjust for inflation and productivity change, but also adjusts for the traffic growth, thus shifts the risk allocation between airlines and airports. For example, Hamburg was the first airport to use incentive regulation in Germany in 2000. They implemented a CPI-X approach, where X stands for the technological growth. Furthermore, X was adjusted according to the growth of passenger traffic, so that the airport was prevented from windfall profits. A more than 3 percent growth in traffic leads to the adjustment mentioned in this process. This system had to be dismissed in 2002 in order to protect the airport on further effects of 9/11terrorist attacks in aviation industry. In addition, dual-till was accepted as the approach to be used in Hamburg. Hamburg was followed by Frankfurt and Hanover, which are operated by Fraport AG, in 2003. Frankfurt also implemented a similar sliding scale mechanism as in Hamburg, but the main different was that there is no threshold (In Hamburg, it was 3 percent) for the adjustment for traffic growth. Hence any change in traffic growth was reflected in the formula CPI-X.

Finally, Düsseldorf changed it regulation method to incentive regulation from rate of return in 2005. Berlin and Nuremberg airports also tried to reach agreements for implementing incentive regulation, however they failed.

7 Empirical Analysis

7.1 Methodology

This master thesis follows the methodology of Barros (2008c) and Barros and Dieke (2008), which apply the work proposed by Simar and Wilson (2007) to Argentinean and Italian airports, with slight differences. In the analysis, a three step procedure is followed in order to determine the efficiency of nine international German airports and one airport group. In the first step, a "bootstrapped input-oriented variable returns to scale DEA" is implemented. In the second step, Spearman Rank Correlation Test is conducted to find out if cost efficiency and revenue efficiency are correlated. Finally, a second stage truncated bootstrapped regression is used to determine the influencing factors of efficiency.

7.1.1 Estimation of Efficiency Scores

An input-oriented DEA was used to estimate the relative efficiency scores of airports. Input oriented model was chosen because focus of the first step analysis is on the cost efficiency of airports. Input oriented DEA calculates the efficiency scores by holding the outputs constant and minimizing the inputs for these given levels of outputs. Another reason for choosing the input oriented model was that, airports are assumed to have a minor influence on the demand, i.e. traffic, at least in short or middle term, leaving them with developing strategies for the supply side, by concentrating on cost minimization for overall efficiency. Besides, variable returns to scale specification is chosen, as the airports in sample are subject to different competitive environment and different constraints in production, which might prevent them to produce on the most optimum scale.

In Section 3.4, Farrell type DEA was explained in detail to give the basic idea behind DEA, and it was also stated that it delivers the same technical efficiency scores given by Shephard type DEA. In this analysis, Shephard input distance function is computed to calculate the technical efficiency scores.

Suppose, $x = (x_{1,\dots,} x_N)$ and $y = (y_{1,\dots,} y_N)$ represent the vector of inputs and vector of outputs, respectively. Production technology is then defined by[19]:

$$L(y) = \{x: x \text{ can produce } y\}, \quad y \in R_+ \tag{8}$$

Following this, Shephard input distance function, which at the same time represents the production technology, is described as follows:

$$D(y,x) = \sup\{\lambda \in R_+ : (x/\lambda) \in L(y)\} \ \text{ w.r.t. } \lambda, \tag{9}$$

where sup (supremum) is used to determine the least upper bound for the input function. λ represents the distance of the production unit from the optimum frontier, hence showing the technical inefficiency of a production unit. If λ takes the value of 1, the production unit presents no inefficiency and assumed to be fully efficient.

As mentioned in the literature review, DEA has been conducted by using either technical or financial data, or a mixture of these two. This analysis focuses on the financial variables of airports. The discussions with aviation experts led to

[19] Keep in mind that this is only an assumed production technology, as we have no information on the mathematical form of the production function.

the conclusion that the technical variables would give misleading results, because not all the details of the complicated system of airport operations can be captured with such variables. These problems were already explained in Section 2.3.2. For this reason it was avoided to include traditionally used information on runways, terminals and aprons. Another motivation on using the financial variables was the fact that no separate analysis on the efficiency of German airports has been conducted with these variables. Analyses which use DEA, SFA or TFP focus on the technical details, whereas analyses which use financial variables rely solely on the partial factor productivity methodologies. Hence, this analysis aimed to shed a light to the financial efficiency of German airports.

Staff costs, other operating costs and ***the sum of tangible assets and inventories*** have been chosen as three inputs. The motivation behind was that the staff costs represent the labor input, tangible assets and inventories represent the capital input and other costs cover the other inputs, so that all the financial means of an airport which are utilized in production are included in the function. Following the conventional wisdom in airport efficiency literature, ***number of passengers*** and ***total volume of cargo*** were chosen as two outputs of airports. Number of air transport movements were not included as output, because of its high correlation with the number of passengers to avoid a double counting. In addition to that, number of passengers and volume of cargo were used as two separate outputs, but not as a combination by using the WLU, because they require qualitatively and quantitatively different inputs.

7.1.2 Correlation between Cost and Revenue Efficiency

Because of the fact that the above explained DEA analysis gives estimates for cost efficiency due to chosen inputs and outputs, the question how it is related to revenue efficiency was tried to be answered in the second step of the analysis. It gives opportunity for a more elaborate conclusion on overall efficiency. In order to calculate the correlation between the two, Spearman Correlation Test was implemented. This is a non-parametric rank statistic, which is applied to two sets of variables. First, production units were ranked according to their ***DEA efficiency estimates***, with best performing observation being the first. Then, ***the ratio of***

total revenues to total costs[20] was calculated for same observations, and they were ranked again from highest to the lowest. The formula for Spearman's *"r"* statistic is the following:

$$r = \left[1 - \frac{6\sum D^2}{n(n^2 - 1)} \right] \qquad (10)$$

where D is the difference between the rank of an observation on DEA efficiency scores and the rank of that on total revenue / total cost ratio. *n* is the total number of observations. The value of the *"r"* statistic is then compared to the critical values, which is given in the table in Appendix 2, in order to confirm or reject the null hypothesis that there is no correlation between the two sets of variables. If the null hypothesis is rejected, then we can conclude that airports with higher cost efficiency scores from DEA also present higher revenue efficiency.

7.1.3 Influencing Factors

Finally, a second stage regression was conducted in order to determine the influencing factors of DEA efficiency scores. Traditionally second stage regressions took the form of a Tobit-model, where the dependent variable (efficiency score) is assumed to be unobservable with a normally distributed error term. However, Simar and Wilson (2007) advocates that this model is not suitable for indicating the determinants of non-parametric (DEA) efficiency estimates, because independent variables are correlated within themselves and also with error terms. They proposed a bootstrapped truncated-regression and implemented Monte-Carlo experiments to show that it outperforms the former analysis.

Following Barros and Dieke (2008), mathematical form of the regression function is determined as follows:

$$TE_j \approx a + Z_j\delta + E_j\,, \quad j = 1,\ldots,n, \qquad (11)$$

[20] It represents the revenue efficiency of airports.

where TE_j is the efficiency score for the j-th DMU[21], a is a constant, Z_j is the vector of independent variables and E_j is the normally distributed error term with zero mean and standard deviation σ.

Besides, algorithm 1 in Simar and Wilson (2007) is also used to bootstrap the regression with 2000 replications of the sample.[22] The decision on the variables which were assumed to influence the efficiency scores of airports were done following an extensive review of literature on airport efficiency (see Chapter 4) and self judgments.

The first variable is the WLU, which is assumed to be an indicator of airport size. It is used to conclude if airports make use of scale economies. Second variable is the percentage of shares, which are held by private companies to test if private airports operate more efficiently than public ones. Third one is a regulation dummy, which takes the value of 1 for incentive regulation and 0 for rate of return. Staff costs are included as the fourth variable to be able to draw conclusions on the importance of labor in the production. Aircraft size, approximated by the ratio of total number of passengers to total number of air transport movements, is another variable used. This ratio, in fact, can at the same time reflect the load factor of an aircraft; however, the data on the fleet mix of German airports confirmed this approximation. Last variable used was the percentage of international passengers served by the airport.

The first and the third step of the analysis were conducted by using the version 2.7.2 of econometric software **R**. The command "boot.sw98", which is included in the FEAR[23] package version 1.11, was implemented for the first step of the analysis. For the third step, the programming codes for R were adjusted to implement the algorithm 1 of Simar and Wilson (2007).

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[21] Decision Making Unit. This term is used here rather than airport, because it refers to an airport for a specific year. For example, Dortmund airport in 1998 and Dortmund airport in 1999 are two different DMUs.

[22] This is different from Barros and Dieke (2008), where algorithm 2 is utilized for bootstrapping. For the detailed econometric specification of this algorithm, see Simar and Wilson (2007)

[23] A package prepared for Frontier Efficiency Analysis with R.

7.2 Data

The analysis aims to specify the relative efficiency of nine German airports and one airport group. The airports which construct the sample of analysis are Bremen, Cologne-Bonn, Dortmund, Düsseldorf, Hamburg, Hanover, Munich, Nuremberg and Stuttgart. In addition to these airports Berlin Airport Group, represented by Tegel, Tempelhof and Schönefeld, was added to the sample as a whole. For the other international German airports, necessary data for this analysis was either not available, or was only partially available.

The largest and the most important international German airport Frankfurt had to be excluded from the sample, because the operating company Fraport AG publishes no separate annual reports for each of the airport owned, but a consolidated company report, where combined information on many airports are presented, including the airports out of Germany. Similarly, annual reports from Berlin Airport Group also present the consolidated income statement and balance sheet of three airports; however the output figures for these three airports were summed up and the airport group was used as a single airport in the analysis relying on the fact that these airports are located in the same city. Nevertheless, conclusion should be made with a special care, as three airports focus on different segments of the market.

Data, covering these 10 airports and years 1998 to 2007, gave only 100 observations, which seemed to be insufficient to acquire reasonable results with 3 inputs and 2 outputs when the DEA is applied. For this reason technology was defined by using a larger unbalanced dataset of 59 European airports, which are listed in Table 5. As a result 442 observations were used to conduct the Data Envelopment Analysis. The characteristics of the data can be seen in Table 6. Furthermore, the fact that we are also interested in the effects of airport size on the efficiency gave lead to keeping a mixed sample of airports with different sizes.

TABLE 5: 59 EUROPEAN AIRPORTS USED IN THE DEA

Country	Airport	IATA-Code	Country	Airport	IATA-Code
Austria	Vienna	VIE	*Italy*	Pescara	PSR
Belgium	Brussels	BRU	*Italy*	Pisa	PSA
Denmark	Copenhagen	CPH	*Italy*	Reggio di Calabria	REG
France	Marseilles	MRS	*Italy*	Rimini	RMI
Germany	Berlin Airp.	BER	*Italy*	Trapani	TPS
Germany	Bremen	BRE	*Italy*	Trieste	TRS
Germany	Dortmund	DTM	*Italy*	Turin	TRN
Germany	Dresden	DRS	*Italy*	Venice	VCE
Germany	Düsseldorf	DUS	*Netherlands*	Amsterdam	AMS
Germany	Hamburg	HAM	*Norway*	Oslo	OSL
Germany	Hanover	HAJ	*Switzerland*	Zurich	ZRH
Germany	Cologne-Bonn	CGN	*UK*	Aberdeen	ABZ
Germany	Leipzig	LEJ	*UK*	Belfast Int.	BFS
Germany	Munich	MUC	*UK*	Birmingham	BHX
Germany	Nuremberg	NUE	*UK*	Birmingham	BHX
Germany	Saarbrucken	SCN	*UK*	Bristol	BRS
Germany	Stuttgart	STR	*UK*	Cardiff Int.	CWL
Italy	Alghero	AHO	*UK*	Edinburgh	EDI
Italy	Ancona	AOI	*UK*	Glasgow	GLA
Italy	Bergamo	BGY	*UK*	Leeds/Bradford	LBA
Italy	Bologna	BLQ	*UK*	Liverpool	LPL
Italy	Cagliari	CAG	*UK*	London City	LCY
Italy	Catania	CTA	*UK*	London Gatwick	LGW
Italy	Florence	FLR	*UK*	London Heathrow	LHR
Italy	Forio	FRL	*UK*	London Luton	LTN
Italy	Genoa	GOA	*UK*	London Stansted	STN
Italy	Lamezia	SUF	*UK*	Manchester	MAN
Italy	Naples	NAP	*UK*	Newcastle	NCL
Italy	Olbia	OLB	*UK*	Southampton	SOU
Italy	Palermo	PMO			

TABLE 6: DESCRIPTIVE STATISTICS FOR 59 EUROPEAN AIRPORTS

Variable	Min	Max	Mean	Median	Std. Deviation
Staff Costs	369864	299105680	40751477	16065467	51475061
Other Operating Costs	305782	628965300	59875292	22540173	93778526
Tangible Assets + Inventories	59673	12657525575	785509750	156994783	1788679641
Passengers	22905	67673000	8688303	3958608	11758649
Cargo	0	1495919	122659	18120	271405

TABLE 7: DESCRIPTIVE STATISTICS FOR 10 GERMAN AIRPORTS

Variable	Min	Max	Mean	Median	Std. Deviation
Staff Costs	3656064	299105680	72184225	53014393	63252816
Other Operating Costs	3631590	462642916	83521831	63716709	92087551
Tangible Assets + Inventories	75385321	2918920242	590422638	375215882	660947780
PAX	610640	33959422	9460447	7660619	7833608
Cargo	0	719076	93745	22275	174444

In the next steps (correlation with revenue efficiency and second stage regression) sample was reduced to the 10 German airports of interest as the effectiveness of these analyses were thought to be independent of the sample size (for the Spearman Rank Correlation Test) and the necessary data for whole the sample was not available (for the second stage regression). Table 7 shows the descriptive statistics with regard to 10 German airports of interest.

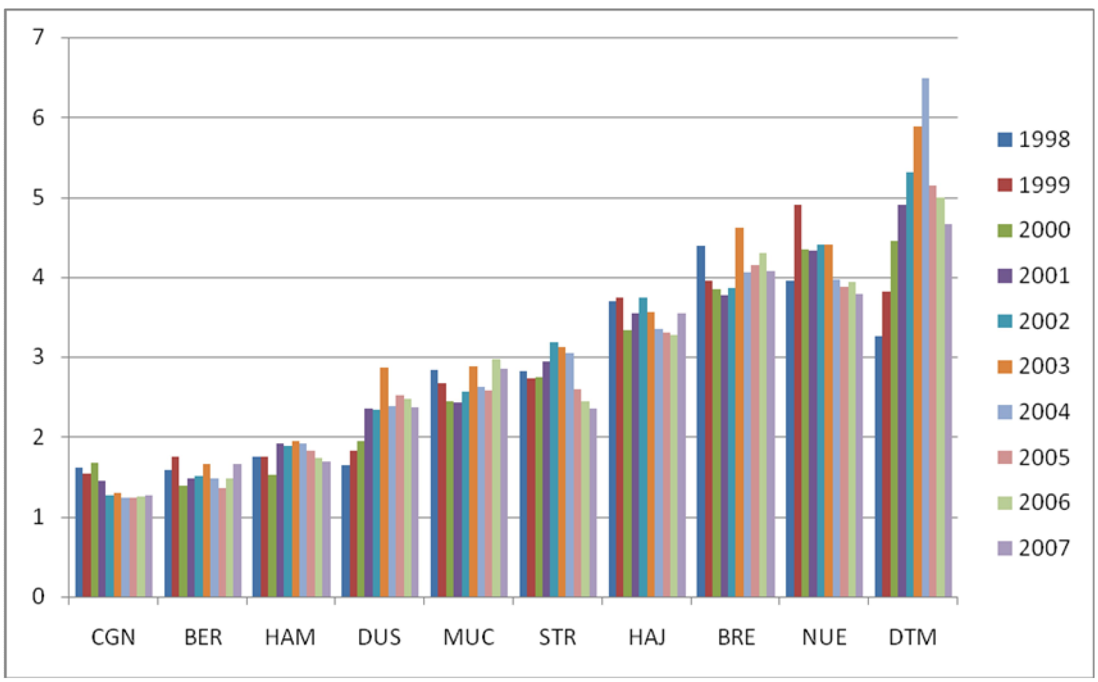
Financial data was obtained from the annual reports of airports, which was collected by German Airport Performance (GAP) Project.[24] Traffic and other data were obtained via direct contacts to airports or other institutions in the aviation industry, again in the framework of GAP Project.

[24] For more details, see www.gap-projekt.de

7.3 Results

Input oriented variable returns to scale DEA efficiency scores are presented in Figure 6. Efficiency increases as the value gets closer to 1. Varying efficiency scores are obtained both among airports and on time horizon. It should be kept in mind that these scores are relative efficiencies but not absolute values. Hence, a decrease (increase) of efficiency could be due to an efficiency decrease (increase) of the airport, an efficiency increase (decrease) of other airports in sample, or a combination of both. Furthermore, DEA efficiency scores proved to be significant, as they happened to be within the confidence intervals obtained by bootstrapping with 2000 replications. The table which shows the confidence interval for this sample can be seen in Appendix 3.

FIGURE 6: DEA EFFICIENCY SCORES



Moreover, the null-hypothesis that the there is no correlation between cost efficiency and revenue efficiency is rejected according to the Spearman rank correlation test.

$$r = \left[1 - \frac{6 \sum D^2}{n(n^2 - 1)} \right] = 0{,}762889 > 0{,}43 = CriticalValue$$

Finally, Table 8 presents the results obtained from the truncated bootstrapped second stage regression.

TABLE 8: SECOND STAGE REGRESSION RESULTS

	Constant	WLU (airport size)	Private Share	Regulation Dummy	Staff Costs	PAX/ATM (Aircraft Size)	Int'l PAX Percentage	Sigma
Coefficient	2,6554	-0,3113	-0,5399	-0,3816	0,0342	-0,0382	5,3755	0,6752
LB 1%	1,6371	-0,4115	-1,9223	-1,1105	0,0209	-0,0550	3,5528	0,5507
UP 1%	3,6626	-0,2044	0,9578	0,2422	0,0466	-0,0199	7,1394	0,8265
Sgnft. 1%	*	*			*	*	*	*
Sgnft. 5%	*	*			*	*	*	*
Sgnft. 10%	*	*		*	*	*	*	*

8 Discussion

8.1 Explaining the Efficiency Scores

Figure 6 ranks 10 German airports according to their efficiency scores. The airports are ordered according to their average efficiency scores for 10 years.

Cologne-Bonn outperforms its counterparts in average scores and also in most of the years. Besides being the best performing airport, it presents efficiency increase when the full period is observed. It is the sixth largest airport in Germany with an increasing focus on low cost carrier (LCC) traffic. In terms of LCC traffic, it offers the highest number of traffic with almost 500 starts in a week and with more than 7 million passengers in 2008 (ADV, 2009). LCC traffic represents a 70 percent share in total passenger traffic. Thus, the airport was able to handle a maximum number of passengers with lower costs. Table 9 gives an overview of LCC shares in 10 German airports between 2005 and 2008. In addition to the passenger traffic, cargo traffic plays an important role in Cologne-Bonn airport. It is the second busiest cargo hub in Germany and seventh in Europe.[25] It is the European hub of UPS Express and the East-European hub for Fedex. Due to the fact that cargo is one of the two outputs in the analysis, this gives a relative advantage to Cologne-Bonn airport on being closer to the most efficient frontier of the sample. However, DHL and Lufthansa Cargo moved its operations to Leipzig at the end of 2007. As a result, total cargo volume in Cologne-Bonn decreased by 18 percent in 2008. Hence the relative performance of Cologne-Bonn attracts interest for the years after 2007.

TABLE 9: LCC TRAFFIC AND SHARE IN 10 GERMAN AIRPORTS*

2005	LCC PAX	Total PAX	%	2007	LCC PAX	Total PAX	%
BER	7,0	17,1	40,70%	BER	10,5	20,0	52,70%
CGN	6,2	9,4	65,50%	CGN	7,3	10,4	69,80%
MUC	3,5	28,5	12,30%	MUC	5,5	33,9	16,30%
STR	2,8	9,3	30,00%	DUS	4,6	17,8	25,90%
DUS	2,6	15,4	16,80%	STR	4,2	10,3	41,20%
HAM	2,1	10,6	19,80%	HAM	3,8	12,7	30,20%
HAJ	1,4	5,6	24,90%	HAJ	1,8	5,6	32,00%
DTM	0,8	1,7	45,80%	DTM	1,6	2,2	74,10%
NUE	0,4	3,8	10,00%	NUE	1,2	4,2	29,20%
BRE	0,1	1,7	4,30%	BRE	0,7	2,2	32,80%
2006	LCC PAX	Total PAX	%	2008	LCC PAX	Total PAX	%
BER	9,0	18,4	49,00%	BER	11,6	21,4	54,10%
CGN	6,7	9,8	68,20%	CGN	7,2	10,3	70,10%
MUC	4,6	30,7	14,90%	DUS	5,2	18,1	28,40%
DUS	3,7	16,5	22,60%	MUC	5,1	34,5	14,80%
STR	3,7	10,0	36,40%	STR	4,4	9,9	44,20%
HAM	3,2	11,9	26,70%	HAM	3,9	12,8	30,40%
HAJ	1,7	5,6	30,10%	DTM	1,9	2,3	83,40%
DTM	1,1	2,0	55,60%	HAJ	1,9	5,6	33,20%
NUE	0,7	3,9	18,50%	NUE	1,3	4,2	31,50%
BRE	0,2	1,7	8,90%	BRE	1,0	2,5	40,50%

SOURCE: Low Cost Monitor 1/2006-1/2009, ADV

***Passenger figures are in millions**

[25] See, www.koeln-bonn-airport.de

Berlin airports follow Cologne-Bonn in the analysis and show an unstable trend on the dynamic efficiency analysis on time. When the sum of passenger numbers for 3 Berlin airports are observed, Berlin is the third busiest in Germany. Thanks to its high number of passengers, demand side contributes to relative efficiency. In addition to that, as Table 9 shows, Berlin airports serve the highest number of LCC passenger traffic in Germany. Air Berlin, which is the second largest airline and the largest low cost carrier in Germany, uses Tegel as its main hub. In addition, Tegel enjoys high levels of international and intercontinental traffic. Schönefeld, on the other hand, serves other LCCs such as Germanwings, Easyjet and Ryanair. Tempelhof airport is located in the center of city and served small business flights, but it was shut down in the end of 2008, because of its persistent huge losses. Nevertheless, our analysis shows that other two airports Tegel and Schönefeld were able to subsidize these losses with their good performance.

Moreover, cost structure of Berlin airports is different than the other airports in the sample, because it outsources its ground handling activities to Globe Ground GmbH. It can be concluded that outsourcing these activities leads Berlin airports to operate more efficiently. On the other hand, it can be observed that Berlin airports cannot transform its physical inputs into revenues as efficient as other airports in the sample. Figure 7 and 8 help us to draw some supporting conclusion for DEA efficiency scores for the 10 sample airports. Figure 7 depicts the total aeronautical revenues weighted by number of ATMs. Additionally, Figure 8 shows the relative performance of airports on concession revenues, indicated by the ratio of total non-aeronautical revenue to total PAX. In both aeronautical and non-aeronautical revenues, Berlin airports seem to be unproductive, contradicting their good results on DEA scores.

One methodological reason for this contradiction can be the distortion which stems from incorporating three Berlin airports into a single production unit. Separate data for the three airports were demanded by contacting the airport company directly to be used in this master thesis; however this attempt was not successful.

FIGURE 7: AERONAUTICAL REVENUES / ATM

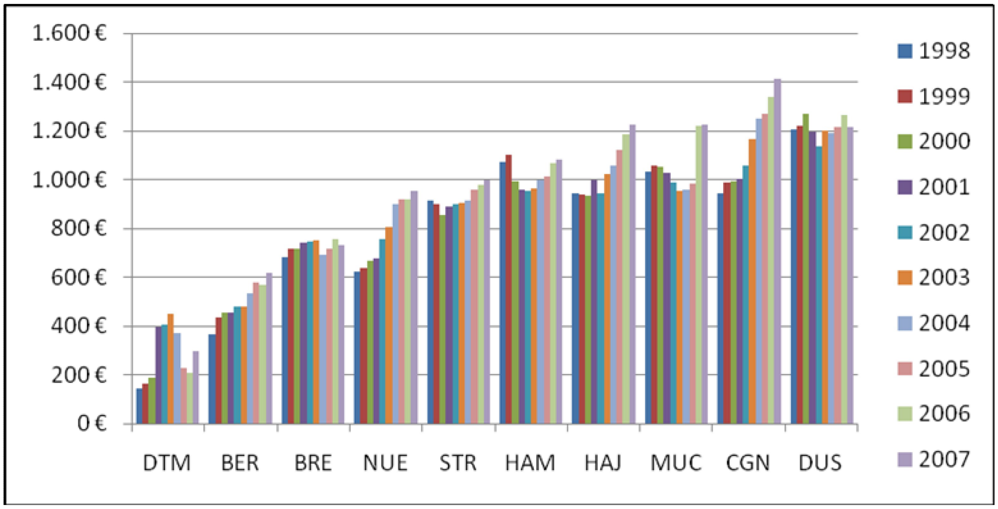
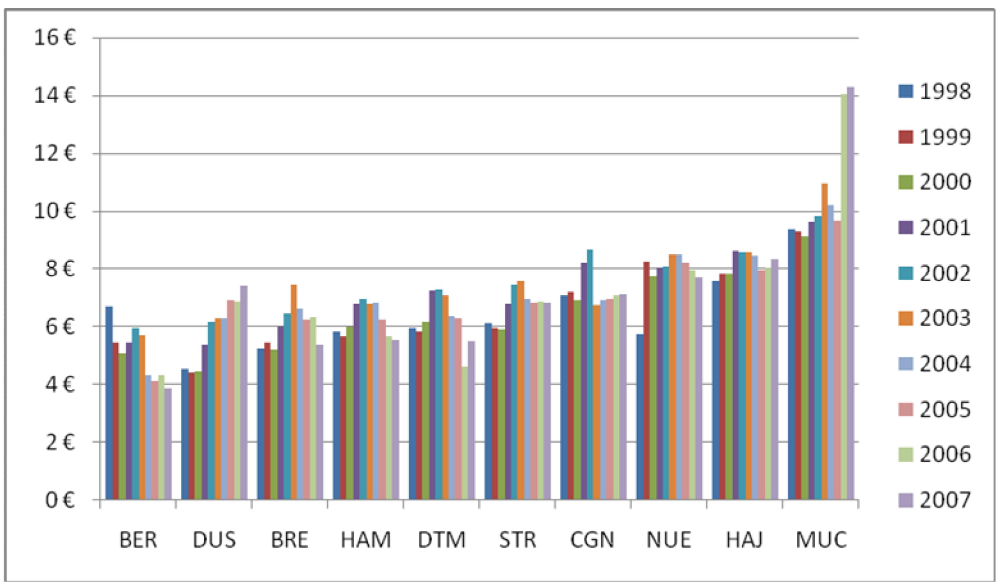


FIGURE 8: NON-AERONAUTICAL REVENUES / PAX



In comparison to the first two airports explained, Hamburg airport's traffic structure mainly composes of main carriers. Being in the northern Germany with not too many close main airports, it enjoys a competitive advantage. Privatization and change from rate of return to incentive regulation to incentive regulation of Hamburg airport took place in 2000 as explained in Chapter 6. It was the first application of incentive regulation to an airport in Germany and proved to be efficient in this case. When DEA efficiency scores are observed, there is a positive trend starting in 2003. One can conclude that the positive effects of privatization and incentive regulation needed a lag to be effective. Hamburg airport is shown to be an example of good management with public-private joint ownership in Germany. Figure 7 also shows that the revenues started to increase from 2003 on.

Although being relatively efficient among other 9 airports, Düsseldorf presents a sharp deterioration within the sample period until 2003. Capacity problems seem to be the main reason behind this. As explained in previous chapters, Düsseldorf undertook main capacity investments, due to the terminal fire in 1996. Hence, Düsseldorf was able to increase its number of passengers only by 13 percent in a 10-year period, which is far behind of the airport industry for the same period. In addition, capacity expansions had negative effects on the costs, as the airport was not able to operate effectively due to constructions. Implementation of incentive regulation in 2005 shows its positive effects on efficiency. Also, capacity expansions, which started at 1996, were completed in the period and seem to pay off starting from 2005. In addition, Figure 7 shows that Düsseldorf is the most expensive airport in the sample (in terms of 10-year average) and Figure 8 shows the important of commercial revenues from 2000 on.

Munich airport presents unstable results. Being the second largest German airport, it increased its number of passengers by 120 percent in 10 years. Lufthansa's strategic choice of Munich as the second hub after Frankfurt, led to this boom in the traffic. On the other hand, costs also increased dramatically. Total operating costs for the same period presents more than 100 percent increase, which prevents Munich to transform the rise in PAX into efficiency scores. In addition, Munich produces the highest level of revenue from concessions (Figure 8) and the third highest revenues from charges (Figure 7) among 10 airports, which shows that inefficiency arises from the supply side and hence there is need for developing strategies for decreasing the costs to operate more efficiently.

As in the case of Cologne-Bonn and Berlin, Stuttgart has also increased its focus on LCC traffic. Germanwings and Tuifly use Stuttgart airport as their base since 2003. Since then, total number of passengers increased by more than 30 percent due to LCC traffic. Despite the increase in traffic, it was able to keep its costs stable. This can be seen in DEA efficiency scores, which shows a decreasing trend starting in 2003.

Hanover and Bremen airports are considered to operate and be managed not efficiently in German airport sector, which is to some extent can be confirmed in this analysis. Hanover is a former military airport, which was transformed into a civil airport in 1952. For this historical reason, it has excess capacity, which influences costs via ineffective use of resources. On the other hand, another possible reason for having such inefficient results could be the high charges. Hanover is the fourth expensive airport on average in Figure 7, which might have decreased the demand from the airlines. This might have also prevented LCCs to choose Hanover as one of their operation nodes in the boom of LCC traffic, which might have in fact brought additional passengers for a better utilization of excess capacity.

Bremen can be regarded as a secondary airport in northern Germany after Hamburg. The strong competition from Hamburg was the main reason that they operated more as a regional airport, which negatively influenced the efficiency. In 2007, Ryanair, the biggest LCC in Europe, started operations to and from Bremen, which helped the airport to reach 2 million passengers. Except these factors, the underlying factors behind the efficiency scores of Bremen are ambiguous.

Nuremberg is the second largest airport in Bavaria after Munich and serves mostly main carriers. Higher staff and operating costs are the distinguishing characteristics, which might stem from the socio-economic situation of state of Bavaria, as depicted also in case of Munich airport. This, in turn, is assumed to influence the cost efficiency negatively. Air Berlin has chosen Nuremberg as a hub, which stimulated the number of passengers served here and this led to the positive trend in efficiency in the last years of analysis.

Dortmund is characterized as the worst performing airport in the sample both in static and dynamic sense. Efficiency scores of Dortmund airport had large jumps from year to year, in a negative way until 2004 and positively afterwards. Dortmund airport is located in western Germany, which occupies a very dense population. Dortmund airport faces a strong competition from Düsseldorf, which is the primary airport of the area, and Cologne-Bonn, which attracted a large amount of LCC traffic. In addition, it shares the overlapping catchment area with some regional airports such as Münster/Osnabrück and Paderborn/Lippstadt. Due to this strong competition, Dortmund was able to increase its traffic only incrementally during the last 10 years, although it invested a large amount on capacity expansions, as explained in Chapter 6. Hence, the new capacity did not match the traffic, leaving airport to perform very inefficiently. Furthermore, management of the airport had no incentive towards a better financial performance, because the losses were always subsidized by the government, which is the owner of airport at the same time.

8.2 Explaining the Relationship between Cost and Revenue Efficiency

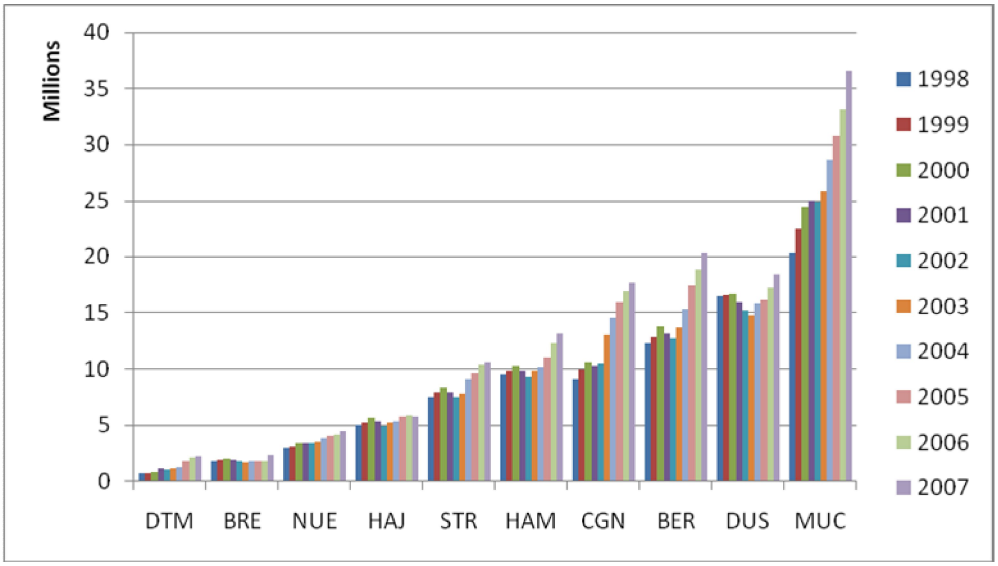
The motivation behind the analysis in the second step was that the DEA covers the costs of the airports, but not the revenues. The revenues were not used as outputs, because it was thought to be highly correlated with the other outputs. Spearman rank correlation test of 10 German airports for 10 years gave a value of 0,76, which is bigger than the corresponding critical value. Hence, it can be concluded that the cost efficiency is monotonically related to revenue efficiency as far as this sample is concerned. This conclusion has already been used in the interpretation of DEA scores above. In order to have a more complete analysis, partial indicators on revenues in Figure 7 and 8 are also used.

8.3 Explaining the Influencing Factors of Efficiency

The second stage regression gave significant results at 10% level, except private share. It also returned coefficients with expected signs, except international percentage of passenger traffic.

WLU had a coefficient of "*-0,3113"*, which decreases the DEA score, hence increases the efficiency. It confirms the proposition that larger airports make use of scale economies (Morrison, 1983; Graham, 2005). Oum et al. (2003), Barros and Dieke (2008), Barros (2008c) also find similar results. Figure 9 shows the size of 10 airports in the analysis, which is approximated by WLU. Munich, Düsseldorf, Berlin and Cologne-Bonn are the largest 4 airports, which show high efficiency scores in the analysis.

FIGURE 9: SIZE OF THE AIRPORTS SHOWN BY WLU

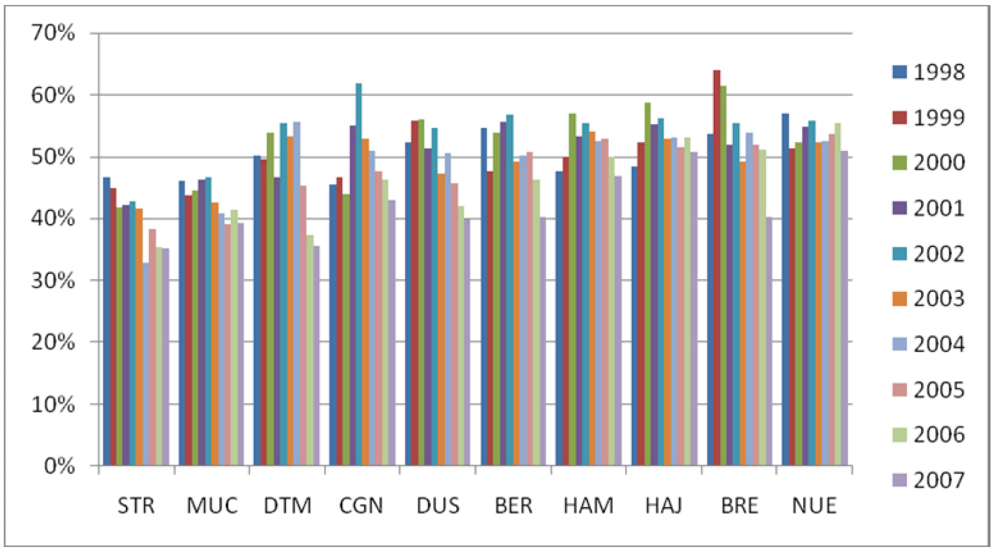


Like airport size, ***private shares*** also shows a positive effect on the efficiency scores of the airports. Being one of the most controversial issues in the airport sector in terms of efficiency, it has been subject to plenty of analyses. This analysis, however, supports the findings of Oum et al. (2008), Vogel (2006) and Barros and Dieke (2008) and contradicts those of Parker (1999), Vasigh and Haririan (2003), Holvad and Graham (2003) and Oum et al. (2006). In our sample, 2 airports with private shares, Hamburg and Düsseldorf, show efficiencies, whereas Hanover shows inefficiencies in comparison to the sample. Furthermore, they get better scores for the years after privatization, which shows that the effects of privatization take place only after a lag. The coefficient for the private share on the regression was "*-0,5399*", which was stronger than the coefficient of airport size. Nevertheless this coefficient is not statistically significant.

As explained in Chapter 5 and 6, transition to the ***incentive regulation*** aimed to increase the efficiency of German airports, which can be confirmed with the negative coefficient from second stage regression analysis. However, it is statistically significant only at 10 percent level. Actually, airports with incentive regulation are the same airports, which were privatized; hence a similar result is inevitable. Hamburg and Düsseldorf again show efficiency increases after incentive regulation started to be implemented.

Staff costs were included in the second stage regression to see the importance of labor in production and its effects on overall efficiency. Staff costs constitute up to 65 percent of total operating costs of airports as shown in Figure 10 below. With its positive sign and a value of "*0,0342"* it restrains the efficiency of airports as expected and it is statistically significant in all levels.

FIGURE 10: SHARE OF STAFF COSTS ON TOTAL OPERATING COSTS



Average aircraft size, approximated by PAX to ATM ratio, is expected to contribute to the efficiency of airports, because it implies more passengers, which are the primary outputs. It also implies more revenue, because larger aircraft pay higher fees. However, the ratio of passenger related charges to aircraft related charges vary from airport to airport.[26] Hence, a detailed analysis of charges structure can help explaining this result more elaborately. One can also conclude that larger aircraft implies a lower average costs, because handling an aircraft has high fixed costs due to the equipment used. The coefficient for aircraft size is "-0,0382" and it is statistically significant.

Only unexpected result in terms of the sign of coefficient comes from ***percentage of international traffic***. In the literature, it is generally supported that

[26] Larger airports seem to have a higher share of passenger related charges.

more international traffic brings a higher efficiency. However, these analyses mostly consider the operational efficiency. Graham (2005) states that handling international traffic requires higher costs and generates higher revenues. Following this, one explanation to the obtained result can be that the effects of international traffic on costs are much higher than the benefits from revenues. As a result, the positive sign of the coefficient can to some extent be explained, as this analysis mainly focused on cost efficiency.

9 Conclusions

This master thesis tries to shed a light on airport efficiency, by explaining it in detail, presenting the methodologies used and stating the influencing factors. An extensive literature review gives opportunity to understand the general framework in terms of methodologies, focus of interest and the data structure. German airports, thereafter, are investigated in detail, because of their importance in Germany and in Europe and also due to lack of previous research. Data envelopment analysis is used to assess the relative efficiency of German airports and conclusions for the efficiency levels are drawn. In addition, influencing factors of efficiency are shown.

Although this analysis tried to capture as much as information on airport efficiency, it was not possible to account for every single variable due to the fact that airports are complex production units. However, the topics related to economics (and finance) rather than technical issues, were tried to be covered as much as possible.

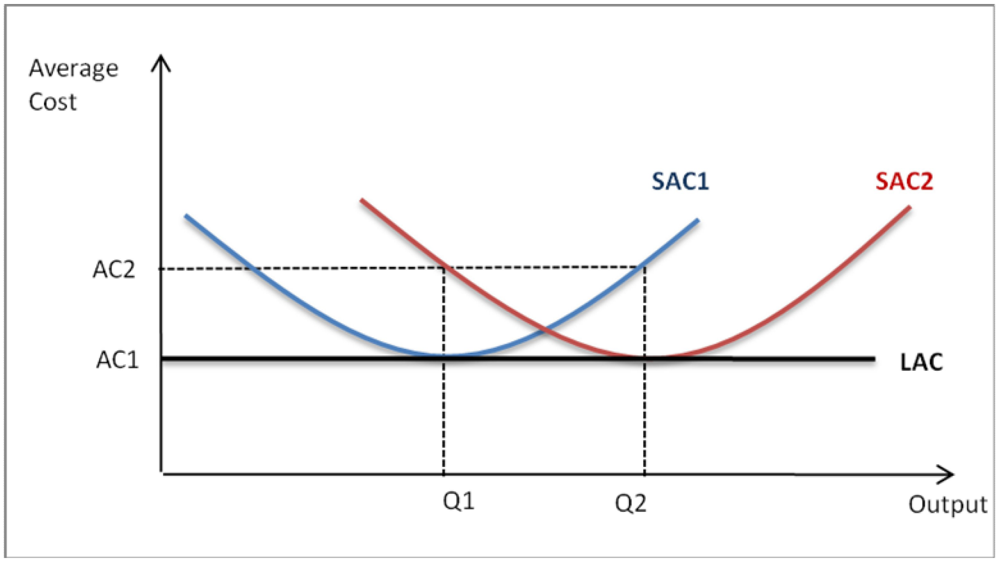
Some obstacles such as unavailability of data, e.g. Frankfurt airport, prevented to get more elaborate results.

One of the most important arguments on the efficiency of German airports was increasing importance of LCC traffic. Especially for the airports with excess capacity, LCC traffic yields extra output, with lower additional costs. The fact that airports have very high fixed costs explains this issue, because marginal average cost of any additional traffic is lower, so that an efficient operation is stimulated. Importance of LCC traffic on efficiency was considered to be captured in the second stage regression. But the data was only partially available, which was depicted by Table 9, which allowed only an informative description of this issue, rather than an empirical analysis.

Capacity expansion is another factor, which has major effects on airport efficiency. On the one hand, capacity expansion requires a large amount of funds, which bring very high lump-sum fixed costs to the airport. These fixed costs are amortized during time, which are reflected in the financial situation of airport with different amounts. On the other hand, despite its all-at-once provision, new capacity needs a long period to bring its demand to the airport. Traffic increases only gradually, year-by-year, achieving its efficient level during a long period. For this reason, efficiency scores for each year are highly dependent on the timing of the expansion.

Capacity expansion is a generally observed difficulty in airport benchmarking, because it is not easy to account for capacity expansions in the methodologies generally used. Morrison (2009) states that, the investment-cycle of airports should be considered in benchmarking in order to identify the effects of expansion. Airports, which undertook capacity expansions recently, happen to be less efficient in terms of their financial conditions and in its operations. Morrison uses a case, which compares 2 airports with 2 different investment strategies, in order to explain this issue with economic theory. For this aim, Figure 11 shows the capacity expansion under constant returns to scale and its effects on costs. Initially, long run equilibrium is where both airports operate along the short run average cost curve SAC1 with output level Q1. With this level of output, the average cost level is AC1. It is assumed that the first airport increases its capacity now, expecting a higher output in the future, namely Q2. This results in a higher level of average costs, AC2, as the airport moves to the new short run average cost curve SAC2. The average cost jumps at-once now and decreases only gradually back to AC1, where the long run equilibrium is reached with output level Q2. On the other hand, second airport does not increase its capacity now, but continues to operate along SAC1. As the demand (Q) increases, its average costs rises gradually along the curve until AC2, where it reaches the output Q2. This is the demand, which cannot be met anymore with the existing capacity. Hence, on this point it undertakes the capacity expansion, which brings it to the long run equilibrium with lower average costs, AC1.

FIGURE 11: CAPACITY EXPANSION UNDER CONSTANT RETURNS TO SCALE



SOURCE: Based on Morrison (2009)

Since the duration of capacity pay-off and the planned horizon of investment[27] for each airport are different, a general conclusion is not possible for the German airports, which were investigated in the sample. For example, the worst performing airport Dortmund had runway extensions and new terminal buildings, which was not able to create its demand so far. However, such problems are inevitable in the airport sector, as long as demand does not match the long term forecast, because these investments are made with a long-term view as a result of traffic forecasts. For these airports, it is still questionable, if the wrong traffic forecast was because of wrong assumptions and strategies or because of external demand shocks and this question should be answered by airport management to explain the inefficiencies.

On the other hand, besides the importance of private-public ownership structure, public ownership of German airports also attracts a special attention. Because of the decentralized political structure of Germany, airports are owned jointly by a number of public authorities. This raises questions about the efficiency of management, which is represented by different authorities. This

[27] One airport can focus on a period of 10 years, another one 20 years, for instance.

structure possibly creates conflicts between different interest groups on the decision processes, influencing the efficiency negatively. For instance, Bremen is owned solely by the city-state of Bremen, whereas federal government of Germany, state of Brandenburg and city-state of Berlin has shares on Berlin airports, although they are both classified as totally public utilities. Number of public shareholders, in addition to the percentage of private share, was tried to be captured in the second stage regression to determine the possible effects on efficiency; however some details did not allow for such an analysis. For example, 2 local administrative units (counties), where Cologne-Bonn airport is located, has minor, symbolic shares in the airport, which makes the number of owners 6, together with federal government, state of North Rhine-Westphalia and the cities Cologne and Bonn.

Regulation of German airports became a very important issue in Germany recently. As confirmed in the second stage regression analysis, introducing incentive regulation has positive effects on the efficiency of airports. Niemeier (2002b) investigates the regulation system for Hamburg airport and makes some policy implications for the other German airports following his analysis. According to him, in order to overcome the inefficient system of regulation in Germany, all airports should learn lessons from Hamburg type of price-cap regulation and implement it. Moreover, he strongly suggests an introduction of an independent regulator, which should apply incentive regulation with dual-till. This regulator should also reinforce competition between airports by privatization, he concludes. Regulation and privatization effects on efficiency were econometrically explained in the second stage regression, which supported Niemeier (2002b), but information on competitive powers of airports was not available to be included in the regression. However, it was briefly discussed, as DEA scores of the airports were separately explained.

Furthermore, "staff costs" was the only variable in our second stage regression, which can be controlled by management according to the literature on airport efficiency. Other variables are not under the control of management. However, in Germany, it is questionable how strong the management is on influencing (minimizing) the staff costs due to the high power of labor unions. Workers in different levels of airport operation are members of large labor unions, which have great influence on politics. This is why German airports, in comparison to its European counterparts, cannot be too effective on cost minimization. Labor strikes in Frankfurt in 2008 and in Berlin airports in the beginning of 2009, which resulted in cancellation of hundreds of flights, is a rough proof of labors' power is in the bargaining process.

Taking all these facts into account, which are either explained and shown by means of empirical analysis or presented with the help of economic theory, airport managements should set their priorities according to the economic, political, operational and financial conditions of airports. Managements should be aware of the factors which they can control and use them to develop strategies for reaching short and long-term goals. Furthermore, they should identify and analyze the factors, which they cannot directly keep under control, and combine them with their strategies in order to be able to achieve an efficient level of operation.

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10 References

BOOKS

Beesley, M.E. (1999), “Airport Regulation,” in: M.E. Beesley, (ed.): Regulating Utilities: A New Era? Institute of Economic Affairs, London.

Charnes, A., Cooper, W.W., Lewin, A.Y., Seiford, L.M., (1995). Data Envelopment Analysis: Theory, Methodology and Applications. Kluwer Academic Press, Boston.

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

Niemeier,H.M. (2004) Capacity Utilization, Investment and Regulatory Reform of German Airports In: P. Forsyth et al., Editors, The Economic Regulation of Airports, Ashgate, Aldershot.

Ray, S.C. (2004), Data Envelopment Analysis, Cambridge University Press.

Shephard, R.W. (1970), Theory of Cost and Production Function, Princeton University Press.

Templin, C. (2007), Bodenabfertigungsdienste an Flughäfen in Europa: Deregulierung und ihre Konsequenzen, Kölner Wissenschaftsverlag, Cologne.

PUBLISHED PAPERS

Adler N. and Berechman J., (2001). Measuring airport quality from the airlines' viewpoint: An application of data envelopment analysis, Transport Policy, 8 (3), pp. 171-81

Assaf, A. (2009), Bootstrapped scale efficiency measures of UK airports, Journal of Air Transport Management, Article in Press, 2009

Averch, H. and L. Johnson (1962). "Behavior of the Firm Under Regulatory Constraint."American Economic Review 52 (1962): 1052-1069.

Barrett, S.D., (2000). Airport competition in the deregulated European aviation market. Journal of Air Transport Management 6 (1), 13–27.

Barros, C.P. (2008a). Technical change and productivity growth in airports: A case study. Transportation Research, Part A, 42, 5, 818-832

Barros, C.P. (2008b), Technical Efficiency of UK airports, Journal of Air Transport Management, 14, 175-178.

Barros, C.P. (2008c), Airports in Argentina: Technical efficiency in the context of an economic crisis, Journal of Air Transport Management, Volume 14, Issue 6, Pages 315-319, 2008

Barros, C.P. and Weber, W.L. (2009), Productivity Growth and Biased Technological Change in UK Airports, Transportation Research Part E, Volume 45, Issue 4, Pages 642-

653, 2009

Barros, C.P., & Dieke, P.U.C. (2007), Performance Evaluation of Italian Airports with Data Envelopment Analysis, Journal of Air Transport Management, 13, 184-191, 2007

Barros, C.P., Sampaio, A. (2004). Technical and Allocative Efficiency in Airports. International Journal of Transport Economics, 31, 355-377.

Bazargan, M., Vasigh, S., 2003. Size versus efficiency – a case study on US commercial airports. Journal of Air Transport Management 9, 187–193

Cohn, N. and de Wit, A. (1999), Benchmark Airport Charges, Journal of Air Transport World Wide, Vol.4 No.2, 1999

Cullinane K., Wang, T.F., Song, D.W., & Ji P. (2006). The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. Transportation Research, Part A, 40, 354-374

Czerny A. (2006), Price-cap regulation of airports: single-till versus dual-till, Journal of Regulatory Economics 30 (1) (2006), pp. 85–97

Fernandes, E., Pacheco, R. R., (2002). Efficient Use of Airport Capacity. Transportation Research : Part A. Policy and Practice, 36, 225-38

Francis G., Humphreys I. and Fry J. (2002), The benchmarking of airport performance. Journal of Air Transport Management 8 (2002), pp. 239–247

Fuhr J. and Beckers T. (2006). "Vertical Governance between Airlines and Airports - A Transaction Cost Analysis," Review of Network Economics, Concept Economics, vol. 5(4), pages 386-412

Gillen, D., & Lall, A. (2001). Non-parametric measures of efficiency of US airports. International Journal of Transport Economics, 28, 283-306

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

Graham A. andVogel H., A comparison of alternative airport performance measurement techniques: a European case study, Journal of Airport Management 1 (2006), pp. 59–74

Graham, A. (2005) ‘Airport benchmarking: A review of the current situation’, Benchmarking: An International Journal, Vol 12, No 2, pp99-111

Hooper, P. and Hensher, D. (1997) ‘Measuring total factor productivity of airports - An index number approach’, Transportation Research, Vol 33E, No 4, pp249-259

Lin, L.C., Hong, C.H., (2006), Operational performance evaluation of international major airports: An application of data envelopment analysis, Journal of Air Transport Management 12 (2006) 342–351

Marques, R.C. and Brochado, A. (2008), Airport regulation in Europe: Is there need for a European Observatory?, Transport Policy 15 (2008) 163–172

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, 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, Vol. 6, No 2, 111-134

Martin, J.C. and Socorro, M.P. (2009), A new era for airport regulators through capacity investments, Transportation Research Part A 43 (2009) 618–625

Martin-Cejas, R. (2002) 'An approximation to the productive efficiency of the Spanish airports network through a deterministic cost frontier', Journal of Air Transport Management, Vol 8, pp233-238

Morrison, W.G. (2009), Understanding the complexities and challenges of airport performance benchmarking, Journal of Airport Management, Volume 3, Number 2, 145 – 158, 2009

Morrison,S.,(1983). Estimation of long-run prices and investment levels for airport runways. Research in Transportation Economics 1,103–130.

Murillo-Melchor, C. (1999) 'An analysis of the technical efficiency and productive change in Spanish airports using the Malmquist Index', International Journal of Transport Economics, Vol 26, No 2, pp271-291

Niemeier, H.M. (2002), Regulation of airports: the case of Hamburg airport—a view from the perspective of regional policy, Journal of Air Transport Management, Volume 8, Issue 1, Pages 37-48

Nyshadham, E. and Rao, V. (2000) 'Assessing efficiency of European airports, Public Works Management and Policy, Vol 5, No 1, pp 106-114

Oum, T. and Yu, C. (2004) 'Measuring airports' operating efficiency: a summary of the 2003 ATRS global airport benchmarking report' Transportation Research, Vol 40E, pp515-532

Oum, T., A. Zhang and Y. Zhang (2004), "Alternative Forms of Economic Regulation and Their Efficiency Implications for Airports," Journal of Transport Economics and Policy, Vol. 38, pp. 217-246.

Oum, T., Adler, N. and Yu, C. (2006), Privatization, corporatization, ownership forms and their effects on the, performance of the world's major airports, Journal of Air Transport Management 12 (2006) 109–121

Oum, T., Yan, J. and Yu, C. (2008), Ownership forms matter for airport efficiency: A stochastic frontier investigation of worldwide airports, Journal of Urban Economics 64, 422–435, 2008

Oum, T., Yu, C. and Fu, X. (2003), A comparative analysis of productivity performance of the world's major airports: summary report of the ATRS global airport benchmarking research report—2002, Journal of Air Transport Management, Volume 9, Issue 5, September 2003, Pages 285-297

Pacheco R. and Fernandes, E. (2003) 'Managerial efficiency of Brazilian airports' Transportation Research, Vol 37A, No 4, pp667-680

Park, Y. (2003), An analysis for the competitive strength of Asian major airports, Journal of Air Transport Management, Volume 9, Issue 6, November 2003, Pages 353-360

Parker, D. (1999) 'The performance of BAA before and after privatisation: A DEA study', Journal of Transport Economics and Policy, Vol 33, No 2, pp133-146

Pathomsiri S., A. Haghani, M., Dresner., and R.J. Windle. (2008). Impact of undesirable outputs on the productivity of US airports. Transportation Research Part E, 44 (2), 235 – 259

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

Pels, E., Nijkamp, P., and Rietvield, P. (2003). Inefficiencies and scale economies of European airport operations. Transportation Research Part E, 39, 341-361

Sarkis, J (2000). Operational Efficiency of Major US Airports. Journal of Operations Management, 18, 335-251

Schmidberger, S., Bals, L., Hartmann, E., Jahns, C. (2009), Int. J. Production Economics 117 (2009) 104–116

Simar, L., & Wilson, P. W (1998), Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models. Management Science, 44, 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, 2007

Starkie, D. (2002). Airport regulation and competition. Journal of air Transport management, Vol. 8, Issue 1, 63-72, 2002

Starkie, D. (2005), Making airport regulation less imperfect, Journal of Air Transport Management 11 (2005) 3–8

Starkie, D., (2001). Reforming UK airport regulation. Journal of Transport Economics and Policy 35, 119–135.

Vasigh, B. and Haririan, M. (2003) 'An empirical investigation of financial and operational efficiency of private versus public airports', Journal of Air Transportation, Vol 8, No 1, pp 91-110

Windle, R. J., & Dresner, M. E. (1992). Partial productivity measures and total factor productivity in the air transport industry: Limitations and uses. Transportation Research-A, 26A(6), 435-445

Yoshida, Y. (2004) 'Endogenous-weight TFP measurement: methodology and its application to Japanese-airport benchmarking', Transportation Research, Vol 40E, pp151-182

Yoshida, Y. and Fujimoto, H. (2004), Japanese-airport benchmarking with DEA and endogenous-weight TFP methods: testing the criticism of over-investment in Japanese regional airports, Transportation Research E 40 (2004), pp. 533–546

Zhang, A. and Zhang, Y. (1997), Concession Revenue and Optimal Airport Pricing, Transportation Research Part E: Logistics and Transportation Review, Volume 33, Issue 4, Pages 287-296, 1997

REPORTS

ACI (2003), Airport Charges in Europe, An ACI EUROPE report, 2003.

ACI (2006), ACI World Air Traffic Report, 2006

ADV, Low Cost Monitor 1/2006, Arbeitsgemeinschaft Deutscher Verkehrsflughäfen, Deutsches Zentrum für Luft und Raumfahrt e.V., 2006

ADV, Low Cost Monitor 1/2007, Arbeitsgemeinschaft Deutscher Verkehrsflughäfen, Deutsches Zentrum für Luft und Raumfahrt e.V., 2007

ADV, Low Cost Monitor 1/2008, Arbeitsgemeinschaft Deutscher Verkehrsflughäfen, Deutsches Zentrum für Luft und Raumfahrt e.V., 2008

ADV, Low Cost Monitor 1/2009, Arbeitsgemeinschaft Deutscher Verkehrsflughäfen, Deutsches Zentrum für Luft und Raumfahrt e.V., 2009

ATRS (2003), Airport Benchmarking Report – 2003: Global Standards for Airport Excellence, Air Transport Research Society, Vancouver

CAA (2000a). The _single till_ and the _dual till_ approach to the price regulation of airports, Consultation Paper. Civil Aviation Authority, London

CAA (2000b). The Use of Benchmarking in the Airport Reviews, Consultation Paper. Civil Aviation Authority, London

CC (2007). BAA Airports Market Investigation, Competition Commission, London

IATA (2007), Economic Regulation, IATA Economics Briefing No:6,

NERA (2001), The Application of Benchmarking to Airports Phase 1: Date Collection and Assessment, National Economic Research Authority, London.

SH&E (2007), Study on the quality and efficiency of ground handling services at EU airports as a result of the implementation of Council Directive96/67/EC, Report to European Commission, London

Tretheway, M. W. (2001): Airport Ownership, Management and Price Regulation, Report to the Canadian Transportation Act Review Committee, Ottawa.

TRL (1999-2004), Airport Performance Indicators, Transport Research Laboratory, Wokingham

WORKING PAPERS

Coelli, T.J. (1996) A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program, CEPA Working Paper 96/8, Department of Econometrics, University of New England, Armidale NSW Australia.

Gillen, D. W. and W. G. Morrison, (2001): ``Airport Regulation,Airline Competition and Canada'sAirport System,'' Working paper, School of Business and Economics, Wilfrid Laurier University, Waterloo, Ontario

Holvad, T. and Graham, A. (2003) 'Efficiency measurement for UK airports: An application of data envelopment analysis', VIII European Workshop on Efficiency and Productivity, Oviedo, September

Kamp V. (2004), Benchmarking of German Airports – Some first Results, Paper for the GARS Research Seminar, "How to make Slot Markets Work", Bremen, November 19-20, 2004

Kunz, M. and H. M. Niemeier, (2000): ``Regulating Airports: Some Lessons from the UK and Germany,'' Paper presented at the 4th Air Transport Research Group Conference, Amsterdam

Malighetti, P., Martini, G., Paleari S., Redondi, R. (2008), The Efficiency of European Airports: Do the Importance in the EU Network and the Intensity of Competition Matter?, Department of Economics and Technology Management Working Paper, University of Bergamo

Müller, F., König, C. and Müller, J. (2008), Regulation of Airport Charges in Germany, Unpublished German Airport Performance project working paper, 2008

Müller, J., Ülkü, T. and Zivanovic, J. (2009), Privatization, restructuring and its effects on performance: A comparison between German and British airports, Unpublished German Airport Performance project working paper

Niemeier, H.M. (2002a), Capacity Expansion and Regulation of German airports - towards reform of the basic rule of the industry, Paper presented at the German Aviation Research Seminar, "The Economic Regulation of Airports: Recent Developments in Australia, North America and Europe," November 8-9, 2002

Petzold, L. (2003), Economic regulation of airports in Germany, 2nd Workshop on applied infrastructure research, 2003, Berlin

Piacentiono, D. (2006), Price Regulation of Airports: Why and How, Griffin's View, Volume 7, Number 2, 2006

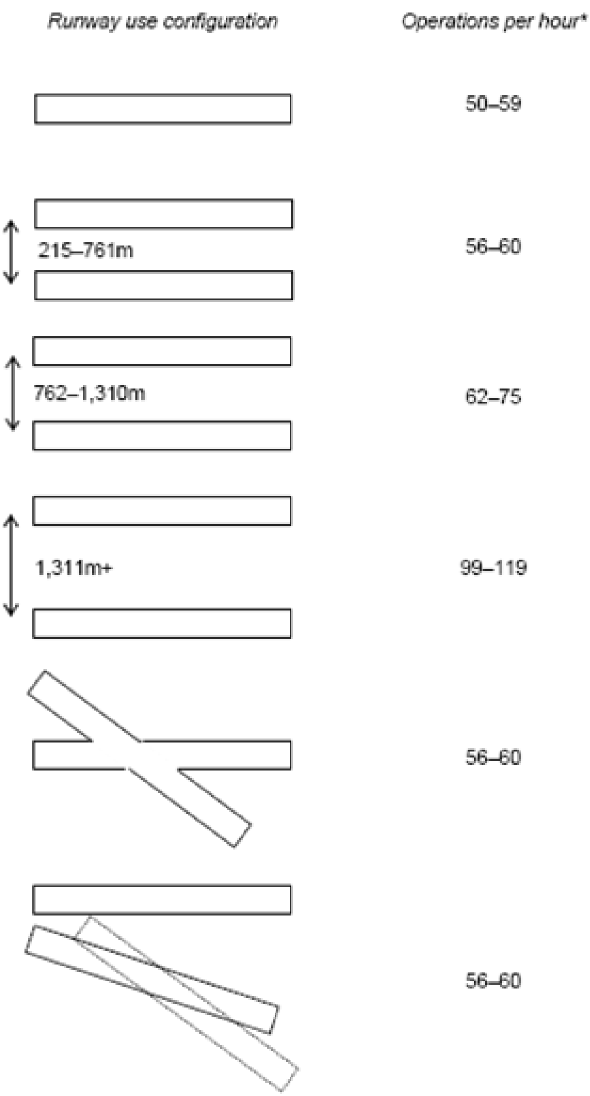
Tretheway, M. W. and Kincaid, I. (2005), Competition between airports in the new Millennium: what works, what doesn't work and why, 8th Hamburg Aviation Conference, 2005

Ülkü, T. (2009), Capacity Measurements in Airport Sector: Drawbacks of Conventional Methods and Benchmarking Airports Using Declared Capacity, Unpublished German Airport Performance project working paper

Vogel, H.A, (2006), Privatisation and Financial Performance of European Airports, University of Westminster, 2006

11 Appendix

APPENDIX 1: HOURLY CAPACITY OF DIFFERENT RUNWAY CONFIGURATIONS



SOURCE: BAA Airports Market Investigation, CC 2007

APPENDIX 2: CRITICAL VALUES FOR SPEARMAN CORRELATION TEST

Number of pairs	Values of r
5	1,00
6	0,94
7	0,89
8	0,83
9	0,78
10	0,75
11	0,73
12	0,71
13	0,67
14	0,64
15	0,62
16	0,60
17	0,58
18	0,56
19	0,55
20	0,53
21	0,52
22	0,51
23	0,50
24	0,48
25	0,47
26	0,46
27	0,46
28	0,45
29	0,44
30	0,43

APPENDIX 3: DEA SCORES AND THE CONFIDENCE INTERVALS

AIRPORT	YEAR	DEA	LB 1%	UB 1%	AIRPORT	YEAR	DEA	LB 1%	UB 1%
BER	1998	1,58077	1,51399	1,68046	HAJ	1998	3,69313	3,53260	3,86373
BER	1999	1,75620	1,66989	1,87005	HAJ	1999	3,74797	3,51158	3,97832
BER	2000	1,38388	1,32555	1,47627	HAJ	2000	3,33143	3,02766	3,60668
BER	2001	1,47142	1,41214	1,56631	HAJ	2001	3,54455	3,30777	3,79756
BER	2002	1,50426	1,44529	1,60201	HAJ	2002	3,73932	3,47301	4,01407
BER	2003	1,66495	1,58381	1,77858	HAJ	2003	3,56408	3,35941	3,78958
BER	2004	1,48066	1,39975	1,58055	HAJ	2004	3,34590	3,14690	3,55604
BER	2005	1,36130	1,26886	1,46148	HAJ	2005	3,30298	3,07701	3,49594
BER	2006	1,47554	1,37140	1,58098	HAJ	2006	3,27856	3,03478	3,47244
BER	2007	1,65685	1,52368	1,78587	HAJ	2007	3,54784	3,31557	3,75204
BRE	1998	4,38735	4,13750	4,67301	CGN	1998	1,62155	1,47231	1,84213
BRE	1999	3,95555	3,57040	4,40071	CGN	1999	1,54119	1,40552	1,73962
BRE	2000	3,84916	3,52135	4,23150	CGN	2000	1,67299	1,51997	1,86898
BRE	2001	3,77712	3,59421	4,02555	CGN	2001	1,44136	1,24416	1,61987
BRE	2002	3,86733	3,65975	4,16355	CGN	2002	1,27348	1,02365	1,41947
BRE	2003	4,61325	4,38482	4,89647	CGN	2003	1,30160	1,15309	1,48089
BRE	2004	4,05712	3,84290	4,35076	CGN	2004	1,23734	1,07037	1,43230
BRE	2005	4,14935	3,93380	4,41990	CGN	2005	1,24287	1,06098	1,46584
BRE	2006	4,29577	4,07859	4,56774	CGN	2006	1,25289	1,02892	1,47970
BRE	2007	4,07297	3,70803	4,40962	CGN	2007	1,27221	1,02592	1,50385
DTM	1998	3,26080	3,05143	3,47430	MUC	1998	2,84026	2,60777	3,04088
DTM	1999	3,82208	3,60390	4,07451	MUC	1999	2,66673	2,48504	2,85426
DTM	2000	4,44851	4,19090	4,75951	MUC	2000	2,44804	2,26538	2,64166
DTM	2001	4,89913	4,66212	5,18912	MUC	2001	2,42640	2,23283	2,62988
DTM	2002	5,31595	5,05294	5,66767	MUC	2002	2,56376	2,36566	2,77337
DTM	2003	5,88731	5,63095	6,23212	MUC	2003	2,88517	2,67473	3,15347
DTM	2004	6,49368	6,17326	6,93271	MUC	2004	2,61948	2,38134	2,93849
DTM	2005	5,13897	4,84091	5,48453	MUC	2005	2,58611	2,25982	2,95552
DTM	2006	4,99915	4,45699	5,40892	MUC	2006	2,97622	2,63812	3,36325
DTM	2007	4,65671	4,15413	5,04073	MUC	2007	2,84827	2,40753	3,27499
DUS	1998	1,63864	1,53952	1,75947	NUE	1998	3,95532	3,48766	4,28733
DUS	1999	1,82112	1,71333	1,95512	NUE	1999	4,90958	4,49492	5,20828
DUS	2000	1,95269	1,79579	2,12531	NUE	2000	4,33804	4,03627	4,60417
DUS	2001	2,34815	2,17780	2,53310	NUE	2001	4,32387	4,02340	4,62071
DUS	2002	2,33704	2,11512	2,55848	NUE	2002	4,40771	4,08893	4,72165
DUS	2003	2,87153	2,69934	3,07159	NUE	2003	4,40283	4,10242	4,73723
DUS	2004	2,37777	2,22609	2,56127	NUE	2004	3,96333	3,70923	4,23907
DUS	2005	2,52229	2,36865	2,70098	NUE	2005	3,87975	3,67169	4,09971
DUS	2006	2,46983	2,28517	2,66337	NUE	2006	3,93779	3,71513	4,18665
DUS	2007	2,36149	2,15253	2,56399	NUE	2007	3,79037	3,59737	3,98483
HAM	1998	1,75242	1,48505	2,13994	STR	1998	2,82414	2,66407	2,95786
HAM	1999	1,74990	1,60631	1,96297	STR	1999	2,72948	2,58011	2,85458

HAM	2000	1,52140	1,41300	1,69069	STR	2000	2,73880	2,59763	2,87117
HAM	2001	1,92119	1,76772	2,14483	STR	2001	2,94285	2,80438	3,08763
HAM	2002	1,88482	1,77082	2,03960	STR	2002	3,18581	3,04603	3,33652
HAM	2003	1,94336	1,83499	2,10294	STR	2003	3,12509	2,99645	3,27446
HAM	2004	1,90980	1,82390	2,03045	STR	2004	3,04360	2,89306	3,27607
HAM	2005	1,81807	1,74144	1,93418	STR	2005	2,59064	2,44325	2,75047
HAM	2006	1,73084	1,64385	1,85674	STR	2006	2,43822	2,27575	2,62464
HAM	2007	1,68494	1,58368	1,81919	STR	2007	2,34958	2,19164	2,53336

***LB 1%: Lower Bound with α=0,01 *UB 1%: Upper Bound with α=0,01**