UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

DEPARTAMENTO DE ANÁLISIS ECONÓMICO APLICADO

Ph.D. DISSERTATION

STOCHASTIC FRONTIER ESTIMATION OF AIRPORTS' COST FUNCTION

AUGUSTO JOSÉ VOLTES DORTA

Las Palmas de Gran Canaria, 2008

D. JAVIER CAMPOS MÉNDEZ SECRETARIO DEL DEPARTAMENTO DE ANÁLISIS ECONÓMICO APLICADO DE LA UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA,

CERTIFICA,

Que el Consejo de Doctores del Departamento en su sesión de fecha 23 de Junio de 2008 tomó el acuerdo de dar el consentimiento para su tramitación, a la tesis doctoral titulada "Stochastic frontier estimation of airports' cost function", presentada por el doctorando D. Augusto Voltes Dorta y dirigida por el Doctor D. Juan Carlos Martín Hernández.

Y para que así conste, y a efectos de lo previsto en el artículo 73.2 del Reglamento de Estudios de Doctorado de esta Universidad, firmo el presente en Las Palmas de Gran Canaria, a 23 de Junio de dos mil ocho.

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

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DOCTORADO EN ECONOMÍA

TESIS DOCTORAL

STOCHASTIC FRONTIER ESTIMATION OF AIRPORTS' COST FUNCTION

Tesis Doctoral presentada por D. Augusto José Voltes Dorta.

Dirigida por el Dr. D. Juan Carlos Martín Hernández

El Director El Doctorando

Las Palmas de Gran Canaria, 2008

…et vive la musique
qui nous tombe du ciel!

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to my supervisor, Dr. Juan Carlos Martín, for his advice and encouragement throughout all the stages of this thesis. I am always impressed by his profound knowledge and experience. Besides, I wish to extend thanks to the whole Department of Applied Economics at my home University in the person of Dr. Concepción Román García and to the Research Group *Economía de las Infraestructuras y el Transporte (EIT)* in the person of Prof. Ginés de Rus Mendoza for their practical guidance and advice, as well as for their constant encouragement. In addition, this work was partly written while I was a guest in the Department of Spatial Economics at the VU University Amsterdam. I wish to thank Prof. Piet Rietveld and Eric Pels for being considerate hosts during my stay. I would also like to thank Patricia Ellman for correcting my English.

However, the realization of this project would have never been possible without the kind attention of many Airport Authorities and other industry agents from the five continents, which were always available to provide the requested data or answer my lengthy and sometimes naive questions. Many of them expressed great interest in the development of this dissertation, which was certainly very important for a junior researcher. They are simply too numerous to cite them all, though I would like to give special mention to Lourdes Ibiricu, from the AENA's Documentation Center in Madrid, where the lengthy process of data collection started back in February 2006.

Finally, but not less important, I also gratefully acknowledge the financial support from my home University in the person of the *Vicerrector de Investigación, Desarrollo e Innovación*. Additional research funds were received during 2007 and 2008 from my sponsors *La Caja de Canarias* and the *Colegio de Abogados de Las Palmas de Gran Canaria* through an INNOVA fellowship. I also wish to acknowledge the important contribution of the *Fundación Universitaria de Las Palmas* in promoting the private sponsorship of academic research.

This thesis is dedicated to my family and to my country.

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SUMMARY

This work aims to provide a suitable methodology to estimate optimal airport charges as a way to improve the provision of infrastructure for air transportation. The setting of airport charges is a most important topic on the international transport policy agenda. In the European Union, a system based on social marginal costs is usually advocated. In addition, a correct analysis of the industry structure, especially regarding the presence of scale economies, seems to be fundamental at this time, when demand forecasts and the industry agents are exerting too much pressure on airport development. In this context, the econometric estimation of airport cost functions is proposed as a suitable solution as it allows a proper identification of these technological features. From the cost function parameter estimates, the scale elasticity of each specified output can be obtained, which lead to the calculation of both the overall degree of scale economies and each output's marginal operating cost. In addition, the determination of the industry's cost frontier also allows the analysis of airport productivity and efficiency to be performed.

However, the lack of financial data on airports explains the relative scarcity of cost function studies in the airport industry, and the use of very different data and methodologies provides inconsistent findings. The present study deals with two big challenges with respect to the methodology and the estimation procedure in order to provide more reliable and comprehensive results.

First of all, this work tries to overcome the single-output limitations in a more satisfactory way, specifying up to four outputs in the cost function. The *passenger* and *cargo* outputs are specified separately, rather than using the aggregate Work Load Units (WLUs), as has been done in the past. Apart from that, *aircraft operations* are normalized in order to avoid biasing the parameters of the cost function. The presence of an aggregation bias in this variable is solved by converting the total number of air traffic movements (ATMs) into "equivalent" aircraft operations holding a base aircraft constant. Finally, *commercial revenues* are also specified as the fourth output in order to account for the cost complementarities in the joint production of aeronautical and non-aeronautical activities.

The second objective is related to the econometric theory of the estimation of transport cost functions. This work follows the approach of Kumbhakar (1997, 2005) including explicitly both technical and allocative inefficiencies in a translog specification of a stochastic cost frontier. Bayesian Inference and Markov Chain Monte Carlo methods (MCMC) are used to estimate the non-linear complexity of this new proposal in the context of international airports, combining the Kumbhakar (2005) methodology and the Griffin and Steel (2007) codification. The model is thus estimated using an unbalanced pool of financial data on 161 airports across Europe, North America, Asia and Oceania between 1990 and 2006.

Individual estimates of long-run marginal costs were obtained, and for the average airport the values for aircraft operations, passengers and cargo are USD 304.80, USD 4.52 and USD 40.02, respectively. Additionally, these marginal cost estimations are compared with actual landing and passenger charges in order to analyze how far these prices are from their theoretically optimal figures. Some interesting conclusions are obtained. In particular, this study finds that most landing charge schemes are overpriced, and in others some degree of cross-subsidization amongst aircraft categories is present. Stochastic frontier results indicate that technical inefficiency ranges from 15 to 18 percent, and allocative inefficiency is about 6 percent of frontier costs at the average airport. The results also indicate the presence of important economies of scale which are not exhausted at any observed output level which, in part, justifies the actual observed trend of expanding airport capacity.

This dissertation is organized as follows: Chapter 1 presents an introduction to airport operations by describing common airport infrastructures and the different processes they serve, and it also introduces the key features of airport planning and management. In particular, infrastructure pricing will be studied extensively in this chapter, which explains the nature and calculation of most important fare categories around the world, as well as the regulatory approaches concerning the setting of charges. The close relationship between air transport demand and airport investments is also addressed, by explaining current trends in airport development, which are justified by the explosive growth in demand and the evolution towards an increase in the aircraft size. The importance of optimal pricing, industry structure and capacity investments underpins this work. The case of Montreal-Mirabel as a failed airport project is presented as an illustrative example.

Chapter 2 provides an extensive survey of the microeconomics of the cost function estimation paying special attention to the estimation of multiproduct scale economies. This issue is also complemented with the most recent developments on efficiency and productivity analysis, focusing on the decomposition of technical and allocative inefficiencies using a state-of-the-art stochastic frontier methodology. Of course, all the previous literature regarding the estimation of airport cost functions, and the analysis of productivity and optimal pricing will be properly reviewed, helping us to contextualize this work in the field of research.

Some methodological issues, such as the scope of the airport activity under study, especially regarding the outsourcing of core activities and the increasing importance of the commercial concessions, are analyzed in Chapter 3. Output definition is then discussed in depth, and the use of aircraft mix indexes in order to convert aircraft operations to "base aircraft" equivalents is properly justified. In addition, econometrical issues related to the presence of near multicollinearity in multi-output specifications are addressed. Regarding the calculation of input prices, this chapter also proposes a theoretically consistent procedure which is related to the estimation of input marginal productivities and the development of an input quantity index. The chapter concludes by explaining the Bayesian structure of the model and the choice of prior distributions for the cost function parameters.

Chapter 4 describes the database, which comprises 161 airports of all sizes around the world. As accounting practices and data quality differ considerably amongst countries, the database features several geographical clusters, for which a deeper analysis will be provided later. On account of the airport heterogeneity, this chapter deals with the search for financial data sources and collection procedures, as well as presenting and discussing several different characteristics (e.g. reporting standards) which are exclusive to certain geographical zones. Therefore, the issue of dedicated terminals at U.S. airports and their effects on reported operational expenditures is properly addressed. Finally, a new standard for airport financial and operational reporting is proposed in order to improve data homogeneity for this kind of empirical studies.

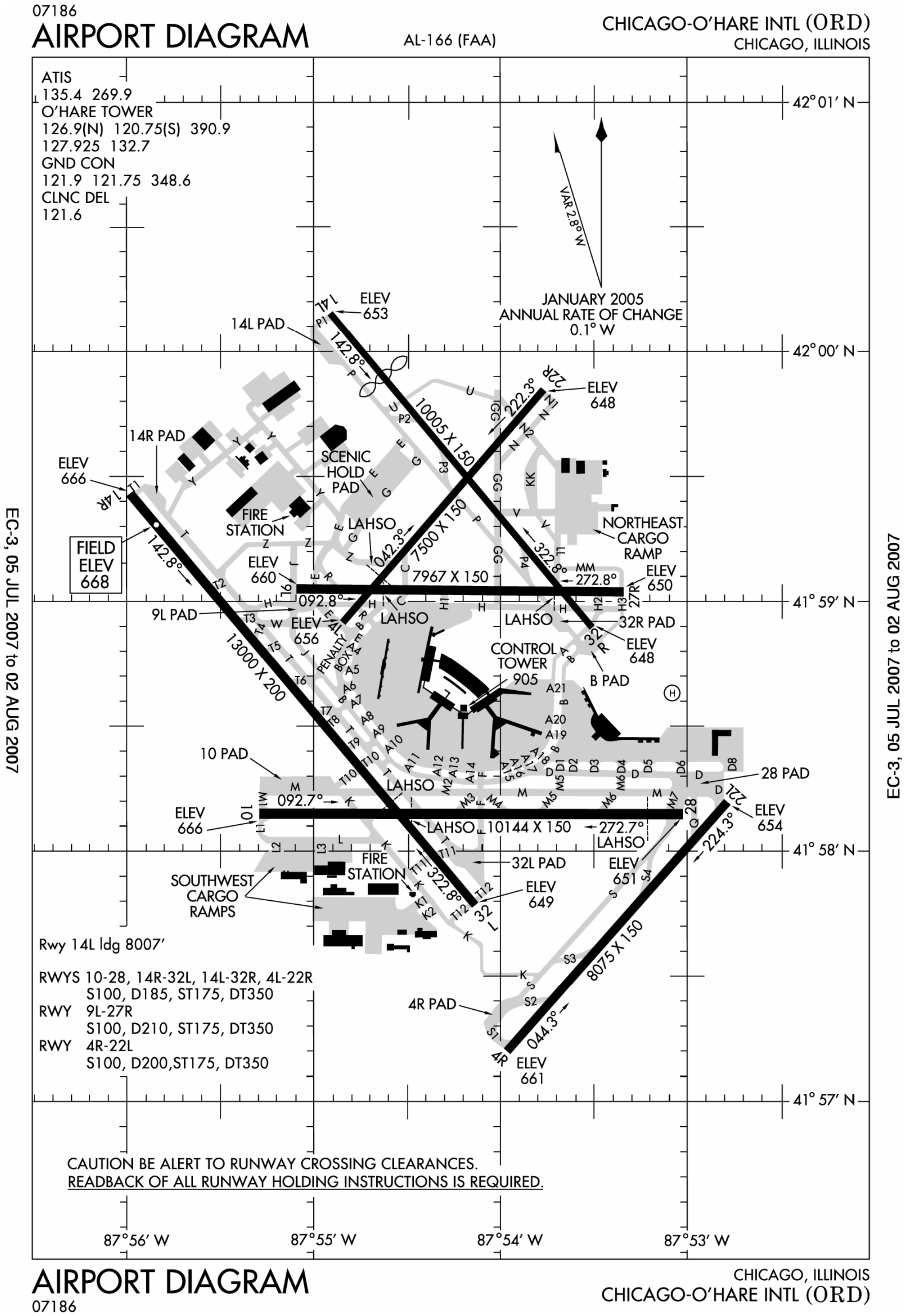
The whole estimation process is explained in Chapter 5. Both long- and short-run models will be estimated, though the long-run one stands as the leading approach. The presence of near multicollinearity in the output vector requires discarding as many second-order parameters as possible in order to obtain parsimonious specifications. This chapter also deals with prior elicitation giving proper justification for all fixed parameters of the model. A brief introduction to the WinBUGS software and a full breakdown of the estimation codes will then be presented. When both long- and short-run models have been successfully estimated, all parameter estimates as well as their posterior densities are shown. This allows individual significance to be tested, and also ensures the model's compliance with all theoretical restrictions derived from cost function theory.

The structure of the airport industry is analyzed in Chapter 6 using the scale elasticities obtained from the estimated cost frontiers. Individual estimations of scale economies will be provided for each airport under study and then used to calculate an approximate value for the industry's minimum efficient scale (MES), in terms of both passenger throughput and aircraft operations. This scale analysis will also be provided for the aviation output subset excluding commercial activities. The calculation of incremental costs is made using a "small value" approach. Empirical evidence about the underestimation of the MES produced by the unweighted aggregation of ATMs is then presented. Finally, the important issue of factor substitutability is analyzed using the Allen partial elasticities of substitution.

Chapter 7 deals with the estimation of both technical and allocative inefficiency (AI). Before presenting the results, the convenience of the selected distribution for the technical efficiency (TE) term is properly tested. The first section gives a general overview of results and provides confidence intervals for the inefficiency parameters and monetary estimations of the annual losses derived from both technical and allocative inefficiencies. Then the average level of TE for the nine major geographical clusters featured in the database is calculated. This section is focused on catching some of the "uniqueness" of airport operations by testing the influence of all country-specific characteristics (such as type of ownership or price regulation) on the airport's performance. Finally, both scale and efficiency results are checked using data on five European multi-airport systems (MAS). Furthermore, the data of two American MAS are used to separate the potential savings derived from traffic consolidation from those related to the individual airports' own inefficient behavior.

Chapter 8 presents both long- and short-run individual marginal cost estimates for each specified output. Using moving averages, a list of reference values for a wide range of production scales is provided. The last subsection makes a very interesting comparison between the individual MC estimations and the actual landing and passenger charges for seven selected case studies in Europe, the US, and Oceania for the year 2006.

Chapter 9 serves as a summary of methodology and results. In addition, future research directions are briefly introduced. The presence of unexhausted scale economies, taking only into account the financial component, clearly indicates the need to include externalities such as noise or congestion in the cost function specification. Hence, the last section of this final chapter addresses the methodological issues regarding the inclusion of such external factors, as a natural extension of this work.



Source: Federal Aviation Administration, National Aeronautical Charting Office (2007)

Figure 0 Chicago O'Hare (ORD) airport diagram

CHAPTER 1

AIRPORTS AND AIR TRANSPORTATION

1.1 The airport's operational environment

An airport can always be defined as a facility where aircraft can take off and land, but nowadays they are more complex transportation facilities, designed to serve not only aircraft but also the necessities of passengers, cargo processing, and surface vehicles. In 2007, there were approximately 49,000 airports around the world, about 30 percent of them located in the United States (CIA, 2007). Airports are uniquely represented by their IATA 3-letter code[1], which is often an abbreviated form of the common name of the airport, such as ATL for Atlanta, or FRA for Frankfurt. In this dissertation, airports will be also identified by this codification, hence an Annex of airport codes is provided at the end (Annex 1). While most common manuals classify airport components by their physical location, it seems more useful for the purposes of this study to classify airport infrastructures by the different processes they serve (Figure 1.1), because these processes will be later defined as outputs in the cost function specification.

Aircraft operations take place exclusively on the airside, which is planned and managed to accommodate the movement of aircraft around the airport, as well as to and from the air. The airfield includes all facilities located on airport property to facilitate aircraft operations. These include runways, taxiways and ramps, and also the air traffic control (ATC) tower, fixed base operators (FBOs) and emergency facilities.

The most important facility on the airfield is the runway (RWY). It is a strip of land on an airport, on which aircraft can take off and land. A properly planned and managed runway system is essential for airport operations, and should meet all technical requirements for safety operations, otherwise the type of aircraft desired would be unable to use the facilities. Smaller or less-developed airports often have one single runway shorter than 1,000 m, commonly made of dirt, grass, or gravel, and intended to serve small aircraft, mainly for general aviation, training, or recreational purposes. As takeoff and landing distances are closely related to the aircraft's weight, heavier aircraft

[1] There is also an ICAO 4-letter code.

typically require longer runways. Therefore, larger airports which serve international flights generally have many runways of 2,000 m or longer[2] made of asphalt or concrete.

The aircraft's physical properties indicate that operations are more efficient and safe if made in the wind direction. As a result, the primary runways are typically oriented towards the prevailing winds of the area. Airports located in areas with winds that blow in multiple directions are commonly planned with additional crosswind runways. All runways are numbered according to the magnetic heading of both operating directions (rounded to the nearest one-tenth). In the case of parallel runways, the suffix L/C/R (Left, Centre, and Right) is added to allow runway identification (see Figure 0).

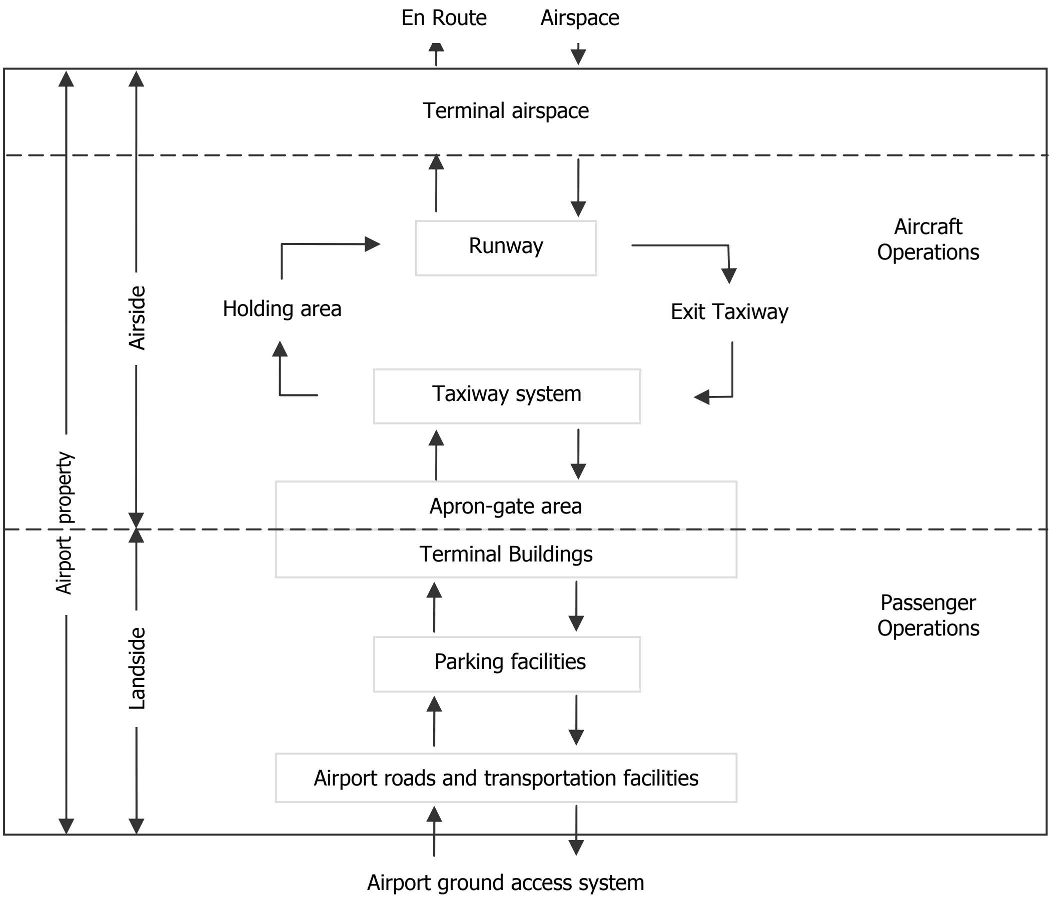
The area where aircraft park next to a terminal to load passengers and baggage is known as a ramp. The areas which provide aircraft parking positions far away from the terminals are generally called aprons. Additionally, the airfield comprises many other infrastructures for aircraft maintenance, crew services, aircraft rental, and hangar rental. These activities are usually performed by an FBO. However, at major airports, particularly those used as either hubs or technical bases, airlines may operate their own support facilities.

At almost every commercial airport there is also an (ATC) system[3], whereby controllers direct aircraft movements usually via radio. This facilitates safety and speed in complex operations where traffic moves in all three dimensions. ATC responsibilities at airports are usually divided into at least two main areas: ground and tower. Ground Control is responsible for directing all ground traffic in designated movement areas, except the traffic on runways. Tower Control controls aircraft on the runway and in the airspace surrounding the airport. They coordinate the sequencing of aircraft in the traffic pattern and direct aircraft in a safe way across the complex circuit. Aircraft which interact only through the airspace must also contact Tower Control in order to be sure that they remain clear of other traffic and do not disrupt operations.

Landing operations start in the airport's Tower Control as an aircraft approaches the surrounding airspace. The pilot requests approach clearance[4] and is instructed to land on a certain runway. After the plane has successfully landed, it will depart the runway and

[2] At sea level, most commercial aircraft require between 1800m and 3000 m of runway length.
[3] In the US, all air traffic operations are supervised by the Air Traffic Control System Command Center (ATCSCC). In Europe, EUROCONTROL provides En Route navigation services for 38 Member States.
[4] For scheduled flights, such a request is usually made while an aircraft is still hours away from the airport, often before the plane even takes off from its departure point.

be transferred to Ground Control, in order to reach the apron/gate area for unloading passengers or cargo into the terminal building. Meanwhile, many other common maintenance procedures are carried out by one or some handling operators, e.g. loading/unloading, cleaning, and refuelling. When a plane is ready to take off it will be instructed by Ground Control to stop short of the runway, at which point it will be turned over to Tower Control in order to leave the airfield and move into the airspace.



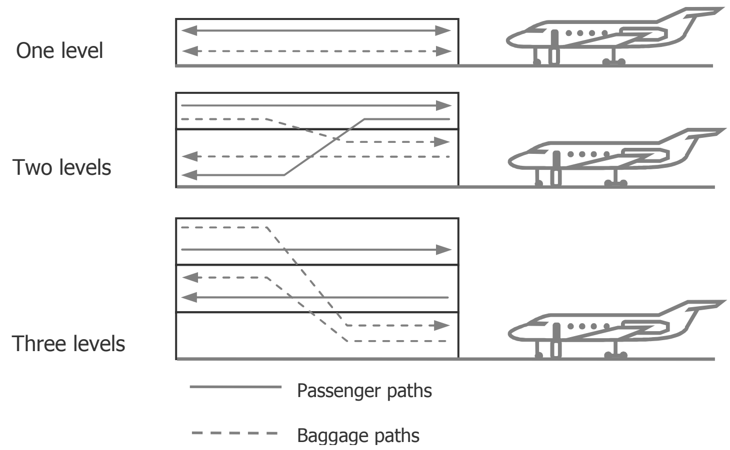
Source: Wells and Young, 2004.

Figure 1.1 The components of an airport

Passenger operation facilities are located exclusively on the airport's landside, which is planned and managed to accommodate the movement of ground-based vehicles, passengers and cargo. The terminal buildings are the most important component of this part of the airport[5]. They provide an interface for passengers and luggage between ground transport modes and aircraft on the airside. Terminal design must take into account passenger needs, processing requirements, and activity levels. Many small and regional airports provide both arriving and departing facilities on a single level, because they rarely handle simultaneous aircraft operations. These airports also experience quite

[5] The waiting areas which provide passenger access to aircraft are typically called 'concourses', although this term is often used interchangeably with 'terminal'.

simple passenger and baggage flows. As activity levels are increased, this in turn increases the operational complexity of the airport, which is managed by distributing the passenger flows over several levels within the terminal (Figure 1.2).



Source: Ashford and Wright, 1992.

Figure 1.2 Vertical separation of passenger and baggage flows

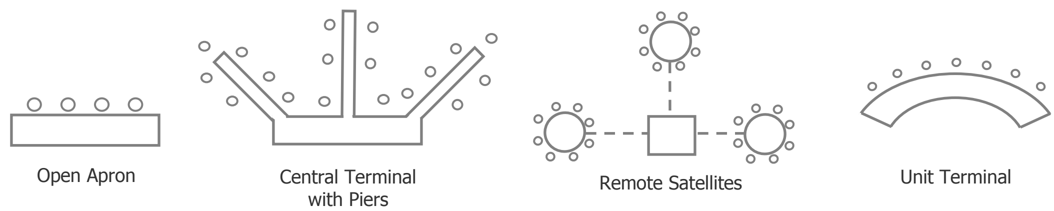
Passenger and baggage flows are separated according to three standard itineraries: departures, arrivals, and transfers. Departing passengers enter the terminal building from the ground access system and make their way to the airside. During this process, they can purchase tickets, check luggage, clear security, do some shopping, and finally board the aircraft through the gates. Arriving passengers are those who enter the terminal by the airside (i.e. air bridges or bus gates). They are sometimes required to clear customs and proceed to the baggage claim areas, then leaving the airport premises using any ground transport alternative. Transfer passengers are the third category. They access the terminal by the airside with the intention of boarding other flights within a short period of time. The type of connection can also lead to a further differentiation between transfer (new ticket) and transit passengers (the same ticket). Generally, both transfer and transit passengers are exempted from further security controls. But sometimes transfers are treated like departing passengers, because they are required to claim their luggage and do the check-in again with the new carrier. In addition, further planning complexities appear when there are different security screening procedures for either departing or arriving passengers according to their origin and destination itinerary. Typically, international passengers are required to pass through tighter customs controls, which depend on international boundary treaties[6].

[6] For example, non-EU citizens traveling between countries in the Schengen area are not subject to border control, which is only carried out at the time of the first entry.

Baggage is usually treated on an exclusive terminal level, and separated from passenger processing. Thus, congestion is reduced because the friction between passengers and cargo is minimized, and the baggage can be sorted, consolidated and moved to aircraft more efficiently. At some small airports, baggage handling is still operated by the incumbent airline, but many airports nowadays operate a consolidated baggage service, either with airport personnel (as in FRA) or on a contract basis with one or more handling operators.

In summary, major commercial airports construct multilevel terminals in order to better organize their passenger and cargo flows. A standard terminal for a medium commercial airport provides at least two levels. A lower level for arrivals, which provides baggage-claim areas, baggage-sorting facilities (not accessible to the public), and transfer facilities for connecting passengers. The upper level includes ticketing and boarding areas, and it also features more amenities and retail space than the arriving section. This scheme could be expanded with additional upper levels for office space, or with an underground level providing access to public rail transport or even to the transit service in multi-terminal settings.

Small airports only have one terminal, while larger airports have several terminals and/or concourses. Early airport terminals directly opened into the airfield, so passengers could walk or take a bus to their aircraft. This design is still common amongst small airports, and even many larger airports have “bus gates” to accommodate aircraft beyond the main terminal. Nevertheless, nowadays the safety of aircraft operations requires that passengers are no longer allowed to walk through the airfield on their own. Therefore, aircraft boarding is usually made using air bridges which connect the terminal gate with the aircraft cabin. The configuration of these boarding positions makes it possible to distinguish between many different terminal design concepts (Figure 1.3). The most common pier design uses a long, narrow building with aircraft parked on both sides. One end connects to a ticketing and baggage-claim area. This design allows ticketing and baggage operations to be centralized under large gate requirements. Piers offer high aircraft capacity and simplicity of design, but often result in long-distance walks from the check-in counter to the gate. Most large international airports have piers, including Chicago O’Hare (ORD) (Figure 0), London Heathrow (LHR), Amsterdam (AMS) or Miami (MIA). A satellite terminal is a building detached from the main terminal and connected by a pier building or some mechanized mode of transport (remote satellites) either above or below the apron. This allows aircraft to park around its entire circumference[7]. Examples of circular satellites can be found at Paris-Charles de Gaulle (CDG) or London Gatwick (LGW), while Orlando Intl. (MCO) and Pittsburgh (PIT) have multiple satellite terminals. Denver (DEN), Cinncinatti-Northern Kentucky (CVG) and ATL have linear satellite terminals connected by central underground passages. The largest airports use U-shaped unit terminals, with aircraft parked on one side and ground transport vehicles on the other. Typically, each unit terminal houses a single airline or alliance, therefore this design results in long walks for interlining passengers, but greatly reduces travel times between check-in and the aircraft. Examples of unit terminals are New York's (JFK) or Dallas (DFW).



Source: Ashford and Wright (1992).

Figure 1.3 Terminal design concepts

International regulations on airport security require that access from landside areas to airside areas should be tightly controlled. Only ticketed passengers are usually allowed beyond the security check areas and special authorization is required to access restricted areas of the airport. Security rules vary but there are common elements worldwide, such as baggage checks, metal screening of individual persons, and rules against any object that could be used as a weapon. Since the 9/11 attacks, airport security has been dramatically increased worldwide. Airports with international flights must also provide customs and immigration facilities. However, as some countries have agreements that allow travel between them without customs and immigration checks, such facilities are not indispensable for an international airport.

Regarding ground transport, on-site parking facilities are commonly provided for passengers, visitors, airport employees, and tenants, and also for the car rentals. Most commercial airports provide both short-term and long-term parking areas. Additionally, the typical international airport may have two grade-separated one-way loop roads, one for departures and one for arrivals[8], which are used by local private vehicles and buses to drop off and pick-up passengers. Major airports may also have a direct rail connection to the central business district of the closest major city. The largest airports

[7] The first airport to use a satellite terminal was LGW. It used an underground pedestrian tunnel to connect the satellite to the main terminal.

in Europe often have direct connections to the closest freeway or are located next to railway routes, e.g. FRA, AMS, LHR or LGW. Regarding local accessibility, many cities provide direct connections to the terminals within their metropolitan mass transit systems, e.g. the AirTrain at JFK or line 8 at Madrid-Barajas (MAD). In some cases, the intermodality is guaranteed because it is possible to check in luggage at the metro/rail station. Finally, additional transport alternatives are provided by car rental agencies, shuttle services, and taxi companies operating in and around terminals.

In addition to passengers, airports are also responsible for moving large volumes of cargo. In order to prevent undesirable interference between ground access passenger traffic and landside freight movements, cargo operations at major airports are completely segregated from the passenger terminal area. The cargo terminal serves four principal functions: 1) conversion of small parcels into standard load units, which can be more easily handled; 2) sorting of loads with different destinations; 3) storage; and 4) provision of documentation space where the physical transfer of goods between air and surface carriers can take place more conveniently, as well as customs procedures. Besides the cargo terminal, major cargo airports provide exclusive cargo ramps and parking aprons (Figure 0). Additionally, cargo airlines often provide their own on-site infrastructure to rapidly transfer parcels between ground and air transportation.

Finally, it is worth noting that the importance of commercial revenues has greatly increased in recent years. Nowadays airports may produce between 20-80 percent of their total revenue from non-aeronautical activities (ATRS, 2006). Recent developments of retail surfaces in terminal buildings give the impression that commercial activities may distort the way airports are envisioned as aeronautical infrastructure providers, i.e. airports in the future can be seen as shopping malls with air traffic in the area, and the primary function of the airports would be linked to the retail services[9].

1.1.1 The airport's provision

Like many other transport infrastructures, most airports have been traditionally owned by public authorities either at local, regional, or national/federal level. The privatization of airports' property and management, along with pressures for capacity expansion and constrained public budgets, has led to the involvement of private firms motivated by the desire to maximize profits. When the industry was privatized, the governing bodies

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[8] This road concept was pioneered at Los Angeles (LAX).

[9] BAA operates seven airports in the UK, and their combined sales of perfume account for 20 percent of the entire UK market. According to the statistics, a bottle of Scotch is sold every 7 seconds at Heathrow.

leased the airport's management to private corporations. For example, the British firm BAA plc operates seven commercial airports in the United Kingdom, including the three busiest London airports (LHR, LGW and STN), as well as several other airports outside of the UK. A great share of both FRA and Vienna (VIE) belong to private investors. In these cases, the public authority has retained a significant share of capital but stands only as regulator.

In the US, most airports are operated directly by government entities or government-created airport/port authorities. Many airports lease part or all of their facilities to outside third firms, especially those related to retail services and/or parking. Nevertheless, the Federal Government is still responsible for providing ATC supervision and stands as the only authority for safety and security issues (Transportation Security Administration, TSA), employing their own security personnel at the airports. Additionally, all commercial airport runways in the US are certified by the Federal Aviation Administration (FAA), but maintained by the local airport under its regulatory authority. It is probably the reluctance to privatize airports in the United States that makes the government-owned, contractor-operated agreement the standard procurement for the operation of commercial airports throughout the world.

Day-to-day operations at commercial airports require strong coordination between airport management and air carriers. Nevertheless, since the air transport deregulation of the US and the EU (Barrett, 2000), this industry has been characterized by competition rather than cooperation. Airport managers lost market power and new entrants frequently sought zero or high discount (90 percent) infrastructure charges. Besides, carriers could decide to radically alter their routes, services levels, or prices without any prior notification, and these changes could affect the performance of the airports involved. However, despite their different perspectives, air carriers and airport management have a common interest in making the airport a stable and successful enterprise. Traditionally, airports and carriers have formalized their relationship through airport use agreements. The terms can vary widely, from short-term (yearly arrangements) to long-term leases of 25 years or more. In some cases, the exclusive use of terminal facilities is guaranteed to a certain carrier and its alliance partners: this is known as a dedicated terminal. Nevertheless, a dedicated terminal agreement could also be based on a ground lease contract, whereby the carrier is responsible for construction and further terminal investments. Within the context of general use agreements, the carrier may conduct subsidiary negotiations for the lease of terminal space for offices, passenger lounges and ticket counters or further equipment.

Another interesting point in this relationship is the way airports allocate the sometimes scarce available capacity. The calculation of an airport's capacity is based on the airport's aircraft mix and the different types of traffic, with information provided by the air carriers. It is measured in "slots" which represents the number of hourly operations the airfield can accommodate under common restrictions such as weather or noise limitations. Standard allocation procedure indicates that a carrier already using a time slot is entitled to claim the same slot in the next scheduling period[10]. In a situation where all slot requests cannot be accommodated, preference is given to scheduled commercial services and programmed non-scheduled air services. Slots may be freely exchanged between air carriers or transferred by an air carrier from one route or type of service to another. The newly-created or unused time slots are included in "slot pools" which are distributed among applicant carriers. European legislation[11] indicates that at least 50 percent of these slots shall be allocated to new entrants if requested (EC, 1993). In spite of that, slot allocation systems are criticized because they do not guarantee efficient allocation (i.e. airlines with the greatest willingness-to-pay for them could not obtain the slots because of the grandfather rights scheme) (Starkie, 2003). In some congested airports, the problem is exacerbated because the system gives an artificial advantage to incumbent carriers, providing them with virtual monopolies by denying access to competitors.

1.2 Airport infrastructure pricing

The operation, development and maintenance of an airport require significant levels of financial resources. The nature of an airport's expenditures depends upon many factors, such as its geographical location or organizational structure. For example, de-icing services may be unnecessary for tropical climates. Analogously, certain operating functions such as police or emergency services might not be provided directly by the Airport Authority (AA) but by other public entities.

Airport operating expenditures can be divided into three general categories: the airside expenditures include depreciation and maintenance for runways and other movement areas (including their lighting systems), electricity and further equipment services.

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[10] This is known in the industry as "grandfather rights".

[11] Slots may be reserved by the Public Administration for regional Public Service Obligations or Essential Air Services (PSO/EAS).

Landside costs account for depreciation, maintenance and custodial services for buildings, other terminal equipment and parking facilities, as well as concession services, utilities such as electricity, water or air conditioning, and waste disposal maintenance. Finally, general and administrative expenditures include payroll expenditures for the maintenance, operation and administrative staff of the airport, and other minor payments for materials and supplies. Non-operating expenditures include financial expenditures on loans or issued bonds, contributions to governmental bodies, and other miscellaneous expenditures.

As noted, the revenues from the operation of the airport are used to cover the operation and maintenance costs. Basic revenue streams have usually come from infrastructure charges levied to air carriers for the use of airport facilities. The setting of airport charges is frequently tied to the regulatory environment imposed by public authorities (Lu and Pagliari, 2004). Under a 'single-till' approach, the entire airport's revenues are taken into account when setting charges, allowing commercial revenues to cross-subsidize aeronautical activities, thus keeping charges paid by air carriers at low levels. For obvious reasons, they generally favor single-till using the demand complementarity as an argument[12]. However, some important allocative inefficiency may appear for very congested airports, because the low aeronautical charges artificially exacerbate the scarcity costs of slots, creating the appearance of a lack of capacity (Starkie, 2001). The existence of cross-subsidies makes it difficult to estimate the "true" returns on the aeronautical assets, and can also distort the optimal investment decisions.

A second alternative mechanism to regulate prices in airports exists and it is known as the 'dual-till' approach in which commercial revenues are not factored into the charges equation, resulting in higher, unsubsidized, prices for airlines. This method is more consistent with the new ICAO (2004a) standards[13] and the White Paper for 2010 (EC, 2002), which defends the user-pays principle; under which prices should exactly reflect the marginal cost of using the facilities. Thus, commercial activities cannot be used to cross-subsidize aeronautical activities and the allocation of costs is more concordant with the user-pays principle.

[12] They consider that smaller charges would allow them to offer cheaper tickets, which would increase the spending of passengers/consumers at the terminals, and thus to maintain a high level of commercial benefits that helps to cross-subsidize this type of regime.

[13] To assess the cost basis for airport charges, ICAO states that "the users should not be charged for facilities and services they do not use" and "the cost of facilities exclusively leased should be excluded".

Airport charges cover services and infrastructure related to both aircraft movement areas and passenger processing areas. These charges are usually differentiated from other activities, such as ground-handling and purely commercial areas. For reasons of simplicity, airport charges will be classified into seven broad categories: landing charges; passenger charges; aircraft parking charges; other aeronautical charges; handling charges; non-aeronautical charges; and rebates and incentives. This work will focus on landing, passenger and non-aeronautical charges because these components are very important in the context of this dissertation.

ICAO's Airport Economics Manual (1991) defines landing charges as: "charges and fees collected for the use of runways, taxiways and apron areas, including associated lighting, as well as for the provision of approach and aerodrome control, being imposed to cover all operation and maintenance costs, and administrative costs attributable to those areas including the expense of all labor, maintenance materials, power and fuels". These charges are usually paid by airlines in a scheme whereby levies are calculated depending on the departing flights but sometimes a charge is paid on landing which covers the subsequent takeoff. ICAO also states: "...Any noise-related charge should be associated with the landing fee, possibly by means of surcharges or rebates...". Noise and emissions are sometimes levied separately from landing, but they are usually subsumed within runway charges formulas.

Landing charges are usually based on two main variables: the maximum takeoff weight (MTOW) of the aircraft using the airport facilities, and other characteristics, such as the geographical location of the origin or destination of the flight[14], the use of the aerobridge or a remote stand, or any other issue that distinguishes aircraft movements. Basic charging schemes usually calculate the landing fees as a charge per metric ton or part thereof. Charges may also be expressed in terms of fixed rates for each weight category, depending on the classification of aircraft. This scheme is also commonly used to calculate noise surcharges: for example, at BAA airports. In France, "multi-factor schemes" are applied and the airports use different noise and environmental coefficients. Table 1.1 provides a classification of the most common calculation schemes of landing charges for commercial aircraft.

Charges may thus differ according to the noise or emissions produced by a given type of aircraft or according to the time of day at which the facilities are used (recognizing daily

[14] In the Spanish case (AENA), this categorization is made according to whether the flight is a domestic (EU), international, mainland EU-island, or inter-insular connection.

or seasonal peak periods or the different costs imposed by daytime and night-time activities). Peak and off-peak charges are justified by differences in the costs of peak period activities[15] and to reflect the opportunity cost of the slots during the peak periods and the willingness of some users to pay more to use the facilities at the most convenient times – thus encouraging better use of the existing capacity. Some airports justify a different landing fee for day and night flights[16] based on the noise impact – often combining the charge with noise categorizations of the aircraft. ICAO guidelines say that noise charges should only be levied on airports which are experiencing noise problems and should be designed to recover no more than the abatement costs.

Table 1.1 Summary of landing charges

Summary of variables	Summary of calculation schemes	
1) Relative to the aircraft:	Unit Rate:	Landing Charge (LC)= Rate (R) x (MTOW)
• MTOW (metric tons)		
• Noise level (PNdB)	Fixed rate:	LC = Fixed rate
• Emmisions (Kg Nox)		
2) Relative to the flight	Two part:	LC = Fixed + [R x (MTOW)]
• Origin or destination	By Multisteps:	LC= A x R1 + (B-A) x R2 + (MTOW - B) x R3
• Type: Pax or cargo		
3) Relative to the time:	Multifactor:	LC= R x MTOW x N x D
• Peak/ off peak		N= noise coefficient
• Day/ night		D = Day/night factor

Source: Own elaboration.

Passenger charges are related to the infrastructure and the services provided at terminals. They are usually expressed in the form of a unit rate per passenger and, nowadays, are generally specified on the passenger's airline ticket. They are generally divided into facilitation charges and security charges (ACI Europe, 2003). Passenger facility charges (PFCs) are applied for the use of areas (and their complementary facilities) inside the terminal buildings that are not accessible to visitors. Passenger Security charges (PSCs) are applied for the provision of inspection and control of passengers and luggage within airport enclosures. One part covers general costs related to civil aviation security services and responsibilities and a second part covers all costs related to the installation, maintenance and operation of the security and baggage systems. The main variables used to calculate these charges are the boarding passengers and their destination. Transfer and transit passengers pay different PSCs in the majority of the airports, but this differentiation depends on whether both security regulations and the distribution of passenger flows within the terminal allow passengers in transit to avoid security controls.

[15] An estimation of this difference states that international peak passenger costs at LHR were £25.69 - £29.52, while off-peak passengers would only cause costs of £0.76 - £0.92 (in 1983 prices). CAA (2001).
[16] Milan airports charge an additional 50 percent of LC for each landing made during night hours.

Aircraft parking charges are applied by the use of designated aircraft parking zones or hangars. ICAO recommends that, to reflect the cost drivers, the charges should be based on MTOW and/or aircraft dimensions (area occupied), length of stay, and the category of the stand location (contact or remote). In most airports, the airlines enjoy a free parking period that varies from the first 90 minutes to 6 hours. Other aeronautical charges are applied to the provision and utilization of infrastructure facilities and installations which are used for traffic control or for the supply of ground-handling services (navigation, air bridges, baggage sorting area, container storage area, waste disposal, environmental control, fire control units and tow services). Air navigation fees are charged for the ATC services within the different Flight Information Regions (FIRs). Charges for the use of air bridges may vary according to whether they are used during peak hours and according to standard turnaround times[17].

Handling charges include ramp handling, passenger transport services, cargo handling and baggage handling. Ramp handling includes the provision of stairs (fixed or hydraulic), ballast sacks, security personal, start-up equipments, and push-back services. Passenger transport service charges cover transport on the ramp (by bus or microbus) and are usually levied either as a fixed charge for renting the vehicle or as a variable charge depending on the type of service and the number of passengers transported. Cargo handling charges are always based upon the chargeable weight of the consignment and are levied for the processing, handling and warehousing of outbound/inbound freight. European Legislation ensures minimum standards of access to ground handling at all European airports with at least 2 mppa. Since this Directive, many airports have outsourced ground handling to independent companies, and so these charges may be categorized as charges for commercial activities. However, several airports still retain these activities in their own hands and usually levy a single, all-inclusive, charge per aircraft and per departing passenger.

Regarding non-aeronautical charges, it is work noting that some activities can be classified as 'aeronautical' or 'non-aeronautical' depending on the form in which the activities are organized. For example, some airports treat handling activities as commercial because these activities are undertaken by handling agents or airlines, and thus these rents are obtained through a concession agreement. Table 1.2 shows how the

[17] A standard turnaround time has been defined for different aircraft, such as narrow-body (60 minutes) and wide-body (90 minutes).

different non-aeronautical activities may be classified into administrative or commercial concessions, licences of use and supplies.

Table 1.2 Non-aeronautical activities

Concessions		Licences of Use	Supplies
Administrative:	Commercial:		
• Land and paved surfaces	• Vending machines	○ VIP/CIP lounges	▪ Electric power
• Offices, commercial desks	• Cash dispensers	○ Left luggage	▪ Water
• Check-in desks	• Duty-free shops	○ Filming	▪ Air conditioning
• Long-term hangars	• Bank offices	○ Advertising	▪ Fuel
• Other facilities	• Rent a car	○ Acc. restricted zones	▪ Telecom.
	• Restaurants/food services	○ Car/Bus Parking zones	

Source:Own elaboration.

Charges levied for the use of space are usually expressed in terms of a unit rate per m^2 per month. Offices, premises and commercial desks are charged for annual periods, with higher rates for short lets, taking into account the location of the premises. Check-in desk charges include the use of weighing conveyors, counters and screens that the check-in personnel use. Commercial concessions rights are commonly regulated by private contractual agreements but some airports apply a “two-part” price scheme in which a fixed part is usually based on the land/office/desks lease charges, and a variable part is normally calculated for each type of activity as a percentage of the turnover per employee of the concessionaire (travel agencies and car rental offices are usually charged under this formula). A surcharge, payable periodically, is applied on the use of supplies, depending on the real value of the supplies, services, materials and products provided directly or indirectly by the airport, and the use of airport property and the facilities and equipment needed to facilitate this type of service. Parking charges usually depend on the time consumed in the facility, differentiating between short- and long-term. In addition, airport managers have the discretion to abate or waive any charge if and when they consider it is in the interest of the airport company to encourage the development of traffic at the airport. For example, special rebates may be offered for new routes and frequencies or even the transfer of operations to new facilities.

1.3 Air transportation and airport expansions

The planning and development of an airport must always be described in the Master Plan, whose development is a matter for top management. However, major investment decisions at commercial airports are always taken in consultation with air carriers. The proliferation of new entrants since deregulation has had a tremendous impact on facilities planning and management. In the last 30 years there have been major developments in commercial aircraft, both in size and performance. Moreover, the increase of the number of passengers and markets served means that an airport should be able to meet facility requirements of many different types of air carriers. For instance, commuter carriers usually do not need the same apron and gate facilities as major carriers. Other new entrants, including low-cost carriers, might want more frequent gate access, but less baggage handling. These minority carriers might challenge major incumbent carriers for a voice in investment decisions at an airport.

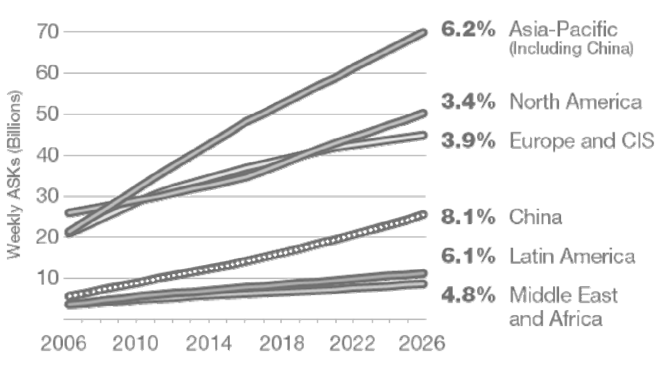
ICAO guidelines on Master Planning (ICAO, 1987) indicate the need to forecast air traffic demand as one of the main steps of airport planning. Airports are designed as infrastructure providers for air transportation, and this industry is regarded as one of the fastest-growing sectors in the world economy. From 1971 to 2001, air passengers grew at an average annual rate of 7 percent. The 9/11 events had a negative short-term impact on passenger demand: according to ICAO estimates, the annual growth rate from 2001 to 2005 was 2.7 percent. Nevertheless, long-term growth is expected to remain strong. ICAO (2006) forecasts a growth rate in passenger traffic of 6.1-5.8 percent per annum over the 2006-2008 period. Emerging countries and expanding regions will experience growth rates of about 10 percent for 2006-2010, while North America will grow at a more modest rate of 4.1 percent per year. China leads the long-term growth in domestic air travel. Its capacity growth rate[18] of 8.1 percent will propel its airline traffic to over half the size of the US market in 20 years. As of 2007, it is expected that many more markets will receive a strong boost as governments liberalize part of the previously restricted market access. New Open Skies agreements between the European Union and the United States and Canada will shortly come into effect. Regarding air cargo figures, an average annual growth rate of 6 percent is expected in the period 2006-2025, not only because of the emerging trade markets between China and both the US and the EU but also because of the increasing strength of China's domestic traffic (Boeing, 2007).

Table 1.3 Yearly traffic growth

Expanding Regions	China	10.8%
	India	9.8%
	Eastern Europe	9.7%
	Middle East	8.0%
	CIS	7.4%
	Rest Asia	7.1%
	Africa	7.0%
	Latin America	6.2%
Developed Regions	Australasia	6.6%
	Western Europe	5.6%
	Japan	4.7%
	North America	4.1%

Source: Airbus Global Market Forecast (2006).

Figure 1.4 Capacity growth within regions



Source: Boeing Current Market Outlook (2007).

[18] The carrier's capacity is measured in available seat-kilometers (ASKs): the number of seats on an aircraft multiplied by the number of kilometers flown.

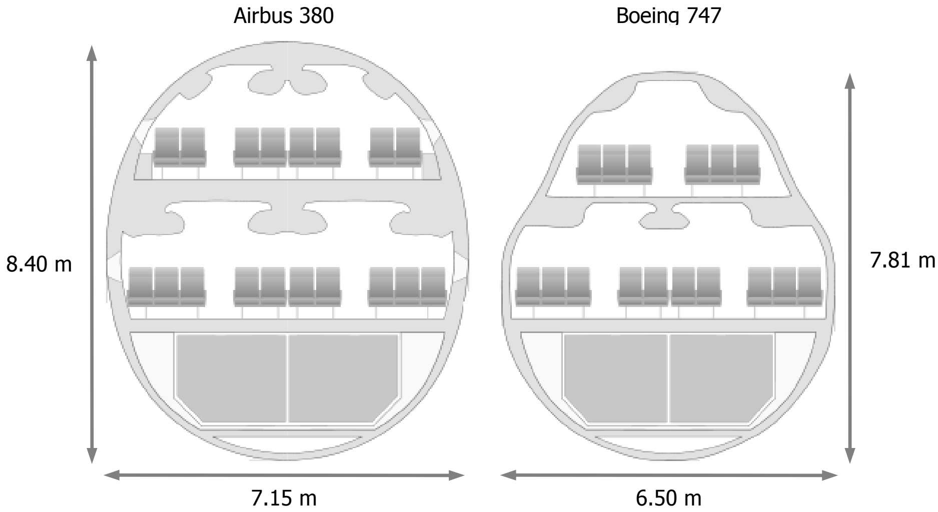
The world's fleet, which includes both passenger and freighter aircraft, will grow from 17,153 at the end of 2005 to nearly 33,500 (+95 percent) by 2025. Current trends in airline development are betting on the combination of larger aircraft, with cheaper operating costs per seat. World jet aircraft size, including regional jets, will increase by 20 percent over the next 20 years, as a result of increased congestion. By 2025, the world's airlines will be operating 1,263 very large passenger aircraft such as the double-decker A380 and 1,228 large freighter aircraft to link hub cities[19], and the number of frequencies offered on passenger routes will more than double (Airbus, 2006). This explosive growth, given current levels of congestion and delays, will present a continued challenge to the world's airports and air traffic management systems in terms of how to provide adequate capacity to cope with this air traffic growth.

Airport authorities are constantly adjusting their strategies to new technological developments, either in terminal buildings or airside facilities. Regarding top commercial airports, almost every Master Plan to date is addressing both demand and new aircraft considerations. Airports used by the A380 in commercial service may need both taxiway and apron reconfigurations, to maintain safe separation margins on account of its large wingspan (11.3 m broader than that of the B747) and the outboard engines. Terminal gates must be sized such that the large wings do not block adjacent gates. In addition, service vehicles with lifts capable of reaching the upper deck, as well as tractors capable of handling the A380's ramp weight, are needed (Lufthansa, 2006).

According to the manufacturer's forecast, about 70 percent of flights of the new A380 will be from just 25 large hub airports (Airbus, 2006), many of which are already so congested that they will need to reconfigure the slot allocation processes. London Heathrow, for example, was built to accommodate only 45 million passengers per annum (mppa), but by 2007 was handling near 70 mppa. The amount of investment needed to accommodate the new A380 at LHR will be several hundred million pounds sterling. Thus, the main unresolved question is: Who will pay these costs? According to Forsyth (2005), the airports' regulatory environment allows the airport authorities to make imprudent investments, since they are able to pass the costs to the users. And as having A380 capability may be a prestige issue for many airports, there is a risk of overinvestment for the introduction of the A380. Moreover, given the large investments and time required to carry out such expansions, there is the possibility that not all the

[19] In particular, 56 percent of the world fleet of very large passenger aircraft will be operated by the airlines of the Asia-Pacific region.

needed changes may be achieved. In this case, major aircraft manufacturers forecast that increased congestion could make average aircraft size even larger, and airlines may be forced to acquire even bigger aircraft in order to meet demand. (Airbus, 2006) It seems that, in a time of unprecedented expansion of air transportation, demand forecasts and the industry's agents are exerting too much pressure on airport development.



Source: Wikipedia, GFDL.

Figure 1.5 Front section size comparison. A380 vs. B747

Many of the world's busiest airports are currently undergoing major expansion projects, which involve the construction or lengthening of existing runways and apron areas, the improvement of ground transport facilities such as parking lots or railway stations, new passenger and cargo terminals, and especially the development of additional boarding piers and loading bridges, in order to increase the average gate and runway capacity and therefore increase the number of hourly operations (slots). Table 1.4 shows all recent, current and planned expansion projects in many of the aforementioned hub airports. The new runway in ATL, for example, is expected to increase the capacity for landings and takeoffs by 40 percent. ORD's overcrowded schedules often lead to cancellations and long delays that affect the whole US airport network[20]. Under a strong investment program, four runways will be added and three removed. A new West terminal is planned and two existing buildings will undergo expansion. The program will expand the airfield capacity by 40 percent and increase the passenger-throughput capacity.

In Europe, expansion trends are quite similar. The new Terminal 5 in LHR opened partially in 2008, but its completion is not expected before 2015. Additionally, the UK Department for Transport released a White Paper which included the proposal for a

[20] In 2006, the BTS official report ranked ORD as the least punctual airport in the United States based on the percentage of delayed flights (BTS, 2006).

third runway at LHR by 2020 (DfT, 2003), which would likely be accompanied by a sixth terminal (BAA, 2005) for a total capacity of 115 mppa. AMS will also not be able to avoid the construction of a second terminal: according to the airport's development director, this is mainly as a result of explosive annual traffic growth of between 4 and 5 percent (Financieele Dagblad, 2007).

Table 1.4 Expansion projects in world's leading airports

Airport	Major expansion projects	Cost
Atlanta, ATL	Fifth runway (2006) International Terminal (2006-2010) South Gate Complex (2011 - …)	\$1.28b \$1b \$1.8b
Chicago, ORD	Four new runways and removal of other three. Expansion of T3 and T5 (2008-…)	\$6b
London, LHR	New Terminal 5 (2008 -2015) New East Terminal (2008-2012) ? Third Runway and T6 (2015-2020)	£4.2b £1.5b n/a
Tokio, HND	Fourth Runway (2007-2010)	¥600b
Los Ángeles, LAX	New International Terminal (2008-2012)	\$1.2b
Dallas, DFW	New International Terminal (2005)	\$1b
París, CDG	Reconstruction of Terminal 2E (2005-2008) Satellite 3 (2007) New Terminal 2G (2007-2008) Satellite 4 (2012)	€145m €645m €83m €450m
Frankfurt, FRA	New Terminal 3 (2007-2015) A380 Maintenance base Fourth Runway and Taxiway	€1.1b €150m €2b
Beijing, PEK	Third Runway and New Terminal 3 (2008)	\$4.6b
Hong Kong, HKG	New Terminal 2 (2007) Improvement of Terminal 1	HKD1.7b HKD1.5b
Amsterdam, AMS	Second Terminal Sixth Runway	€2.5b n/a

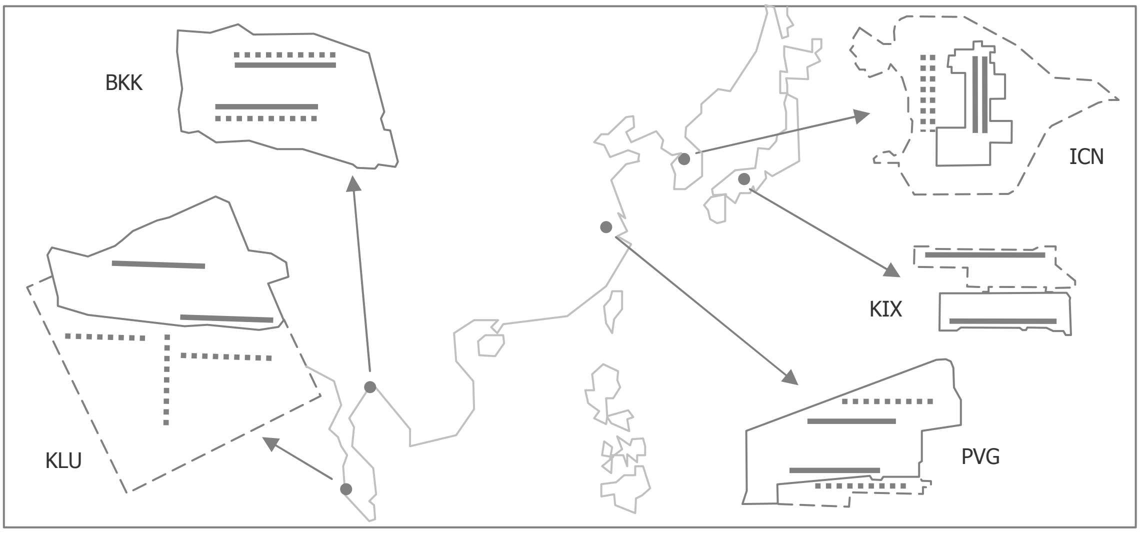
Source: Airports' Master Plans.

The conventional rule of thumb is that a terminal building should provide approximately 20,000 m^2 per mppa[21] (BIA, 2006). Hence, according to the aforementioned figures, the biggest airport investment projects should be located in expanding countries of the Asia-Pacific region. In 2007, China had only 467 airports for a total area of 9.6 million km^2 (about the same as the US). Considering the current number of airports in the US (+14000), the differences in population and the huge development of both general and commercial aviation expected in China, it is clear that it will be necessary to build many aeronautical infrastructures. Apart from that, airports are also intended to be recognized as trade icons for these emerging regions. One of the most representative projects of this new airport era is the new terminal 3 at Beijing PEK. As of 2008, it is the largest airport terminal complex built in a single phase with 900,000 m^2 gross floor area, providing 66 new aerobridges for a total of 120 gates.

In spite of being very new infrastructures, almost all leading airports in the Asia-Pacific Region are also currently undergoing huge expansion projects. Many of them even

[21] For cargo facilities, the average building utilization rate in the US is 1.75 sq. feet (0.16m^2) per imperial ton of cargo (ANC, 1999).

require the expansion of already reclaimed land areas, such as Hong-Kong or several Japanese airports. Many of these projects are presented in Figure 1.6, which indicates the planned developments in the number of runways or new land acquisitions. For example, Shanghai (PVG), inaugurated in 1999, has a Master Plan which foresees the construction of three additional runways. Kuala Lumpur (KLU)'s total airport area is planned to reach 100km^2 (+115%) making room for three new runways. The fourth phase of Incheon's (ICN) construction will provide two new runways with a final area of 47.44 km^2. It is expected to handle 100 mppa and 7 million metric tons of cargo annually and it is projected to be transformed into one of the top-ten busiest airports in the world by 2020. Osaka (KIX) has also projected a new terminal and several aprons, a 4,000m second runway, and a new cargo terminal, expanding the total airport area to 10.55 km^2, on island created from reclaimed land (KIX, 2007).



Source:KIX infrastructure report 2007-2008.

Figure 1.6 Trends for upgrading large-scale airports in Asian countries

Megaprojects are not only associated with airport expansion, but also with the planning and construction of entirely new airports. These new airports are closely related to the development of certain emerging regions as commercial and business centers which usually require particular architectural, engineering and financial solutions. Dubai World Central can be considered a paradigmatic example, as it is being developed to become the world's first integrated logistics platform. At the heart of this huge community will be Dubai World Central International Airport (JXB), which will feature more than 25 km of runways, an annual cargo capacity of 12 million metric tons (16 cargo terminals) and a passenger throughput of +120 mppa (more than 50 percent the capacity of ATL). It is the *busiest* airport ever planned, and it is scheduled to be fully operational by 2017. In summary, the airport industry is definitely growing faster than ever, and its output is exceeding its past scale in every corner of the world.

Table 1.4 above shows that either the construction of a new airport or the expansion of operating capacity involves a large amount of public resources. Land acquisition is often necessary in order to carry out either terminal or runway expansion plans; surrounding communities are destroyed, and residents need to be relocated. Apart from that, the traffic generated by airports both in the air and on the surface can be a major source of noise and air pollution which may interrupt the sleep of nearby residents and produce serious health effects.

In addition, these projects are usually resisted by local residents because they often cause negative externalities on the countryside, the local flora and fauna, and local weather patterns. For example, it is usually necessary to flatten out large areas[22] which can cause fog to appear in sites where fog had rarely been seen before. The removal of natural cover and other airport construction practices can result in unsightly soil erosion and sedimentation, changing drainage patterns in agricultural areas. The use of impermeable surfaces decreases the infiltration of rainwater into the ground and increases the quantity of runoff and the likelihood of flooding. Airports located on the coast may harm the water environment, thus endangering fish and wildlife. Furthermore, because of the risk of collision between birds and aircraft, large airports undertake bird population control programs to ensure the safety of air travellers.

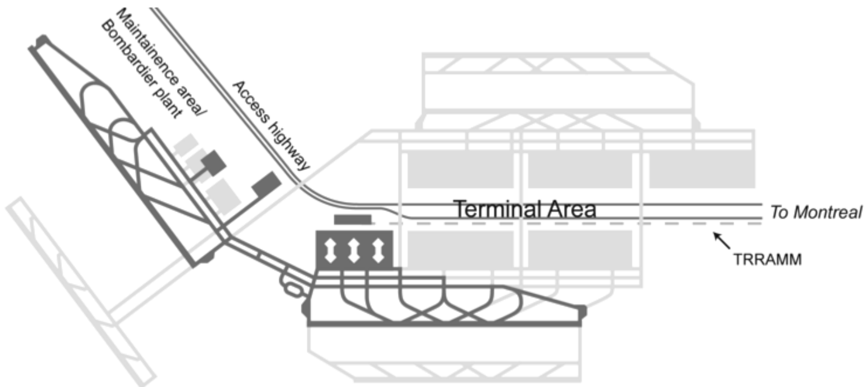
On the other hand, airports are also a big source of indirect employment in the surrounding areas: because some industries need to be located in the vicinity of airports, and local regional planners see how the economic attractiveness of the area is increased.

Hence, apart from financial expenditures and, of course, the expected economic benefits, the environmental impact is a key factor to be considered. Land use in the vicinity of airports is severely restricted for both safety and noise insulation purposes. Therefore, an airport expansion, like many other civil engineering projects, always requires lengthy public consultation procedures[23] and a huge amount of financial support that can be guaranteed by federal/local authorities, private investors or self-improvement funds. For that reason, the decision to expand airport facilities, even under capacity and demand pressures, should not be taken lightly, i.e. by considering the

[22] During the land reclamation stage in KIX, three mountains were excavated to obtain the 21 million m^3 of landfill which were needed to complete the thirty-meter layer of earth over the sea floor (KIX, 2007).
[23] Of course, this does not apply to China.

project's grandiosity as a decisive factor. The largest airport in the world in terms of area is King Fahd Intl. (DMM), which covers 780 km² but manages only 3.5 mppa. It is an airport which features 8,000 m of runways and 327,000 m^2 of terminal floor area but remains idle most of the time.

However, Montreal-Mirabel (YMX) is the best example of an overcapacity airport project that has not fulfilled the prior expectations of demand. As of 2008, YMX is the second largest airport in the world in terms of area, though a lack of traffic meant that it was never expanded beyond its first phase (Figure 1.7). Today, YMX is used exclusively for cargo flights[24]. Its passenger operations ceased in 2004, after many years of limited charter service.



Source:Wikipedia, GFDL.

Figure 1.7 Mirabel's projected airport layout

The history of YMX is as follows. The economic boom experienced by Montreal in the 1960s led government officials to predict that the city's Dorval airport (YUL) would be completely saturated by 1985, so they decided to build a new airport capable of absorbing the expected increase in passenger traffic. The first proposals were drawn up to expropriate 392 km² of land located in an area served only by a long road link. The area of operations represented only 69 km², about 19 percent of the total expropiated area. The excess land was planned to serve as a noise buffer and as an industrial zone that would eventually be developed. Local residents fiercely opposed the massive land expropriation. However, construction started in June 1970.

The inauguration of the new airport was rushed to 1975. It was decided to transfer only international flights to Mirabel until 1982. However, after 1976, the airport began to decline in importance because of the increasing use of longer-range jets that did not need to refuel in Montreal before crossing the Atlantic. This trend, coupled with

[24] In 2006, Aéroports de Montréal entered into an agreement to turn Mirabel into a theme park.

Montreal's decline in favor of Toronto, dramatically reduced the amount of projected air traffic into Dorval. The result was that a second airport was no longer needed. To ensure the airport's survival, all international flights for Montreal were banned from Dorval from 1975 to 1997. This forced originating passengers to travel far out of town for their flights, and to take long bus rides for connections from domestic to international flights. The construction of a high speed rail alternative (TRRAMM [25]) was projected but it collapsed because of lack of funding. Thus, Mirabel was forced to cope with an inadequate road system and a non-existent rail transit.

Mirabel was originally designed to be eventually expanded to six runways and six terminal buildings. The expansion was supposed to occur in a number of phases and be completed by 2025. However, the airport never got beyond the first phase of construction, where the first terminal was designed to handle 6 mppa. By 2005 one of the two runways was completely closed, and the demand in Mirabel was never greater than 3 mppa in its whole existence. Meanwhile, Dorval has now been renamed as Montreal-Trudeau, and has recently completed a $716 million expansion plan that enables the terminal to have a capacity of 20 mppa, Further improvements that started in 2007 will increase the capacity of the airport to handle up to 26 million passengers. In December 2006, more than 35 years after the expropriation, the Canadian Government announced the return of 4,450 ha of the Mirabel area.

Moreover, Toronto-Pearson (YYZ), YUL's main competitor and busiest airport in Canada, has become one of the world's most expensive airports[26] (TRL, 2006). After a $4.4-billion airport redevelopment project, the AA had a debt of $6 billion. Its managers increased the aeronautical fees but the high fares are threatening growth opportunities in favour of the other airports serving South Ontario which have started an aggressive pricing policy. Airports were thought to be natural monopolies, but nowadays it is evident that they operate in a very strong competitive environment. So, even when airports are operating under capacity constraints, they need to evaluate carefully the limits of future expansion. These and other good examples[27] of failed airport investments need to be analyzed before starting pharaonic airport megaprojects.

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[25] Transport Rapide Régional Aéroportuaire Montréal-Mirabel.

[26] At YYZ, the landing fee for a 747-400 is about $13,000.

[27] The construction of Lambert-St.Louis Intl. (STL)'s $1 billion runway 11/29 began in 1998, and continued even after traffic growth declined following 9/11 and the de-hubbing of STL by American Airlines in 2003. The project required the relocation of seven major roads and the destruction of 2,000 homes. This runway provided no-longer needed extra capacity. Moreover, its use has been abandoned because of its distance from the terminals.

1.4 The economic perspective

Primary airports provide major infrastructure for air transportation, and the privatization of airport management does not change the fact that they are still providing a public service, and, for this reason, they should be operating under or very close to social welfare maximization objectives (for the region of influence). If an airport's available infrastructure is now reaching its technical capacity, assessing if this is because of poor management or an inadequate pricing policy is a capital issue, in order to: 1) change airport regulations; 2) renegotiate long-term concession agreements; or 3) avoid a further dead investment of both financial and physical public resources.

Hence, any valid airport regulatory tool should account for, first, the existence of inefficiencies, which could be derived from the exercise of market power in the commercially-oriented private provision of aeronautical activities (loss of service, high fares or under-investment), or from pressures from incumbent carriers concerning capacity expansion (if it means slot allocation to new entrants) (Evans and Kessides, 1993). The interest in airport performance has therefore increased after privatization, so it would help to determine the main variables that an airport manager needs to control to improve efficiency. This type of study can be very helpful in policy decisions aiming to choose the best framework to organize the airport system.

Second, many authors have suggested that, with expansion, airports will benefit from scale economies (i.e. decreasing average costs) derived from production synergies which improve operating efficiency. However, others have suggested the very opposite, arguing that increases in size will lead to increased operational and administrative complexities that will result in a loss of efficiency (Jeong, 2005). Thus, the effect of increased airport output on costs remains controversial, and it has not been fully explored. However, today, the study of this issue is more than necessary in order to rationalize new airport investments. It will be crucial in order to decide whether an existing airport expansion is a better alternative than a new airport development. The presence of scale economies would always support the expansion alternative, as the separate production of aircraft movements in a multiple airport system may become more expensive than their joint production[28].

And, third, it is evident that the choice of any pricing alternative has a direct effect on demand and congestion; so, if prices are not optimally set, false market signals could

[28] This analysis does not account for land restrictions: sometimes, airports could not be further expanded, which led to the existence of multiple airport systems in the largest metropolitan areas.

incorrectly guide dynamic decisions about optimal capacity investments. As social welfare has to be the objective of airports, optimal charges should be based on social marginal costs (SMC) or second-best prices, in the sense of optimal departures from SMC pricing, if cost recovery or other constraints exist. This means that estimates for each category of SMC are needed. For example, a good starting point to estimate marginal social costs could include: 1) the marginal landing or takeoff cost of an additional aircraft of a particular type arriving/departing at a particular time; 2) the marginal cost of an additional work load unit (WLU), either 100 kg of freight or 1 passenger, differentiating the type of facilities that have been used to service it; 3) the marginal noise and emissions cost of an additional aircraft of a particular type or classification arriving/departing in a particular direction at a particular time (given the meteorological conditions and the site characteristics); and 4) the marginal congestion costs of an additional aircraft of a particular type arriving/departing at a particular time. Because of the lack of information, this dissertation will focus on items 1) and 2) above but a robust methodology will be provided in order to expand the model specification with new outputs: environmental and congestion costs.

The econometric estimation of airport cost functions is proposed as a suitable methodology to analyze all the three mentioned features. From the cost function parameter estimates, each output's scale elasticities can be obtained, and it is straightforward to calculate both the overall degree of scale and each output's marginal operating cost (under a multi-output approach). These monetary values can be used as important reference points for optimal pricing, airport regulation, and even for master planning. Finally, a consistent estimation of the airport's operational efficiency level will be obtained by combining a state-of-the art stochastic frontier methodology and a worldwide database. Chapter 2 will now discuss some of the microeconomic and statistical issues of the proposed methodology.

CHAPTER 2

THEORETICAL BACKGROUND AND PREVIOUS LITERATURE

2.1 The microeconomics of the cost function

A good understanding of the production process is the basic step to analyze the structure of the airport industry. The technology can be expressed as a mathematical relationship between a set of outputs Y and a set of inputs X as $F(X,Y)=0$. As this function $F(.)$ is commonly unknown, several approaches have been used to deal with the problem. For example, the engineering assessment of optimal input productivities, which stands at first sight as the most accurate solution. However, accounting for best practices in the airport industry by direct measurement is very difficult because of the great influence of external factors related to the airport's geographical location, such as wind patterns or height above sea level. This makes it very difficult to obtain reliable and generalizable results. In addition, engineering-based approaches should reflect the firm's ideal behavior rather than the actual one, and marginal cost pricing derived in this way may result in overcharging (Link and Nilsson, 2005).

Therefore, regarding airport operations, the econometric estimation of *F(.)* appears to be a more suitable solution. In addition, it is well known that technology may be equivalently represented either by a production or a cost function under certain regularity conditions (Shephard, 1953). Taking into account that this kind of study requires collecting data from the firms in the industry, an easier access to financial figures than to technical data explains why the cost approach has been used more extensively in current research in many transport industries.

In economic terms, the productive process of a firm can be formally represented by the *technology*. If a firm uses a vector X of r inputs to produce a vector Y of n outputs, the technology T can be defined as the set of observed pairs with the property that Y can be produced by X, that is:

$$T=\{(X,Y)/Y \text{ can be produced from } X\}. \qquad 2.1$$

The redaction of Chapter 2 and Chapter 3 has benefited greatly from the work of Tovar (2004).

The technology satisfies some basic regularity properties, such as: that positive inputs are required to produce positive outputs, and that an increase in inputs makes possible at least a weak increase in outputs. Given these conditions, there exists a continuous transformation function $F(X,Y)$ which is non-decreasing in X and non-increasing in *Y,* such that $F(X,Y)\geq 0$ if and only if $(X,Y)\in T$ (McFadden, 1978). The technical optimality is reached on the boundary of *T* that represents the non-dominated input combinations that can produce a given output vector Y, or the non-dominated output combinations that can be obtained from a given vector of inputs X. For a given Y^0, $F(X,Y^0)=0$ represents the analytical expression of an isoquant, and, for a given X^0, $F(X^0,Y)=0$ represents the analytical expression of the production possibility frontier. In the monoproductive case, Y is represented by a scalar, and *F(.)* can be expressed in terms of the production function $f(X)$, thus $F(X,Y)=f(X)-Y$.

Assuming that firms in the industry are price takers in input markets, the *cost function* is defined as the minimum cost incurred by the firm to produce the output *Y* at input prices ω, given the technology *T.* Thus, the firm faces the problem of finding the set of inputs that minimize the expenditure needed to produce *Y:*

$$\begin{aligned}&\underset{X}{Min}\ \omega X' = \omega_1 X_1 + \ldots.. + \omega_r X_r\\&\text{s.t. } F(X,Y)\geq 0.\end{aligned} \qquad 2.2$$

The solution of this problem is represented by the vector of conditional input demands $X^* = X^*(\omega,Y)$, and it is reached on the boundary of *T,* i.e. when $F(X,Y)=0$. Once the conditional input demands have been obtained, the expression of the multiproduct cost function is determined by replacing X^* on the objective function in 2.2. Hence,

$$C(\omega,Y)=\omega X^{*\prime}(\omega,Y)=\omega_1 X_1^*(\omega,Y)+\ldots..+\omega_r X_r^*(\omega,Y). \qquad 2.3$$

This is usually known as the long-run cost function, which means that all inputs may vary in the time period considered. However, this issue requires some serious discussion because the airport's capital assets are commonly supposed to be fixed and can not be easily adjusted to meet capacity requirements in the short run. When some inputs are thought to be fixed, the short-run cost function $C(\omega,Y,\bar{X})$, which considers the restriction to the problem 2.2, is a better approach to analyze the industry's technology. In any case, the long- or short-run model can be empirically tested.

As noted, the calculation of the degree of *scale economies* gives a great deal of practical information about investments, regulation and pricing in the airport industry. They can be calculated either from production or cost functions, in order to measure the increase of output achieved by expanding all inputs in the same proportion. Let us first consider the case of one single output and the production function on the frontier $Y = f(X)$. If all the inputs are expanded proportionally by the factor λ with $\lambda > 1$, the amount of output obtained can be expressed by $f(\lambda X) = \lambda^S Y = \lambda^S f(X)$. Thus, returns to scale in the technology can be obtained by the analysis of the parameter S and are classified in the following categories: i) increasing returns to scale (IRS) when $S > 1$. This means that the output increases by a proportion higher than λ, i.e. $f(\lambda X) > \lambda f(X)$; ii) decreasing returns to scale (DRS) when $S < 1$. This means that the output increases by a proportion lower than λ, i.e. $f(\lambda X) < \lambda f(X)$; and iii) constant returns to scale (CRS) when $S = 1$. This means that the output increases by the same proportion λ, i.e. $f(\lambda X) = \lambda f(X)$. Therefore, the size of S determines univocally the degree of scale economies in the technology. In addition, the concept of returns to scale can also be interpreted by looking at the cost function. Thus, if the firm uses λX to produce $\lambda^S Y$, then the cost incurred by the firm is:

$$C(\omega, \lambda^S Y) = \sum_r \omega_r \lambda X_r(\omega, Y) = \lambda \sum_r \omega_r X_r(\omega, Y) = \lambda C(\omega, Y) . \qquad 2.4$$

Differentiating 2.4 with respect to Y yields:

$$\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} = \lambda^{1-S} MC(\omega, Y) , \qquad 2.5$$

where $MC(\omega, Y)$ is the marginal cost function $\frac{\partial C(\omega, Y)}{\partial Y}$.

Differentiating 2.4 with respect to λ yields:

$$\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} = \frac{\lambda^{1-S} C(\omega, Y)}{SY} = \frac{\lambda^{1-S} AC(\omega, Y)}{S} , \qquad 2.6$$

where $AC(\omega, Y)$ is the average cost function $\frac{C(\omega, Y)}{Y}$.

From 2.5 and 2.6 the following expression is obtained:

$$S = \frac{AC(\omega, Y)}{MC(\omega, Y)} . \qquad 2.7$$

Thus, economies of scale (or increasing returns to scale) exist when average cost is greater than marginal cost.

It is easy to show that $S > 1$ if and only if $\frac{\partial AC(\omega, Y)}{\partial Y} < 0$. Formally:

$$\frac{\partial AC(\omega,Y)}{\partial Y}=\frac{\partial(\frac{C(\omega,Y)}{Y})}{\partial Y}=\frac{1}{Y}\left(\frac{\partial C}{\partial Y}-\frac{C}{Y}\right)<0 \quad \Leftrightarrow \quad \frac{\partial C}{\partial Y}<\frac{C}{Y}$$

$$1<\frac{C}{Y\frac{\partial C}{\partial Y}} \quad \Leftrightarrow \quad 1<\frac{AC(\omega,Y)}{MC(\omega,Y)} \quad \Leftrightarrow \quad 1<S.$$

An important consequence of the existence of economies of scale is that producing the total output with two or more firms (multi-airport system) generates a higher cost than producing it with one single firm (expanded airport). That is, there exists a natural monopoly. In this case, marginal cost fares do not cover total costs, and, consequently, economic efficiency may not be achieved without subsidies. Formally, Y^M is the amount of output that represents the size of the market, and Y^j the output produced by firm *j*. In the presence of scale economies, the average cost is decreasing, and therefore for a given firm $AC_j(\omega,Y^j)>AC(\omega,Y^M)$. Thus:

$$\sum_j C(\omega,Y^j)=\sum_j AC_j(\omega,Y^j)\cdot Y^j>\sum_j AC(\omega,Y^M)\cdot Y^j=C(\omega,Y^M)\,. \qquad 2.8$$

This is closely related to the concept of subadditivity which tries to generalize this result to multiproduct industries. Subadditivity means that one firm can produce *Y* cheaper than any combination of two or more firms. However, in the case of multiproduct firms, the analysis is more complicated because scale and scope are often blurred.

All the previous results can be adapted to a multiproduct specification of the cost function, which is definitely more appropriate for describing airport operations. Considering multiple outputs $Y^1,Y^2,\ldots,Y^k$, differentiating 2.4 with respect to Y_i yields:

$$\frac{\partial C(\omega,\lambda^S Y)}{\partial \lambda^S Y_i}\frac{\partial(\lambda^S Y_i)}{\partial Y_i}=\lambda\frac{\partial C(\omega,Y)}{\partial Y_i} \quad \Leftrightarrow \quad \frac{\partial C(\omega,\lambda^S Y)}{\partial \lambda^S Y_i}=\lambda^{1-S}m_i\,, \qquad 2.9$$

where m_i is the marginal cost function defined for each output Y_i, i.e.

$$MC_i=\frac{\partial C(\omega,Y)}{\partial Y_i}=m_i\,.$$

Differentiating 2.4 with respect to λ yields:

$$\sum_{i=1}^{n}\frac{\partial C(\omega,\lambda^S Y)}{\partial \lambda^S Y_i}\frac{\partial(\lambda^S Y_i)}{\partial \lambda}=C(\omega,Y)\,. \qquad 2.10$$

Replacing 2.9 in 2.10, we obtain:

$$\sum_{i=1}^{n}\lambda^{1-S}m_i S\lambda^{S-1}Y_i=C(\omega,Y)$$

$$S = \frac{C(\omega,Y)}{\sum_{i=1}^{n} m_i Y_i} = \frac{C(\omega,Y)}{\sum_{i=1}^{n} \frac{\partial C(\omega,Y)}{\partial Y_i} Y_i} = \frac{1}{\sum_{i=1}^{n} \frac{\partial C(\omega,Y)}{\partial Y_i} \frac{Y_i}{C}} = \frac{1}{\sum_{i=1}^{n} \eta_i}, \qquad 2.11$$

where η_i is the elasticity of the cost function with respect to product Y_i.

Sometimes it is interesting to study the behavior of $C(\omega,Y)$ as the level of production of a particular product Y_i is introduced, keeping the rest of the bundle at some positive level. This is known as incremental analysis. Hence, the incremental cost of producing Y_i in addition to a given bundle is defined as:

$$IC_i(\omega,Y) = C(\omega,Y) - C(\omega,Y_{n-i}) = C(\omega,Y) - C(\omega,Y_1,\ldots Y_{i-1},0,Y_{i+1},\ldots,Y_N). \qquad 2.12$$

The average incremental cost is defined as:

$$AIC_i(\omega,Y) = \frac{IC_i(\omega,Y)}{Y_i}. \qquad 2.13$$

Moreover, the degree of scale economies specific to product Y_i is defined as:

$$S_i(\omega,Y) = \frac{IC_i(\omega,Y)}{Y_i \frac{\partial C(\omega,Y)}{\partial Y_i}} = \frac{AIC_i(\omega,Y)}{\frac{\partial C(\omega,Y)}{\partial Y_i}} = \frac{AIC_i(\omega,Y)}{m_i}. \qquad 2.14$$

The presence of increasing product-specific returns to scale indicates that at least that product should be produced by one firm. These concepts can be extended to a subset of R products. Thus, the degree of scale economies specific to a subset *R* of *N* is given by:

$$S_R(\omega,Y) = \frac{C(\omega,Y) - C(\omega,Y_{N-R})}{\sum_{j\in R} Y_j \frac{\partial C(\omega,Y)}{\partial Y_j}} = \frac{IC_R(\omega,Y)}{\sum_{j\in R} Y_j \frac{\partial C(\omega,Y)}{\partial Y_j}}. \qquad 2.15$$

When $S_R(\omega,Y) > 1$, the marginal cost prices do not cover incremental costs.

Apart from providing infrastructure for air transportation, the airports also generate revenues from commercial activities. Because of the nature of the data, the specified output vector should also include this non-aeronautical output in order not to bias the parameters of the cost function. For that reason, the concept of S_R will be used in this work when calculating those returns to scale associated exclusively with the subset of aeronautical outputs[1]. In this context, data on the incremental costs of aeronautical activities is rarely provided in the AA's financial statements. Therefore, incremental costs are more likely to be predicted using the estimated cost frontier.

[1] This issue will have important consequences regarding the type of price regulation which is applied to airports, especially in the discussion of single-till vs. dual-till regulation.

Economies of scope are said to exist over the product set *N* at *Y* if and only if

$$C(\omega,Y) < \sum_{i=1}^{k} C(\omega,Y_{R_i}), \qquad 2.16$$

where R_i is a non-trivial orthogonal partition of the product set *N*. The degree of scope economies at *Y* relative to $R \subset N$ is defined as:

$$SC_R(\omega,Y) = \frac{C(\omega,Y_R) + C(\omega,Y_{N-R}) - C(\omega,Y)}{C(\omega,Y)}. \qquad 2.17$$

Thus $SC_R(\omega,Y) > 0$ implies the existence of economies of scope, and it is not convenient to split the output production into two different specialized firms producing Y_R and Y_{N-R}, respectively. $SC_R(\omega,Y)$ can take a value between -1 and 1 (note that $0 \le C(\omega,Y_R), C(\omega,Y_{N-R}) \le C(\omega,Y)$).

In the airport industry, the presence of scope economies cannot be analyzed between passenger and aircraft movements because its separate production would not make sense. On the contrary, some degree of scope can be identified between passengers and cargo, which could possibly provide an economic justification for either the consolidation of both outputs at major hubs or the development of super-specialized cargo airports.

Moreover, from 2.15 and 2.16 it can be seen that scope and scale economies are related in the case of multiproduct firms:

$$S(\omega,Y) = \frac{\alpha_R S_R(\omega,Y_R) + (1-\alpha_R) S_{N-R}(\omega,Y_{N-R})}{1 - SC_R(\omega,Y)}, \quad \text{where } \alpha_R = \frac{\sum_{j \in R} Y_j \frac{\partial C(\omega,Y)}{\partial Y_j}}{\sum_{j=1}^{N} Y_j \frac{\partial C(\omega,Y)}{\partial Y_j}}. \qquad 2.18$$

Equation 2.17 indicates that, in the absence of economies of scope, scale economies could be represented by a weighted average of product-specific scale economies. However, when economies of scope exist ($SC_R(\omega,Y) > 0$), this result is not valid because the denominator in 2.17 is less than 1, and therefore, scale economies are greater than the weighted average of product-specific scale economies. Therefore, the existence of scope economies (i.e. $SC_R(\omega,Y) > 0$), as well as scale economies specific to the subsets *R* and *N-R* (i.e. $S_R(\omega,Y_R) > 1$ and $S_{N-R}(\omega,Y_{N-R}) > 1$), is a sufficient condition for the existence of global scale economies. In addition, even in the presence of constant returns to scale specific to *R* and *N-R*, the existence of scope economies would imply IRS. And, finally, the existence of sufficient big scope economies could produce scale economies even in the case of specific DRS to *R* and *N-R,* respectively.

The *cost complementarity* is related to the behavior of the marginal cost of a given product as the level of output of other products increases. Thus, a twice-differentiable multiproduct cost function exhibits weak cost complementarities over the set of products *N* up to the output level $\widehat{Y}$ if:

$$\frac{\partial^2 C(\omega,Y)}{\partial Y_i \partial Y_j} \equiv \frac{\partial m_j}{\partial Y_i} \equiv C_{ij}(\omega,Y) \leq 0\,,\ i \neq j \text{ for all } 0 \leq Y \leq \widehat{Y}\,, \qquad 2.19$$

being the strict inequality over a set of output levels of non-zero measure. The presence of weak cost complementarities implies that the marginal cost of producing any product *j* does not increase with increases of the quantity of any other product *i*; therefore, the production of *j* is favored with the conjoint production of *i,* and conversely. Panzar (1989) showed that the existence of weak cost complementarities is a sufficient condition for the presence of economies of scope at *Y*.

Finally, it would be very interesting to determine to what extent the technology allows *substitution among production factors.* For example, in airports, the analysis of the pattern substitution between outsourcing, own labor and capital is one of the issues that can be addressed. When input markets are not perfect or allocative inefficiency exists, the degree of the importance of the problem will be exacerbated whenever production factors are not good substitutes, but this is not very important if input factors are good substitutes. Since the cost function describes the technology, the degree of substitutability among the production inputs can be analyzed by means of the Allen elasticities of substitution (AES). These elasticities are defined as:

$$\sigma_{AESij} = \frac{\lambda_{ij}}{S_j} \text{ where } \lambda_{ij} = \frac{\partial x_i}{\partial w_j}\frac{w_j}{x_i} \text{ and } S_j = \frac{w_j x_j}{C}\,. \qquad 2.20$$

Higher AES indicate greater flexibility in factor substitution, since airports are able to substitute the use of one factor with another without sacrificing much output. Conversely, negative AES implies the rigidity in factors' pattern of substitution. In addition, AES provide useful information about the curvature of the Hessian matrix of the cost function with respect to input prices, which allows regularity restrictions on estimated parameters to be checked.

2.2 The econometric estimation of cost functions

The estimation of long-run or short-run cost functions ($C(\omega,Y)$, $C(\omega,Y,\overline{X})$) requires observations on costs, outputs, input prices and potential fixed factors, associated with firms whose behavior is assumed to be cost-minimizing. Some functional form has to be postulated in the stochastic specification of the cost function, namely:

$$C = H(\omega, Y, \overline{X}) + \varepsilon \,, \qquad 2.21$$

where C, ω, Y and $\overline{X}$ are observed variables, and ε is the error term. The function H is explicitly formulated through unknown parameters reflecting some type of relationship between C and the independent variables. The evaluation of these parameters is the objective of the econometric process (Jara-Díaz, 1982). Duality ensures that both approaches (cost vs. production) contain the same information. Hence, given a cost function that satisfies certain regularity conditions[2], we may use it to define a production function or technology which in turn may be used to derive our original cost function. Therefore, the specification of a function C which satisfies some properties may be interpreted as the total cost function of some underlying production function or technology, even though we could not always express it explicitly[3]. Diewert (1971) showed that it is possible to make very general specifications of the structure of cost functions while maintaining these classical restrictions on the underlying structure of production. In this way, it is desirable to specify a form which is flexible (i.e. no a priori restrictions are imposed on its first- and second-order derivatives). Caves et al. (1980) established that, to be attractive for empirical applications, as well as all previous duality conditions, a flexible functional form should also be parsimonious in parameters, and contain the value zero for output quantities, in order to properly assess economies of scope and incremental costs. They discuss three flexible forms for a multiproduct cost function:

i) *Hybrid Diewert* (Hall, 1973). It imposes CRS as long as the underlying production function is linear. Additionally, the very large number of parameters to be estimated makes it generally unsuitable for empirical exercises. It takes the form:

$$C = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{r} \sum_{l=1}^{r} \alpha_{ijkl} (Y_i Y_j W_k W_l)^{\frac{1}{2}} \,. \qquad 2.22$$

ii) *Quadratic* (Lau, 1974). It does not satisfy the homogeneity condition (a priori), nor can it be imposed by parametric restrictions without sacrificing its flexibility.

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[2] The cost function must be non-negative, real-valued, non-decreasing, strictly positive for positive output, and linearly homogeneous and concave in w for each Y.

[3] Duality is discussed in Shephard (1953), McFadden (1978) and Uzawa (1964).

Additionally, fixed costs (α_o) are not properly specified to catch their variability through different production subsets[4]. It takes the form:

$$C = \alpha_o + \sum_j \alpha_j y_j + \sum_i \beta_i w_i + \sum_i \sum_j \gamma_{ij} y_i w_j + \tfrac{1}{2}\left[\sum_i \sum_j \delta_{jh} w_j w_h + \sum_i \sum_j \rho_{ik} y_i y_k \right]. \quad 2.23$$

iii) *Transcendental logarithmic "translog"* (Christensen et al., 1973). Of all the functional forms tested over the last 30 years, this is probably the most popular method which has been widely used in different empirical analyzes. It provides a local second-order approximation to any cost structure and allows a great variety of substitution patterns to improve the model specification of other frontiers which are based on constant elasticities of substitution[5]. Linear homogeneity can be imposed by introducing certain linear restrictions on the parameters to be estimated, which also significantly reduces the number of parameters to estimate. However, as output values enter in logarithmic form, the translog has no finite representation if any output has a zero value[6], and for this reason such a model is not adequate when researchers are principally interested in studying scope economies. It takes the form: (eq. 2.24)

$$\ln C = \alpha_o + \sum_j \alpha_j \ln y_j + \sum_i \beta_i \ln w_i + \sum_i \sum_j \gamma_{ij} \ln y_i \ln w_j + \frac{1}{2}\left[\sum_j \sum_h \delta_{jh} \ln w_j \ln w_h + \sum_i \sum_k \rho_{ik} \ln y_i \ln y_k \right]$$

Sometimes the model is estimated by deviating the explanatory variables with respect to an approximation point (usually the mean value of the sample). For example, all the variables can be normalized as follows:

$$\widehat{y}_i = \ln(y_i) - \overline{\ln}(y_i). \quad 2.25$$

This procedure simplifies the calculation of outputs' cost elasticities (α_j) and Hessian values (ρ_{ik}). The first parameters are essential in identifying economies of scale and cost subadditivities (Jara-Díaz, 1983), i.e.

$$\left. \frac{\partial \ln C(w,y)}{\partial \ln y_i} \right|_{\widehat{y}\widehat{w}} = \alpha_j + \sum_{k=1}^{n} \rho_{ik} \widehat{y}_j + \sum_{j=1}^{r} \gamma_{ij} \widehat{w}_j \bigg|_{\widehat{y}\widehat{w}} = \alpha_j \quad 2.26$$

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[4] This issue may be easily solved using *dummy* variables (Mayo, 1984).

[5] These are the constant elasticity of substitution family (CES), which includes the well-known Cobb-Douglas technology. For more than one output or two inputs, this characteristic is really restrictive, so not many production processes can be adjusted by this specification (McFadden, 1963; Uzawa, 1963).

[6] This issue can be solved using a Box-Cox transformation. However, when this approach is used, the interpretation of the parameters is blurred (Caves et al., 1980). A more detailed discussion on this topic can be consulted in Weninger (2002).

$$S = \frac{C(w,y)}{\sum_j \frac{\partial C(w,y)}{\partial y_j} y_j} = \frac{1}{\sum_j \alpha_j}. \qquad 2.27$$

The translog cost equation (2.24) is linear in parameters, and upon making the necessary assumptions about the stochastic error terms, classical least squares regression techniques can be applied (Stevenson, 1980). Nevertheless, the translog function is usually estimated conjointly with the cost minimizing input cost share equations by means of a seemingly unrelated equations (SURE) regression (Zellner, 1962), and for this reason maximum likelihood estimators are likely to be used. Cost minimizing input demands (for a quadratic specification) or input cost shares (for a translog) can be introduced in the model specification by applying Shephard's lemma. This procedure allows researchers to include *(r or r-1)* additional equations to the cost function, where r is the number of inputs[7] that have been considered in the technology. As no additional parameters are included in the model, the estimation becomes more efficient, or, in econometric parlance, the number of degrees of freedom is larger.

$$s_i = \frac{w_i X_i}{C} = \frac{\partial C}{\partial w_i}\frac{w_i}{C} = \frac{\partial \ln C}{\partial \ln w_i} = \beta_i + \sum_{j=1}^{m} \delta_{ij} \ln w_j + \sum_{j=1}^{s} \gamma_{ij} \ln y_j . \qquad 2.28$$

Regarding output definition, transportation firms generally move different kinds of commodities (k) between many origin-destination pairs (o/d) at different periods (t). Thus, the output is represented by a vector (Jara-Díaz, 1983):

$$[Y] = \left\{ Y_{od}^{kt} \right\}. \qquad 2.29$$

Airports do not provide transportation directly but they do provide infrastructure for transportation firms. Nevertheless, air carriers provide o/d differentiated products which may make different uses of the airport infrastructure, therefore affecting airport expenditures in a very different way. For example, aircraft movements to long-haul destinations need to carry more fuel, which increases takeoff weight, so more runway length is required. Additionally, behavioral patterns of arriving, departing and transfer passengers impose very different costs on landside infrastructures. Therefore, for both airports and transportation firms, it may be unfeasible to display perfect output disaggregation, because researchers normally have only a limited number of observations from which to estimate the parameters of the cost function. So, researchers usually face the problem of how to aggregate the information in order to minimize the

[7] It is well known that it is not possible to include all the cost share equations in order to avoid singularity of the disturbance covariance matrix. However, in the case of the quadratic model, r additional equations can be added because this problem is not present.

well-known hindrance of information losses[8]. Therefore, a good alternative could be to construct an aggregate output index. As seen in Caves et al. (1982), the multilateral output index for a translog specification can be written as follows, where y_{ik} indicates the i^{th} output for the k^{th} airport and R_{ik} represents its revenue share:

$$\ln y_{kl} = \ln y_k - \ln y_l = \frac{1}{2}\sum_i (R_{ik} + \overline{R}_i)(\ln y_{ik} - \ln \overline{y}_i) - \frac{1}{2}\sum_i (R_{il} + \overline{R}_i)(\ln y_{il} - \ln \overline{y}_i)\,. \quad 2.30$$

Moreover, it may be beneficial to add some output attributes directly into the cost function in order to mitigate the effects of aggregation biases. An alternative way was first introduced by Spady and Friedlaender (1978), and it is known as the Hedonic approach. This method tries to control the effects of output quality or attributes on total cost by adjusting output measures. This hedonic cost function is typically specified as:

$$C = C(\phi^i(y_i, q_i), w, t)\,, \quad 2.31$$

where ϕ represents outputs which are hedonic quality-adjusted. As seen in Oum and Thretheway (1989), the hedonic translog form has less parameters than the general specification[9]. This method can represent a substantial saving of valuable degrees of freedom for estimation and hypothesis tests. Nevertheless, the hedonic cost function has to be viewed as an exact function, not an approximation, on account of the separability imposed between ϕ and the rest of the arguments. In addition, as it is nested within the general specification, the hedonic hypotheses can be tested.

Additionally, for panel data, it would also be interesting to account for technological change and technological bias (both in inputs and in scale) in order to test Hicks' neutrality[10]. Technological development is defined as an inward movement in input space of the production-isoquant frontier (Stevenson, 1980). Viewing the time variable (t) as a proxy for the level of technological development (T_d), and studying it from the duality of the cost function, it can be measured as (1) below:

$$(1)\, T_d = \left.\frac{\partial \ln C}{\partial t}\right|_{Y,w}; \; (2)\, I_b = \left.\frac{\partial S_i}{\partial t}\right|_{Y,w}; \; (3)\, S_c\big|_w = \frac{\partial \ln C}{\partial \ln Y}; \; (4)\, S_{bi} = \left.\frac{\partial S_c}{\partial t}\right|_{Y,w}; \; (5)\, \frac{\partial^2 S_i}{\partial t \partial w_j}$$

Given the existence of technological advancement, the measure of input bias can be analyzed by (2), where S_i is the cost share of the i-th input[11]. T_d may also give biased

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[8] For a review on this topic using ton-miles as the aggregate measure, see Jara-Díaz (1982); and for an explanation of full disaggregate output in railroad industry, see Jara-Díaz and Winston (1981).
[9] Oum and Thretheway (1989) show that, for the specific case of 3 output variables, 3 inputs and only 1 output attribute, the general translog has 21 more parameters to estimate than in the hedonic approach.
[10] Hicksian neutrality (regarding input biases) implies that technological change does not alter factor proportions or factor cost shares.
[11] A positive value implies that T_d is probably affecting the use of factor proportions.

results with respect to scale characteristics of the production process. Such biases could alter the increasing returns to scale (IRS) range, and therefore they could have some important policy implications. The scale measure is given by (3), and the scale bias is obtained by (4)[12]. Therefore, if the data adequately fit the estimation of all the time parameters, then it is necessary to include a time variable (t) into the model by specifying a truncated third-order translog function. The proposed model (without an approximation point) is as follows:

$$\ln C = H + \phi_1 t + \frac{1}{2}\phi_2 t^2 + \sum_i \psi_i t \ln w_i + \frac{1}{2}\sum_i \sum_j \psi_{ij} t \ln w_i \ln w_j + \sum_k \theta_k t \ln y_k + \\ + \frac{1}{2}\sum_k \sum_l \theta_{kl} t \ln y_k \ln y_l + \sum_i \sum_k \theta'_{ik}\, t \ln w_i \ln y_k \ , \qquad 2.32$$

where H represents the second-order translog model.

Up to this point, the methodological process is straightforward. First, data is collected from real-world firms, whose behavior may substantially differ from cost-minimizing (eq. 2.2). Afterwards, data is fitted to a functional form in order to obtain a second-order local approximation (usually around the mean of the sample) of the real cost function $C(\omega, Y)$. However, if some firms are not efficient, this representation overestimates the theoretical cost function, thus biasing the degree of economies of scale and marginal costs. Therefore, it is usually necessary to question the neo-classic paradigm of the cost-minimizing behavior, including therefore the effect of introducing each firm's inefficiencies into the specification.

2.3 Productivity and efficiency analysis

The study of cost inefficiencies arises from the certainty that the minimum cost estimations, provided by the methodology described above, do not fit well with the firms' actual expenditures. In the real world, some firms deviate from the optimizing behavior. Given the input quantities, a producer is said to be technically inefficient if it fails to produce the maximum possible output. Similarly, allocative inefficiency (AI) is related to a non-optimal input allocation, given input prices, i.e. even reaching the maximum possible output, there would be another input combination in the same isoquant which presents a lower cost.

There are different methods to deal with these topics, such as Total Factor Productivity (TFP), Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA).

[12] A positive value implies the minimum efficient size can be attained at a lower level of output.

Which of these methods to choose is a weighted decision between personal beliefs and data availability. TFP is based on the ratio of output over input. When there is more than one input and/or output, it requires weights to be specified, which are usually based on price information[13]. These price-based index-number (PIN) methods only require information about quantity and price data concerning inputs and outputs for two firms or periods. This method is easy to implement and interpret. In the airports field, Oum and Yu (2004) analyze the performance of 90 international airports using what they called Variable Factor Productivity (VFP). Additionally, application of TFP can be found in: Hooper and Hensher (1997) and Abbot and Wu (2002) for Australian major hubs; Barros and Dieke (2007) for a panel of Italian airports; and Yoshida and Fujimoto (2004) and Yoshida (2004) for the Japanese airport system. Nyshadham and Rao (2000) use TFP to evaluate the efficiency performance of 24 European airports. More recently, Fung et al. (2007) have found the average annual growth in the productivity of Chinese regional airports to be above 3 percent using panel data from 1996 to 2004. Oum et al. (2006) analyze the differences in the airports' operational efficiency with respect to their ownership structures, using a VFP approach and panel data of major international airports from 2001 to 2003. They found strong evidence that publicly-owned airports are significantly less efficient than airports which are mainly in private hands. Nevertheless, this methodology has a very serious drawback, as the differences between two TFP measures cannot be decomposed for a better and, in some cases, essential analysis. For example, it is not usually possible to analyze technical change, and technical, scale, and allocative efficiencies, knowledge of which requires the estimation of the technology, and hence of a production (or cost) frontier.

The other two main approaches are used to construct frontiers, and therefore their data requirements are considerably higher. Once a frontier is fitted, the efficiency is calculated as its distance to each observation. DEA is a non-parametric technique which uses linear programming to fit a piecewise linear surface over the data points. It is by far the most popular methodology in airport benchmarking, and it has been applied in a relatively large number of studies. This includes Martín and Román (2001) to evaluate the performance of 37 Spanish airports; Parker (1999) analyzed the performance of BAA before and after privatization; Sarkis (2000) extended the DEA to the US. Gillen and Lall (1997) and Pels et al. (2001) separate airport operation into landside and

[13] These index numbers are derived from Laspeyres or Paasche indexes (Diewert, 2000).

airside, and develop separate DEA models to evaluate both productive efficiencies[14]. The main advantage of DEA relates to the identification of some peer firms as those efficient firms (situated on the frontier) to which the rest of firms should be compared with respect to their operational similarity. Moreover, it does not require the adoption of any functional form or distributional assumption for both the frontier and the inefficiency term, as SFA does. On the other hand, DEA results cannot be affected by unpredictable and uncontrollable factors which may give the firms' performance its true random nature. Such a feature can, however, be attained applying SFA[15]. According to Coelli et al. (2003), the main advantages of SFA methodology are: (i) environment variables are easier to deal with; (ii) it allows us to conduct statistical tests of hypotheses concerning any parameter restrictions associated with economic theory; and (iii) allows an easier identification of outliers. On the other hand, estimation results are sensitive to distributional assumptions on the error terms, and it requires large samples for robustness, so it is very demanding regarding information requirements.

SFA is an econometric method that estimates a production (cost) frontier as follows:

$$C = f(y, w) + u_i + v_i\,, \qquad 2.33$$

where y is the output set; w is the vector of input prices; v is the white noise, which captures the effects of those unpredictable perturbations; and u is a disturbance term, which is usually interpreted as an indicator of the technical inefficiency of each airport. Nevertheless, under this first approximation, these effects capture not just the potential technical inefficiencies but also incorporate the AI and the influence of other variables that have not been fully specified in the model and that do not usually change over the sample period, such as the type of ownership and the geographic location of each airport. In spite of that, this single parameter approach has been widely used in the previous literature on stochastic frontiers, though under different distributional assumptions on the inefficiency term. Note that it should follow a one-sided[16] distribution, since inefficiency can only take a positive value within the cost approach, or negative values if the production model is used. In the case of the cost models, some statistical distributions that have been used are:

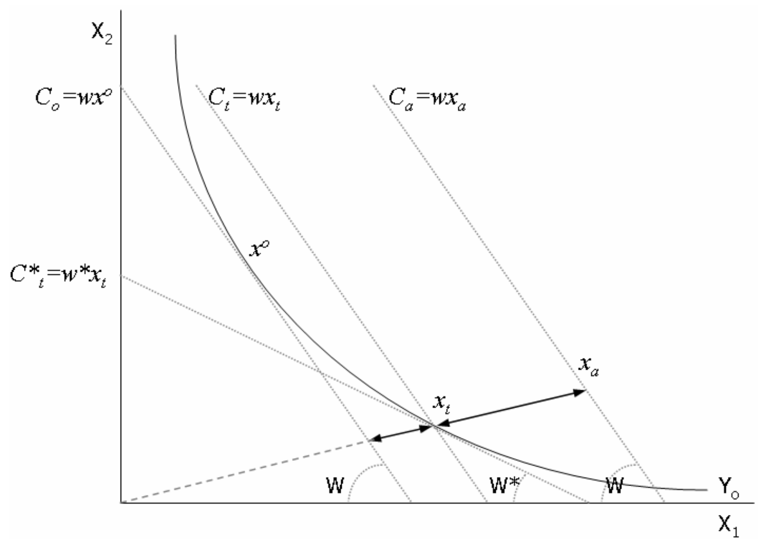
$$u_i \longrightarrow N^+(\mu, \sigma_\mu^2);\;\; u_i \longrightarrow \exp(\mu);\;\; u_{it} \longrightarrow \exp\{\eta(t-T)\}u_i\,. \qquad 2.34$$

[14] See also Fernandes and Pacheco (2002) and Lin and Hong (2006).

[15] The econometric estimation of technical efficiency in an SFA framework was introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977). See also Koop and Diewert (1982), Kumbhakar (1991) and Kumbhakar and Lovell (2000).

The model that presents the truncated normal distribution was introduced by Stevenson (1980). This specification was improved in the model on the right which was developed by Battese and Coelli (1992), as firm effects are also assumed to be truncated normal random variables, and they can also be systematically varied with time. However, under this approach, the same trend is imposed on all firms through the fixed parameter η which is not firm-specific. Cuesta (2000) generalizes this model by introducing $\eta_{i.}$.

Nevertheless, recent results in Kumbhakar and Wang (2006) show that failure to include the cost of AI explicitly in the cost function (i.e. lumping) biases the estimates of the function parameters, returns to scale, input price elasticities and cost inefficiencies. Hence, it would be desirable not to lump both inefficiencies in a single parameter. Joint estimation of technical and allocative inefficiencies in a translog cost system presents a serious complexity that is known as the "Greene problem" (Greene, 1980). This problem is that the cost function and the deviation from optimal shares are complicated functions of allocative inefficiency (Kumbhakar and Tsionas, 2005a). Previously to Kumbhakar (1997), AI was said to be independent of output and price levels. However, this restriction does not allow any links to be established between firm size and its effects over AI. In order to solve this issue, Kumbhakar uses a "shadow price"[17] approach in order to assess an exact relationship between AI and cost share equations, introducing a theoretically consistent dependence between AI and output and price levels using a translog specification[18].



Source: Díaz-Hernández et al. (2001).

Figure 2.1 Decomposition of inefficiency

[16] Many other distributions have been proposed: Meeusen and van den Broeck (1977) used an exponential distribution; Aigner et al. (1977) used a half-normal; and Greene (1980) proposed a gamma distribution.
[17] Aigner et al. (1977) defined AI as the departure of MRS from the ratio of input prices.
[18] Díaz Hernández et al. (2001) derived the same relationship using a quadratic specification.

Under this approach, the observed cost (C_a) is explained by four components (Fig. 2.1): (i) the minimum cost provided by a cost frontier *(C^o),* which is tangent to the isoquant at the optimal input quantities *(x^o)* under the observed vector of input prices (w); (ii) TE is measured by the radial distance between the observed cost (C_a) and the technically efficient cost (C_t), and it is usually measured by e^u. However, the TE input demands (x^t) cannot be directly derived by applying Shephard's lemma on (C_t), because the firm does not minimize costs at this point. To overcome this limitation, Kumbhakar (1997) proposed finding a non-observed shadow price vector (w*), under which this input demand (x^t) is now also allocatively efficient for a new minimum cost function (C*), and now Shephard's lemma can be applied; (iii) AI is represented by the radial distance between (C_t) and (C^o), derived from the departure of (x^t) from (x^o); (iv) unforeseen exogenous shocks might be also specified, giving the firm's performance its true random nature. Kumbhakar (1997) derived the relationship between the shadow price vector and the allocative distortions from the first-order conditions of the cost minimization problem (2.2), as the relevant prices to the firm are *(w*)*, i.e.

$$\underset{X}{Min}\; C^* = w^*x \quad \text{s.t. } F(X,Y) \geq 0 \qquad w^* = [w1, w_2\exp(\xi_2),\ldots,w_j\exp(\xi_j)] \qquad \frac{f_j(x)}{f_1(x)} = \frac{w_j\exp(\xi_j)}{w_1},$$

where $\xi_j \neq 0$ represents the allocative inefficiency for the input pair *(j,1).* The fictitious price reduction imposed by $\xi_j < 0$ indicates overuse of input j with respect to the reference input 1. Conversely, positive values, $\xi_j > 0$ indicate that the observed demand of input j is below its optimal quantity. Taking all this into account, the actual costs are modelled as follows:

$$C^a = e^u \sum w_i x_t(w^*), \tag{2.35}$$

where u represents the technical inefficiency of the airport, and

$$C^* = \sum_i w_i^* x_t(w^*). \tag{2.36}$$

Applying Shephard's Lemma on 2.36:

$$x_i(w^*) = \partial C^* / \partial w_i^* = (\partial \ln C^* / \partial \ln w_i^*)(C^*/w_i^*)$$

$$C^a = e^u \sum w_i (\partial \ln C^* / \partial \ln w_i^*)(C^*/w_i^*) = e^u \sum C^* S_i^* [w_i / w_i \exp(\xi_i)]$$

$$C^a = e^u C^* \cdot G, \quad where\ G = \sum S_i^* \exp(-\xi_i), \tag{2.37}$$

in which S_i^* is the *i-th* input cost share under the vector of shadow prices *w**. Note that $\exp(-\xi_i)$ will not affect the share equation of the input used as reference. Under a translog specification, the above relationship can be expressed as follows:

$$\ln C^a = \ln C^* + \ln G + u + v. \qquad 2.38$$

The expression of $\ln C^*$ is exactly the same as presented in Section 2.2, but the price vector is replaced with the new *w** values. The specification of an exponential allocative inefficiency in this logarithmic expression allows an easy separation of the ξ_i terms from the terms that belong to the minimum cost frontier C^o. Therefore:

$$\begin{aligned}
\ln C^* &= \ln C^o(w,y) + \ln C^{al}(\xi,w,y) \\
\ln C^{al}(\xi,w,y) &= \ln G + \sum_i \beta_i \xi_i + \sum_i \sum_j \gamma_{ij} \xi_j \ln y_i + (1/2) \sum_j \sum_h \delta_{jh} \xi_j \xi_h \\
\ln C^a(w,y) &= \ln C^o(w,y) + \ln C^{al}(\xi,w,y) + u + v,
\end{aligned} \qquad 2.39$$

where *u* now accounts only for technical inefficiency; *v* is the usual white noise; and $\ln C^{al}$ represents the percentage increase in costs due to allocative distortions, which depends on the estimation of the allocative inefficiency parameters. However, the above specification can not be individually estimated. Generally, the econometric models that have been used to resolve the decomposition of the inefficiency terms (the Greene problem) must be estimated as a system of equations, since uniequational models cannot be used to separate the lump effect (Kumbhakar, 1997). These models should be integrated by both the cost function and the cost shares obtained by applying Shephard's Lemma, i.e.

$$\begin{aligned}
S_i^a &= \left(w_i x_i^* / C^a\right) = \left(w_i^* x_i^* / C^*\right)\left(C^*/C^a\right)\left(w_i / w_i^*\right) = S_i^* / G\exp(\xi_i) \\
S_i^* &= S_i^o(w,y) + S_i^{al}(\xi,w,y) \\
S_i^a &= S_i^o + \lambda_i \;\; ; \;\; \lambda_i = (S_i^o[1 - G\exp(\xi_i)] + S_i^{al}) / G\exp(\xi_i),
\end{aligned} \qquad 2.40$$

where λ_i measures the deviation from optimal cost shares, and it is a well-defined function of the allocative parameters, input prices and output[19]. In summary, the translog cost system can be written as:

$$\begin{aligned}
\ln C^a &= \ln C^o + \ln C^{al} + u + v \\
S_i^a &= S_i^o + \lambda_i \qquad \mathrm{i} = 2, \ldots, r.
\end{aligned} \qquad 2.41$$

The empirical estimation of this kind of model is restricted to panel data in which both technical and allocative inefficiency are either assumed to be fixed parameters or

[19] Technical inefficiency does not affect cost shares, since all inputs are used excessively in the same proportion, i.e. the market share function is homogeneous of degree zero in input quantities.

functions of the data and unknown parameters. In Kumbhakar and Tsionas (2005a, 2005b), the authors provide a Bayesian approach to estimate this econometric specification, where specialized numerical methods, such as Markov Chain Monte Carlo (MCMC), are used to provide parameter estimates. Allocative inefficiency is modelled via price distortions from which firm-specific inferences are drawn on input over- or underutilization. As this procedure is featured in this work, it will be explained in the methodological section (Chapter 3).

2.4 The previous literature

Major regulatory decisions on industry structure are related to the identification of scale economies from production or cost functions. However, Jeong (2005) observes that only a few studies have dealt with the costs of airport infrastructure services, and that the use of very different methodologies and data sources provide inconsistent findings, mainly related to: 1) major limitations about capital costs and capital input levels; 2) a partial view of the airport activity, especially when dealing with the output definition; and 3) the difficulty in collecting comparable data across different-sized airports.

As a very first approach, Keeler (1970) used Ordinary Least Squares (OLS) to estimate two Cobb-Douglas partial cost functions for both capital and operating costs, using air transport movements (ATMs) as the output variable. He found constant returns to scale in airport operations using pooled time series and cross-sectional data from 13 US airports between 1965 and 1966. However, these results are limited by a very small database, and, as mentioned, by the study's partial rather than total approach.

Doganis and Thompson (1973, 1974) estimated a Cobb-Douglas cost function[20], and also parameterized models for capital and operating costs separately. They used work load units (WLUs)[21] as the output variable. They found significant economies of scale up to 3 million WLUs using cross-sectional data from 18 British Airports for the year 1969. However, their results suffer from the same modelling limitations as Keeler[22].

Tolofari et al. (1990) used pooled cross-section time-series data for seven British Airport Authority (BAA) Airports for 1979-87 to model a short-run total cost (SRTC) function with fixed capital stock. Then, capital costs are added to total variable costs to

[20] They categorized expenditures into total, capital, maintenance, labor, administrative and operating costs. They also considered investments in development programs and ATC services into the cost figures.
[21] 1 WLU is equivalent to 1 passenger or 100kg of cargo (Doganis, 1992).
[22] Tolofari et al. (1990) argued that all studies which separately estimate an operating costs model and a capital costs model would result in biased parameter estimates because the error terms are likely to be correlated, and the separate estimation of the equations fails to adequately model this.

derive short-run total costs. For each airport the minimizing capital value is calculated and substituted into the short-run variable costs (SRVC) function. A constant which represents the cost of capital is included to give long-run total costs. To allow for a flexible functional form, they adopted the translog function, whose variables were output (in WLUs), the input prices of labor, equipment, and residual factors, capital stock, passengers per ATM, percentage of international passengers, percentage of terminal capacity used, and a time trend. Using Zellner's (1962) SURE estimators, they found that there were economies of scale up to 20.3 million WLUs. A significant finding, however, is that it could not be easily generalized because only one airport in the sample (LHR) operated more than 20 million WLUs.

Main et al. (2003) constructed four Cobb-Douglas cost function models, using WLUs or passengers as the output measure, and including depreciations or not. The explanatory variables were WLUs or passengers, price of staff, price of other costs, passengers divided by ATMs, the percentage of passengers classified as international, and total assets. The price of staff was estimated by dividing staff costs by numbers employed. Prices of 'other costs' were estimated as expenditure on other costs divided by the value of tangible assets. They found economies of scale up to 5 million WLUs or 4 million passengers, using a data set of 27 airports in the UK for 1988 and another data set of 44 airports around the world between 1998 and 2000.

Rendeiro (2002) estimated a translog total cost function, using WLUs as the output measure and considering capital and labor costs, using a *pool* of data of 40 Spanish airports referring to the years 1996–1997. The results point out that those airports whose traffic volumes are between 1 and 3 million WLUs, showed a higher average level of relative efficiency than airports considered small or large.

In order to examine economies of output scale under the given state of capital infrastructure and facilities, Jeong (2005) estimated a translog specification (for both first- and second-order expansions) for total operating costs, using three different output definitions: passengers, WLUs, or output index (constructed with the above-mentioned multilateral procedure). Additionally, he used a similar aggregated input index (excluding capital costs) and a cost-of-living index as a proxy for the factor price.[23] The models also include other characteristics which affect operating costs, such as the percentage of international passengers, the percentage of delays, the percentage of cargo volume in WLUs, and the share of contractual costs as a function of the total operating costs. In addition, some dummy variables were included such as hub size, snowbelt area, and financial management structure. This study found that economies of output scale in the airport industry were present up to 2.5 million passengers or 3 million WLUs, using a cross-sectional database from 94 US airports for the year 2003.

Low and Tang (2006) analyzed factor substitution and complementarity using a database of major international airports in the Asia Pacific region. Using WLUs as the output variable, the specification of the translog cost function imposed constant returns to scale and neutral technical change. The results indicate a high degree of substitutability between outsourcing and labor, as well as a very important complementarity between outsourcing and capital. Finally, Martín and Voltes-Dorta (2008) provide a first approximation to a multiproduct cost function, providing evidence of the inappropriateness of the monoproduct approach, as it biases the estimation of scale economies. They also found unexhausted returns to scale in airport operations using a unbalanced pooled database of 41 international airports of all sizes between 1991 and 2005. This result seems to be more in line than the previous literature with current airport expansion trends, which are far beyond the aforementioned scales.

The study of airport inefficiencies using SFA is very limited in the literature, especially on the cost side. In a very interesting work, Pels et al. (2003) proposed two stochastic production frontiers for both ATMs and air passenger movements (APMs), using the first predictions as an intermediate input for the second. They found that European airports were relatively inefficient, and most airports displayed constant returns to scale in ATMs but exhibited increasing returns to scale in APMs. They used data from 34 European airports between 1995 and 1997 [24].

A recent study (Oum et al., 2008a) analyzes the effect of ownership forms on airport cost efficiency by applying SFA using a broad database of international airports between 2001 and 2004. A short-run multi-output cost frontier was estimated including commercial revenues in the specification. The cost model, adding the labor share equation, was estimated using a similar procedure to the one which will be used in this dissertation through MCMC under a Bayesian framework. The random deviation from the frontier was related to dummy variables indicating several ownership forms. The results indicate that airports managed by private companies or public corporations are more efficient than those managed by government agencies or port authorities.

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[23] As he mentions, an important shortcoming is that he uses consumer rather than producer prices.
[24] However, they did not consider labor inputs in the model.

Table 2.1 summarizes all the previous literature, helping to place the present contribution within the airport cost function research. This work features the first long-run stochastic cost frontier with a multiproduct specification (including commercial revenues), which allows a broader view of the airport operations, in order to obtain more reliable estimations of scale economies. Additionally, the use of a much bigger database allows us to obtain results that are more credible.

Table 2.1. Cost function studies in the airport industry

Study	Functional form	Data	Output	Conclusions
Keeler (1970)	Cobb-Douglas	Panel of 13 US airports, 1965-1966	ATMs	No economies of scale exist in ATMs
Doganis and Thompson (1973, 1974)	Cobb-Douglas	Cross-section, 18 UK airports, 1969	WLUs	IRS between 1 and 3 million WLUs
Tolofari et al. (1990)	Translog	Panel of 7 BAA airports, 1979-1987	WLUs	IRS by 20.3 million WLUs
Main et al. (2003)	Cobb-Douglas	Cross-section, 27 UK airports, 1988 (CRI) Panel of 44 airports worldwide, 98-00 (TRL)	Passengers or WLUs	IRS by 4 million passengers or three million WLUs
Pels et al. (2003) - Production Frontier	Translog	Panel of 34 European airports 95-97	ATMs or Passengers	CRS in ATMs IRS in passengers.
Jeong (2005)	Translog	Cross-section, 94 US airports, 2003	Passengers or WLUs or Output index	IRS by 2.5 million passengers or 3 million WLUs
Low and Tang (2006)	Translog	Panel of 9 major Asiatic airports, 1999-2003	WLUs	CRS were imposed
Martín and Voltes-Dorta (2008)	Translog	Unbalanced panel of 41 international airports, 1991-2005	WLUs and ATMs	Unexhausted IRS
Oum et al. (2008a) - Cost Frontier	Translog	Unbalanced panel of 109 international airports, 2001-2004	Passengers, ATMs and Commercial revenues.	-
Voltes-Dorta (2008) - present study	Translog	Unbalanced panel of 161 international airports, 1991-2006	Passengers, Cargo, ATM-equiv. and Commercial rev.	Unexhausted IRS

Source: Jeong (2005).

Regarding airport pricing and optimal charge determination, some of the most important works are Vasigh and Hamzaee (1998), Stanmeyer and Cote (1995), and Lim (1980). Although many past studies have addressed the issue of airport pricing, only a few of them have focused on the monetary estimation of optimal charges for real case studies. Most of the academic research on this subject concerns congestion or runway peak pricing and slot auctions. This includes, for example, Morrison (1987), Morrison and Winston (1989), Gillen et al. (1989), Zhang and Zhang (1997), Oum et al. (2004) and Pels and Verhoef (2004). More recently, Johnson and Savage (2006) provide an analysis of peak pricing in the severely congested ORD. See also Van Dender (2007). Peak pricing theory proposes charging operators the marginal cost of landing on a given runway at a given time, and this has been the prevailing approach since the 1960s, though the experience has been very disappointing (Schank, 2005). Morrison and

Winston (1989) found that optimal airport pricing, even without any infrastructure investment, would generate \$3.82 billion in benefits (1988 dollars). Combined with efficient infrastructure investment, it could generate \$11.01 billion benefits.

Considering more specifically airport cost recovery and marginal cost estimations, useful references include Levine (1969), Carlin and Park (1970), Morrison (1983) or Oum and Zhang (1990). Morrison (1983) showed that, if capacity is divisible and costs are homogeneous in the volume/capacity ratio, then social marginal cost pricing leads to exact cost recovery for airports. The social cost of an aircraft operation is the sum of average private delay cost, the additional delay costs imposed on other aircraft, and the additional cost imposed on the airport authority. Morrison's estimations include various cost functions including maintenance, administration, runway construction, land acquisition, capacity rental, and delay expenditures in order to compute optimal long-run toll costs. He finally estimated the marginal maintenance, operations and administrative costs of airports to be \$12.34 (1976 dollars) per ATM.

Carlin and Park (1970) calculated social marginal runway costs for LGA, focusing on delay costs and peak considerations. Their estimates range between USD 3 for a midnight operation and USD 1,090 for an arrival between 15:00 and 16:00 hrs. Full marginal cost pricing, however, could not be optimal, as it would reduce the operations thereby reducing marginal costs. Recalculated fees might not converge to equilibrium.

Link et al. (2006) make use of an alternative approach to traditional cost function analysis. Focusing on staff costs and using time-series instead of cross-sectional data, they specified a SARMA model to identify a relationship between the number of scheduled person-hours in the service area and the traffic volume measured in ATMs. This study gives some interesting results, such as an estimation of the marginal cost (MC) for an extra ATM of EUR 22.60[25]. However, for international departures this MC ranges between EUR 25 and EUR 72[26]. Nevertheless, regarding numerical estimates, all those previous works were focused on individual case studies, and their conclusions could be hardly generalized to the whole airport industry.

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[25] These figures are comparable to those obtained by Morrison (1983) (€32.97 adjusted for 2000 euros).

[26] When comparing these results with other airports, it has to be borne in mind that the person-hours include all outsourced activities.

CHAPTER 3

SOME METHODOLOGICAL NOTES

3.1 Scope of analysis

At the first stage of any empirical work, the subject under study must be clearly and exactly defined. In the airport industry, the transport provision is generally mixed with all kinds of commercial services and other external effects. Hence, it is necessary to have in mind what kind of activities should be considered in the analysis. This dissertation aims to provide a reliable methodology to estimate optimal airport charges that can be used in the economic justification for airport expansion or for simply improving the allocation of airport infrastructure to the different users. Therefore, on the one hand, it would not seem appropriate to ignore any external effect generated by the operation of an airport. That implies a purely private analysis of the industry which may not fulfill the objectives of this study. On the other hand, the scope of analysis is mainly determined by data availability. This issue is discussed in the present section.

In an airport, there are different categories of activities which are carried out. According to Doganis (1992), services and activities in the airport can be divided into three distinct groups: essential operational services; traffic handling services; and commercial activities. This work proposes a slightly different approach by defining some standard activities for what is called the "transport core" and the "transport perimeter"[1]. The first type of activities includes those involved directly in the transportation of passengers and cargo, and the second one also includes other adjacent but relevant activities in terms of externalities and complementary products. This categorization is important because of the extreme complexity of the airport's operational environment may compromise the homogeneity of collected data.

Data collection is a cumbersome activity for researchers. However, when airports are operated by an AA that provides all services without any outsourcing, this task is simplified because all the relevant information can be obtained from a single financial

[1] This terminology is not arbitrary. The "perimeter" of consolidation incorporates all parent companies into the consolidated accounts of the group. In this context, the parent companies may develop those activities included in the transport "perimeter" of the airport, such as retail, consulting or even real state.

statement. Unfortunately, this is not a very common operating structure for the airports included in the database, whose day-to-day operations require the involvement of a significant number of firms that carry a great part of the airport's operating costs. This is illustrated in Table 3.1, which shows the disaggregation of Hamburg Airport (HAM)'s activities, which is a representative example of the operational structure for an average European airport.

Table 3.1 Disaggregation of activities in Hamburg Airport

Transport core		Transport perimeter	
Administration	*Flughafen Hamburg*	Retail	*CSP*
Air Traffic Control	*Deutsche Flugsicherung*	Real Estate	*Flughafen Hamburg*
A/C Handling	*GroundSTARS, CATS*	Noise/ Externalities	*[?]*
Pax. Handling	*AHS*		
Cargo Handling	*GroundSTARS*		
Maintenance	*GroundSTARS*		
Security / Customs	*Secuserve/Foreign Office*		
Emergency services	*Flughafen Hamburg*		

Source: HAM (2005).

Airport administration is always the responsibility of the Airport Authority (AA). ATC services are usually regulated and operated by national civil aviation authorities which manage every national airport, so comparisons between airports of different countries may be problematic. The same applies to police and customs services, at least for European airports, as these activities are not directly performed by airport employees. Therefore, both these activities were eliminated from the data collection and this meant that many US airports such as the ones included in the New York system (JFK, LGA, EWR) had to be excluded from the database, because of the internalization of police services (Port Authority Police) and the subsequent distortion of labor expenditures[2]. Emergency services can be provided either by the AA or by local/national/federal bodies. Nevertheless, they do not have a significant impact on major airport's expenditures, and therefore collection procedures are not further concerned with them.

Handling and maintenance are usually outsourced, except for limited exceptions such as FRA or AMS. In this case there are two possibilities, i) all major concessionaires are related companies that are included in the consolidation perimeter of the parent company (i.e. the AA). In this case, the consolidated accounts provide a good classification of expenditures, i.e. the payroll and utilities of handling companies will be accounted as labor and material costs, respectively; ii) if the concessionaires are not related companies, the costs of providing handling can be found under the heading "contracted services" which lumps both payroll and utilities expenditures. In addition,

[2] In addition, for security reasons, the number of airport security personnel is usually kept confidential.

obtaining information about the number of employees for all concessionaires may be extremely complicated even for a single airport, and the construction of a proper database could be impossible to attain. Therefore, this work uses a simplified approach and considers all contracted services as materials expenditures, in spite of knowing that a huge amount of labor is also lumped within them. The price of materials will be directly affected by the degree of outsourcing, which can vary considerably among airports. This is a problem that cannot be easily handled, but this approach can be also used to measure approximatively the degree of sustitutability between the airport's own and its outsourced labor, which is of great interest to airport management.

As noted, the transport perimeter includes both commercial activities and all external effects resulting from airport operations, such as noise or pollution. Regarding the first category, retail activities are sometimes performed by a related company whose financial data can be consulted in the consolidated accounts. However, current airport financial reporting standards do not provide the kind of disaggregated information that a researcher needs, and there is no practical way to determine either the retail employees or the incremental costs of non-aviation activities. Therefore, there is no other alternative but to include both retail expenditures and revenues in the cost function specification. This may look like another shortcoming. But, according to Oum et al. (2003), it is necessary to include commercial activities in the output vector because otherwise important demand complementarities between aviation and commercial outputs would be ignored, thus producing biased estimates.

Other "undesirable" airport activities, such as noise production, are not provided by any firm but merely by airport operations. Hence, as no financial record is kept, the consideration of these activities lies beyond the scope of this work, but a simple analysis will be presented in Chapter 9. In conclusion, homogeneity of data would require an "activities" approach as presented in Figure 3.1. However, given the existence of a wide variety of organizational structures, and, in order to ease the process of data collection, this work proposes instead a "firm" approach, i.e. the subject under study will be the transport perimeter of each airport (excluding externalities), as financially recorded in the consolidated accounts of the different AAs, which will be the main source of data for this empirical exercise.

Once this first step is addressed, it is necessary to define all variables the model has to account for. The theoretical background in this cost approach requires the researcher to define, at least, one (set of) output/s, one (set of) input/s and their respective prices.

3.2 Output definition

According to Jara-Díaz (2007), the literature on transport cost functions does not provide a universally accepted form of output treatment, mainly because of an implicit reluctance to try to understand transport technology. The description of a product has usually referred to its qualitative characteristics, defining a physical unit of reference in order to measure production. These two considerations (definition and measurement) are very important when dealing with multiproduct firms because they both determine the number of different outputs to consider in the analysis. Product differentiation only according to qualitative characteristics may lead to an extreme output overspecification if no significant technological heterogeneity is also imposed (e.g. the use of different inputs/technology).

While analysing the possible sources of scope economies, Baumol et al. (1982) implicitly define the relevant output vector as "*n* otherwise independent production processes that are capable of sharing the services of some productive inputs". In this dissertation, the concept of technological independence will be interpreted as follows: all outputs to be considered for empirical research should be somehow differentiated, either in their use of exclusive inputs sets or, if all factors are in common, in their distinctive combination. This certain degree of technological exclusivity gives the output separation its true value. No relevant conclusions in terms of cost complementarity can be drawn from two outputs that share all inputs and technology, because they are actually the same.

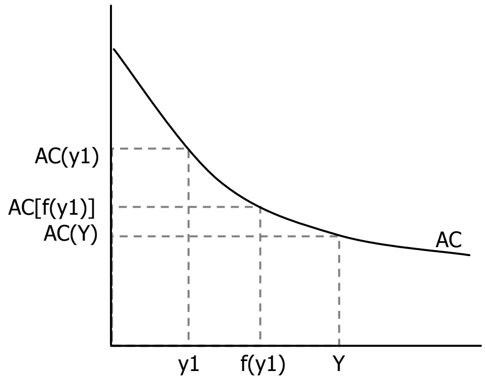
However, it is quite common in transportation-related industries that a wide range of qualitatively-differentiable products do not present relevant technological exclusivities, as they are differentiated only by factors such as size or distance travelled. In order to avoid overspecification of the output vector, the homogenization of qualitative-but-not-technologically-differentiable outputs (from now on "related outputs") depends on the definition of an appropriate physical unit of reference that enables the technological independence in the specified output vector to hold. This is illustrated in Figure 3.1, where the operation of two cargo containers of different sizes (y_1, y_2) is studied. Both production processes can not be considered independent because they are serviced using the same set of inputs (capital and labor) and in the same proportions (1:1). In these cases, this study assumes the existence of an exact relationship between related outputs $y_2=f(y_1)$, which allows us to aggregate them in "base output" units y_1.

Source: Own elaboration.

Figure 3.1 Homogenization of technologically similar outputs

This procedure requires, as noted, a significant knowledge of the underlying technological processes. However, it allows the dimensions of the output vector to be optimized by summarizing all irrelevant cost complementarities (between related outputs) in a single scale result referring to the physical unit that has been chosen to measure aggregated production. This is clearly shown in Figure 3.2. The consideration of the exact relationship between related outputs makes the complementarity turn into subadditivity (i.e. scope turns into scale), allowing an easier analysis of the industry structure and a better presentation of results, i.e.

$$SC(Y)=\frac{C(Y_1)+C(Y_2)-C(Y_1+Y_2)}{C(Y_1+Y_2)}=\frac{C(Y_1)+C(f(Y_1))-C(Y_1+f(Y_1))}{C(Y_1+f(Y_1))}\,.$$



Source: Own elaboration.

Figure 3.2 Scope turns into scale

Airports do not provide transportation directly, but provide all the necessary infrastructures for air traffic. Their multiproduct nature is related to the very different use that aircraft, passengers/baggage and freight make of airport facilities. The existence of exclusive infrastructures related to each of the three above-mentioned users ensures technological independence. Hence, this 3-dimensional output vector (Doganis, 1992) could be considered the starting point to the study of airport cost functions.

3.2.1 Aircraft operations

Air traffic movements (ATMs − also called aircraft operations or runway operations) are generally defined as either a landing or takeoff movement, mostly performed by a commercial carrier but also by general aviation (GA), emergency or military aircraft. In this work, only commercial ATMs will be considered in order to keep data homogeneity, mainly because of the greater involvement of GA in the US airports in comparison with the rest of the world. From the airport's perspective, the output is defined as the provision of infrastructure to the carrier in order to perform such movements. However, the ATM variable, as defined above, implies the aggregation of landings and takeoffs which may not be fully comparable in terms of infrastructure usage. Since landings and takeoffs are usually produced in sequence and jointly charged, this study will only consider the number of landings, redefining the ATM variable to represent a landing-takeoff (LTO) cycle.

In spite of being the airport's characteristic feature, the provision of infrastructure for aircraft operations has not always been defined as the final product of the airport. Pels et al. (2003) consider that the objective of both the carrier and the airport is to maximize passenger throughput. Hence, ATMs were considered as an intermediate good that is consumed in the production of passengers, and efficiency gains can be achieved by increasing load factors. In the same line of reasoning, TRL (2000) suggested the use of airport throughput units (ATUs) that weight WLUs by a load factor measure, which is, again, inversely proportional to the number of ATMs:

$$ATUs = \frac{WLU^2}{ATM} = WLU \times \frac{WLU}{ATM}.$$

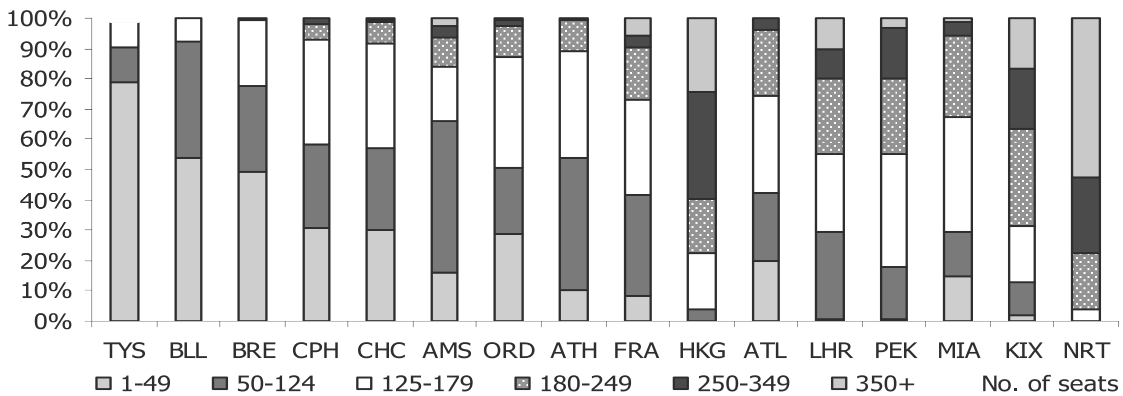
This dissertation, however, considers that these approaches are more suitable to measure efficiency in the air transportation industry (airport + carriers), where passengers can be considered as the basic product. However, regarding the provision of airport infrastructure, the important role of aircraft services cannot be neglected. Increasing load factors depends almost exclusively on the airlines' marketing strategies[3]. And it is also clear that airports do not try to "minimize" their "demand" of aircraft operations that, in turn, generate the majority of their aeronautical revenues. The approach carried out in this work considers that airports simply try to minimize operating costs by adjusting their factor demands to the forecasted ATM and PAX level.

As seen in Table 2.1, only the studies of Keeler (1970) and Oum et al. (2008a) have directly specified ATMs in the cost function, WLUs being preferred by far. The main reason is that the specification of aircraft operations leads to a problem of output separation, as aircraft may be completely different, having a different impact on

[3] However, airports that are more oriented to commercial activities can introduce adequate incentives throughout pricing policies in order maximize profits.

infrastructure damage, and hence on the airport's capital expenditure (Link and Nilsson, 2005). Heavier and larger aircraft require longer, wider and stronger runways and take up more space on the aprons (AIAL, 2006). Taking into account the positive relationship between the size of an airport and the size of the average aircraft that operates in it, the aggregation bias should not be significant for small databases (like the ones used in the past), where all airports were similar in size. However, the database used in the present study features airports of all sizes (as required for a proper estimation of the cost function and the degree of scale[4]), and there thus appears to be a very significant aggregation bias to deal with. Moreover, the introduction of the A380 in a limited set of major airports will make this issue even more relevant in the future.

In other words, the specification of the aggregated number of ATMs without any transformation is implicitly making the very restrictive assumption that the mean aircraft is constant among sample airports (i.e. the aircraft mix[5] is constant). However, this restriction does not hold if the sample airports vary in size and regions, as in our case (Figure 3.3). Aircraft operations at small airports should not be weighted equally as those performed at major hubs where the average aircraft is larger.



Source:IATA, ACI, ATAG (2003).

Figure 3.3 Different aircraft mixes in sample airports (2002)

This work will present some evidence that one of the major consequences of the plain aggregation of ATMs is that the degree of economies of scale is underestimated, because its calculation is based on the misspecification of a homogeneous output for all sample airports. If larger aircraft impose higher costs for the infrastructure and are wrongly specified as homogeneous outputs (i.e. weighted the same as smaller aircraft),

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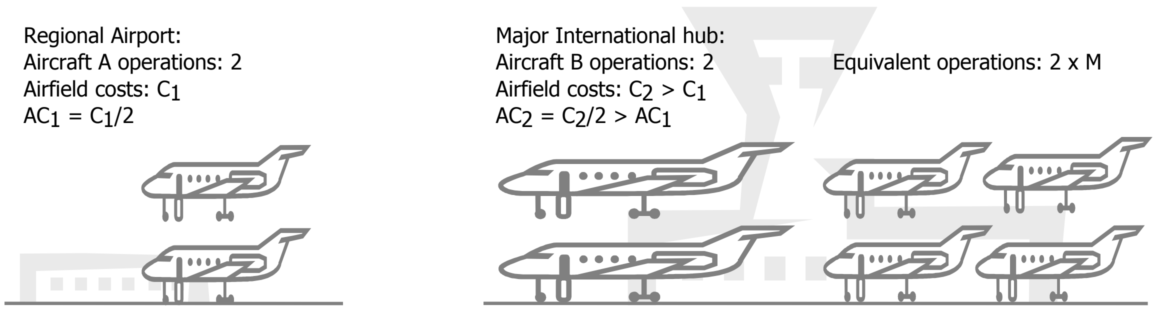
[4] In fact, Baumol et al. (1982) shows that in order to determine whether costs are subadditive at a particular output level, researchers need to have observations of costs incurred by smaller firms.

[5] The airports' "aircraft mix" indicates the proportions of the most important aircraft categories using the airport, and it is crucial for airfield planning. The FAA, for example, has published its own regulations and has financed research regarding the calculation of mix indexes, in order to determine minimum runway requirements and predict ATC congestion (Pfleiderer, 2003).

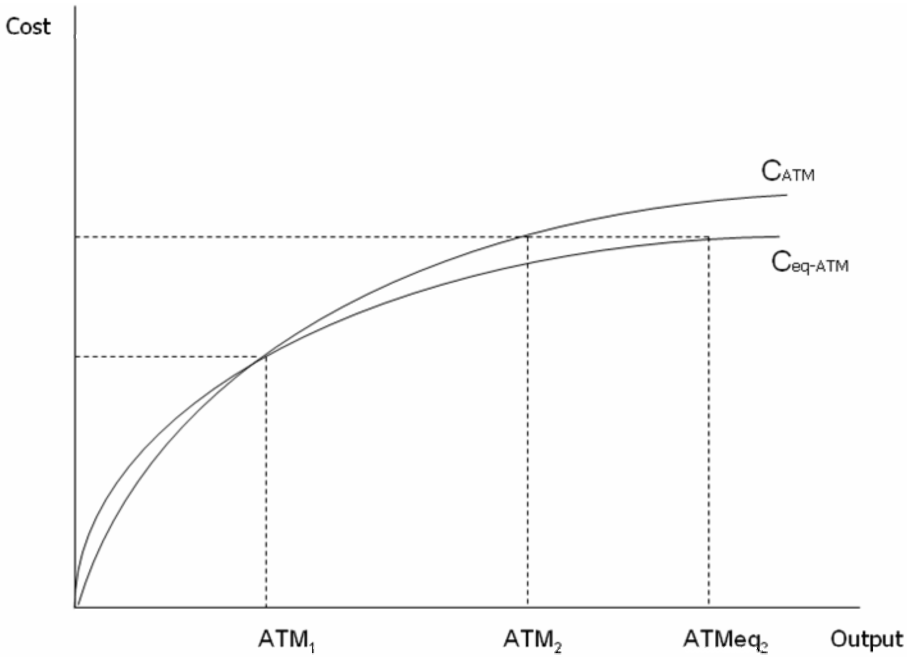
the AC will tend to increase with aircraft/airport size, inducing the presence of DRS in aircraft operations or, at least, underestimating the degree of scale (Figure 3.4). The obvious solution is the standardization of aircraft operations in "base aircraft" units.



Source: Own elaboration.

Figure 3.4 Aircraft mix and scale economies

This is graphically shown in Figure 3.5. C_{ATM} represents an IRS cost function estimated using a plain aggregation of ATMs. Assuming, as mentioned, that aircraft size increases with airport size[6], the homogenization will consider the average aircraft size of the small airport as the "base aircraft". Hence a new cost function is estimated using the "equivalent *ATM*s" variable ($C_{eq\text{-}ATM}$). Note that a higher output expansion could be achieved using the same resources and, for this reason, the parameters of the new cost function should indicate a higher degree of scale economies[7].



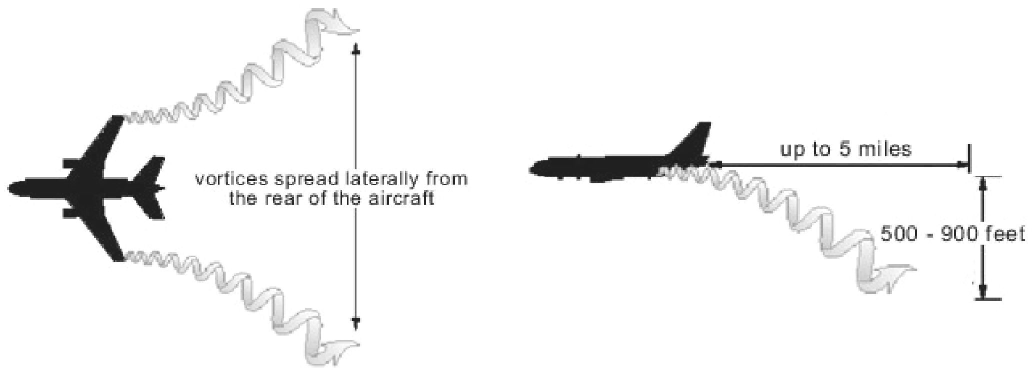
Source: Own elaboration.

Figure 3.5 Underestimation of the degree of scale

[6] In Figure 3.7, it can be seen that this is usually the case for the airport industry.
[7] Choosing the other airport (ATM_2) as reference leads to exactly the same conclusion.

Because of the close relationship between aircraft size and airport development, the latter should not be analyzed as a scale issue but as the combination of the scope economies related to the new aircraft categories that begin service with each capacity expansion. Performing such an exhaustive analysis would require the specification of every known aircraft model as a separate output in the cost function. As of 2007, the number of different aircraft models operating to/from US airports is 353 (BTS, 2007). For that reason, there is need to optimize the dimension of this output vector by assessing the technological relations between related aircraft categories in order to homogeneize them in “base aircraft” units as explained before. The first step is to address the common technological properties related to LTO cycles of different aircraft models. The three LTO stages to be analyzed are: the airspace/ATC; runways/taxiways; and parking/apron areas. Proper scaling factors for related aircraft models will be discussed after establishing the different aircraft categories included in the final ATM vector.

Regarding airspace and ATC, it is difficult to find any technological difference among aircraft categories. The reason is that no single commercial flight can be operated without one of them, and hence their production should not be considered independent[8] with respect to these inputs, although different aircraft will inevitably require different quantities. A safety separation distance between aircraft is always necessary to avoid simultaneous runway occupancy and should be large enough to diminish the risk associated with the wake vortex of the leading aircraft. At the time of determining the amount of airspace needed by a certain aircraft category, it is crucial to understand this physical phenomenon (Figure 3.6.)



Source:www.pilotfriend.com

Figure 3.6 Wingtip vortices

[8] In this study, GA has not been considered and all commercial flights are almost exclusively operated under Instrumental Flight Rules (IFR), where aircraft separation is provided by ATC. In addition, all sample airports have control towers.

The aircraft's lift is generated by the creation of a pressure differential over the wing surfaces. This causes the air to move outwards under the wing and then curl up and over the upper surface, thus starting a wake vortex. As shown in Figure 3.6, the vortices spread laterally away from the aircraft and descend 150 to 275 m (500-900 ft) at distances of up to 8 km (5 miles) behind it, generating a very dangerous environment for the following aircraft. Wake turbulence is especially hazardous during the landing and takeoff phases of flight because the aircraft is operating closest to the ground and there is little margin for recovery in the event of encountering another aircraft's wake turbulence. The intensity or strength of the vortex is primarily a function of aircraft weight, wingspan, and flap setting. The strongest vortices are produced by heavy aircraft flying slowly in a "clean" configuration (no flaps being employed). With the purpose of assessing wake turbulence separation between leading and following aircraft, ICAO has established both landing and takeoff separation minima. These recommendations are based upon wake vortex categories that are, in turn, based upon the Maximum Takeoff Weight (MTOW) of the aircraft. Most recent publications already include the A380[9]. In Table 3.2, the strong relationship between the amount of airspace consumed by the leading aircraft and its MTOW can be seen.

Regarding departures, ICAO regulations are conveniently expressed in terms of time between operations. Generally speaking, an aircraft of a lighter category must not be allowed to takeoff less than 2 minutes behind a heavier aircraft. An additional minute should also be considered after the takeoff of an A380.

Table 3.2 ICAO landing separation minima (nautical miles)

Following Aircraft	Leading Aircraft					
	Light (0-17) C172	Small (18-40) Crj-705	Medium (40-136) A320 - B737	Upper-Medium B757	Heavy (136+) B747	Super Heavy A380
Light	2.5 or 3	4	6	6	8	10
Small	2.5 or 3	3	4	5	6	8
Medium	2.5 or 3	2.5 or 3	3	4	5	8
Upper-Medium	2.5 or 3	2.5 or 3	3	4	5	8
Heavy	2.5 or 3	2.5 or 3	2.5 or 3	2.5 or 3	4	6
Super Heavy	2.5 or 3	2.5 or 3	2.5 or 3	2.5 or 3	2.5 or 3	4

Source: De Neufville and Odoni (2003), Wikipedia.

Nevertheless, the amount of airspace (in terms of the separation imposed on the following aircraft) required for any specific aircraft category could have some influence on the airport-operating opportunity costs, especially in congested airports. Furthermore, the traffic mix has a large impact in determining peak airside capacity (in

9 As of 2007, ICAO arrival separations for the A380 are from 2 to 4 nmi greater than the 747. Airbus is working to prove to ICAO that these figures are too conservative. It is important for the distances to be

terms of movements per hour), and, consequently, MC pricing should reflect this issue. However, this is beyond the scope of the present study because of data availability constraints, and it will be an area of future research.

The next factor in the LTO cycle is the direct use of runway/taxiway areas for landing, taxiing, and takeoff, which implies direct contact with the infrastructure and, for this reason, has a large impact on the airport's capital expenditure. Runways and airside areas are generally designed[10] to accommodate the aircraft considered to be the most demanding (i.e. the critical aircraft) that is anticipated to utilize them. The ICAO and FAA regulations on field length requirements for a given class of aircraft are based on its performance in several specified operations, from completing a normal takeoff to 11m (35ft) to stopping after aborting a takeoff from a height of 15m (50ft). Safety margins (15 to 67 percent) are then added to allow for variation in pilot skills or environmental conditions[11]. When determining the Takeoff distance (TOD), many factors are considered, such as the aircraft's weight (MTOW), the lift forces generated by the wings, or the thrust of the turbines. Using the aircraft database of Annex 2, it should be concluded that there is a high correlation between aircraft size (MTOW and wingspan) and the required TOD, but the latter tends to increase less than proportionally.

The independence in the provision of movement areas for different aircraft depends on how the extra length of runways/taxiways required by heavier categories is interpreted. It could be taken either as a different input, which is exclusive to larger airliners or simply as a higher quantity of the same common factor. An argument in support of the second alternative is that airside infrastructures are commonly planned and built in excess of capacity in order to accommodate the (optimistic) forecasted traffic levels. These traffic increases are closely related to the evolution of the average aircraft size, as shown in Figure 3.7. The number of aircraft operations at the 38 all-size airports of the American sample (see Chapter 4) is classified in four weight categories (CAT1 to CAT4) using the information provided by BTS (2007).

The service of very large aircraft (CAT4) is always "supported" by higher levels of smaller aircraft traffic, and hence diversity increases with airport size. In addition, using the same database, average aircraft size was found to increase steadily with the scale of

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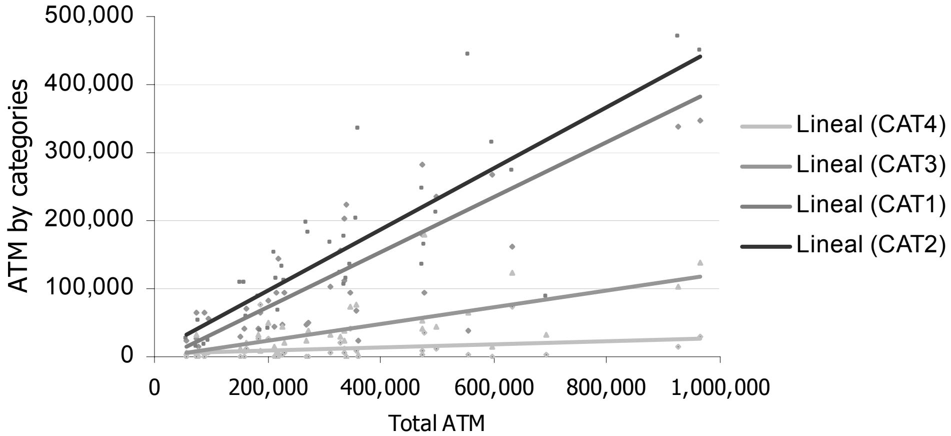
revised downwards before the A380 enters in service at severely congested airports such as LHR.

[10] This analysis is focused on the runways, and it is assumed that other movement areas are properly sized with respect to them.

[11] The demonstrations take place under standard conditions of airfield altitude and temperature.

production. The interpretation of these results is as follows: airports have developed through a continuum of aircraft dimensions, and hence airside capacity is gradually adapted to larger aircraft. Therefore, no critical investments are needed for servicing a single aircraft model because its technical upgrades can be considered as being differential from the previous one. Under this approach, there is no way to justify the existence of a technological breakpoint in the aircraft continuum[12], and hence the provision of runways and movement areas for a wide range of aircraft categories can not be considered as independent production processes. In fact, in the US these movement areas are fully shared by all aircraft types, in extreme cases even by GA.



Source: Own elaboration.

Note: CAT = Category

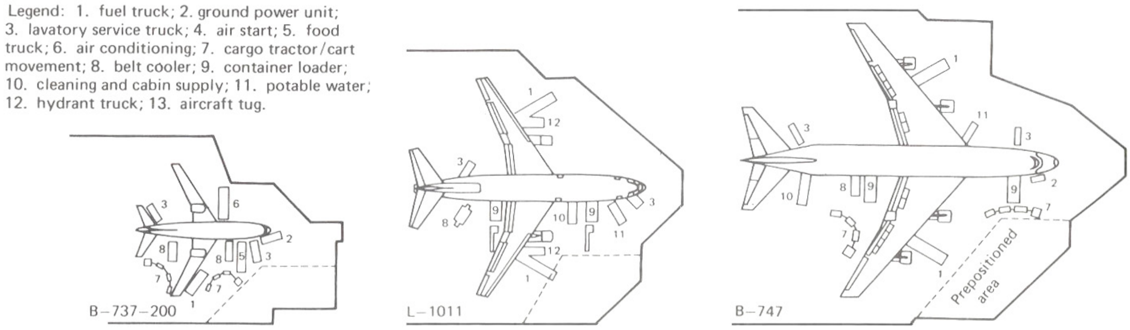
Figure 3.7 Aircraft mix vs. ATM

However, this reasoning may be questioned if the A380 is considered[13], but the A380 user manual (Airbus, 2005) indicates that its runway length requirements are not significantly different from other very large airliners. Much has been said about the widening of the runway to 60 or 75m but recently the A380 has been allowed to operate on 45m runways without restrictions and on the straight sections of standard 22.50m taxiways (Airbus, 2007). In addition, the A380 will only be operating from a selected set of major international hubs which already serve the B747 and similar models. Therefore, there is apparently no reason to establish a technological breakpoint in the provision of runways and movement areas for the A380, which, moreover, would not be properly justified by a single aircraft model with, for the moment, residual traffic.

The last element to consider is the use of paved areas for the basic handling operations, such as fueling, cleaning and the loading and unloading of passengers and cargo. If this

[12] The absence of specialized widebody airports gives support to this interpretation. A direct calculation of the degree of scope economies in the joint service of wide- and narrow bodies is therefore not possible.
[13] There are no A380 observations in the database.

area is located adjacent to the terminal, it is known as the apron, which is divided in individual "stands" or "contact positions". Their design depends heavily on the physical characteristics of both the aircraft and ground service equipment (Figure 3.8). Container loaders and aircraft tugs differ between narrow and widebody aircraft. As an example, a new taller catering truck had to be developed to deal with the A380's height. However, these little differences do not count as a technological change, because they represent the same input used in a higher quantity. In this line of reasoning, the decision to develop a more powerful tow truck for the A380 instead of using two standard widebody trucks simultaneously could be interpreted in terms of operational efficiency, i.e. the same towing service is provided more efficiently with an exclusive vehicle.



Source:Ashford and Wright (1992).

Figure 3.8 Aircraft apron requirements

Another important difference between airports concerns to the fueling facilities. Major hubs usually provide fueling pipes beneath the apron that are connected to a central fuel storage. In contrast, the conventional system at small airports is by fueling trucks. Regarding passenger access to/from the landside, both contact and remote procedures are offered. Remote positions are reached by bus and by using mobile staircases, which is characteristic of small regional airports that only service small aircraft.

The boarding of passengers at contact positions is usually made through jetways/airbridges. With a few exceptions, they are attached at one end to the terminal building and have the ability to swing left or right. The cab, located at the end, can be raised or lowered, extended or retracted, and may even pivot, in order to accommodate aircraft of different sizes[14]. As in the previous case, both refueling and boarding services are considered to be essentially the same for all aircraft categories, and only differ in the required quantity. The fact that they are provided in several different ways only reflects each airport's own solutions. They will be tested in terms of efficiency under the

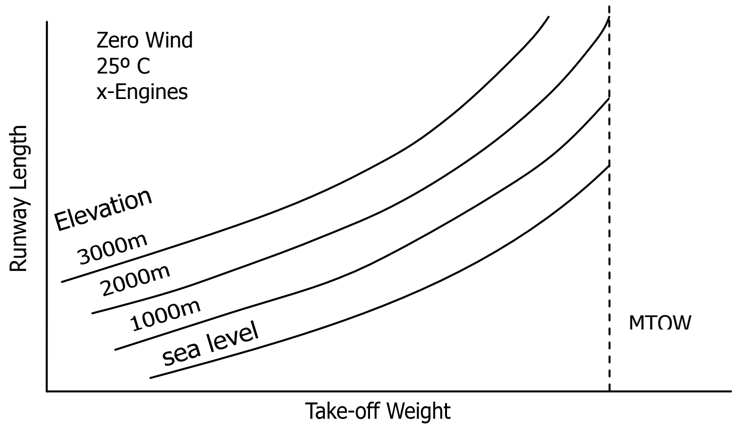
[14] For the operation of the A380 at FRA, Lufthansa has announced that three jetways will be provided for simultaneous boarding.

assumption that the cost function indicates the best practices for each scale of production.

In summary, no significant technological exclusivities were found among the aircraft vector as their production is closely related. Hence, aircraft operations are *defined* as a single output, discarding any presence of cost complementarities and scope economies in favor of a single scale effect. Thus the main issue remains to propose a base output unit and a valid scale factor to *measure* the output level. This is clearly seen in Figure 3.4, where aircraft B operating exclusively at the international hub is weighted by an M-index using A as the base aircraft.

As aircraft are differentiated by their impacts on costs, a first alternative could be to define the base aircraft by its average cost (if available), and to calculate the number of other aircraft-equivalent operations according to cost proportions. (i.e. $M = AC_2/AC_1$). Therefore, if aircraft B at the bigger airport imposes (on average) three times more costs than aircraft A at the regional airport, it seems reasonable that it should be weighted by three in the database. However, this procedure imposes CRS in aircraft operations, as AC remains constant for all ATMs in the sample, which is not exactly the final objective of this work. The use of this engineering approach does not allow scale effects to be identified and depends on the characteristics of the individual airports. For this reason, this method has not been applied here, and the procedure to obtain the 'equivalent traffic' movements will be based on the different use of runways which is imposed by the technical characteristics of the aircraft.

As noted, the LTO cycle is quite complex and involves many different infrastructures, and developing a single measure of airside usage for each known aircraft category[15] is not the main objective of this dissertation. Therefore, runway usage will be used as a simple proxy for airside usage in order to obtain the number of equivalent traffic movements. In a very interesting paper, Littlechild and Thompson (1977) estimate a Runway User Index for very different aircraft types. Discussion with the chief BAA engineer suggested that the most important cost drivers related to both capital and maintenance of runways were takeoff distance, runway pressure and manoeuvrability, which were standardised and weighted in the proportion 5:2:1. Without further engineering assessment, an intuitive and oversimplified approach to solve the problem would be to assume that runway usage increases linearly with takeoff distance. For example, if the average aircraft A requires 1500 m. of runway to take off and the average aircraft B requires 3000 m., then the standardization of data to ATM_{eq} would require weighting by 2 every ATM_B (if "base movement" is defined as ATM_A)[16]. Nevertheless, takeoff distances (TODs) are not independent of the airport's geographical location, because air density decreases with increasing temperature and altitude[17], hence affecting the amount of lift generated by the wings and requiring longer takeoff runs. Figure 3.2 shows a typical runway length diagram provided by the aircraft manufacturer, in which it can be clearly seen that environmental variables play a key role in determining the TOD. As a matter of fact, there is no single TOD for any aircraft, and, most important, it is not comparable among airports. Hence, it is not a suitable variable to define a "base aircraft".



Source:B737's manual.

Figure 3.9 Takeoff runway requirements

However, a second look at Figure 3.9 reveals the existence of at least one characteristic that is not subject to change, i.e. the Maximum Takeoff Weight (MTOW) of the aircraft, which is always fixed by design. The MTOW is defined as the heaviest weight at which the pilot is allowed to attempt takeoff under any conditions. It does not vary either with altitude or air temperature, and therefore is fully comparable among airports. This fact explains the specification of this variable in practically every landing charge schedule around the world. In addition, the aircraft's MTOW encompasses the information contained in the three above-mentioned cost drivers, as heavier airliners will always use more runway distance at higher pressures and, additionally, will require more apron space for manoeuvring. Using the aircraft database of Annex 2, the correlations of both wingspan (proxy for manoeuvrability) and TOD with the weight variable were found to be 95.13 percent and 82.53 percent, respectively.

[15] Such a valuable study would deserve special attention in international forums such as IATA or ICAO.
[16] Conversely, if base movement is defined at B, all operations at A should be weighted by ½.
[17] Airports located in warm climates and high altitudes are called "hot and high" airports. An example is DEN, which features the longest commercial runway in the US in order to allow longer takeoff runs.

Once MTOW has been selected as the weight variable, a functional form needs to be proposed in order to calculate ATM_{eq}. Three different approaches will be discussed. As noted, MTOW grows more than proportionally to TOD. Therefore, taking into account the aforementioned runway usage proportions, a decreasing approach in MTOW seems, at first sight, to be the most appropriate method for scaling aircraft. The only empirical evidence that can be provided about this topic might also support this alternative. Using the database of BTS (2007) and the 38 airports in the American sample, a very simple Cobb-Douglas cost function has been estimated, using a disaggregated output vector of ATMs in four weight categories. The results are shown in Table 3.3 (R^2 is 0.851).

The output cost elasticities obtained from this vector of parameter estimates provide four different marginal cost estimations, which are used to obtain the average marginal cost per metric ton, as shown in Table 3.4. These results indicate that additional metric tons in larger aircraft impose significantly lower costs on the infrastructure than the previous ones, and hence, any appropriate runway charging schedule should feature decreasing unit rates per metric ton MTOW.

Table 3.3 Disaggregated specification of aircraft operations

	Coefficient	Std. error	t-Statistic	Prob
constant	11.97518	0.015323	781.4924	0.0000
wc	0.444364	0.036170	12.28556	0.0000
wm	0.296130	0.030866	9.593886	0.0000
wp	0.273263	0.039369	6.941055	0.0000
CAT1	0.074727	0.008649	8.640159	0.0000
CAT2	0.383004	0.024442	15.66975	0.0000
CAT3	0.098201	0.023746	4.135504	0.0000
CAT4	0.003594	0.005973	0.601692	0.5476

Table 3.4 Marginal costs and unit rates per aircraft category

	Average MTOW	Marginal Cost	Unit Rate
CAT1	22.60	239.58	10.60
CAT2	62.73	509.97	8.13
CAT3	119.32	528.10	4.43
CAT4	218.37	406.95	1.86

However, this approach is applied only by a few airports around the world, e.g. OSL. Many other airports (e.g. in Italy and Spain) charge increasing unit rates to heavier aircraft. According to Graham (2003), this pricing policy is explained by the higher “ability to pay” of large carriers. Notwithstanding this, airports may be considering many other external factors such as noise/emissions or congestion issues that lie for the moment beyond the scope of this study. Given these two conflicting approaches, the true technological relationship between MC and MTOW will be left as unknown, and hence this dissertation applies a linear approach in MTOW, which, in fact, is the most widely applied throughout the world, including at the US and Australian airports. This allows us to avoid further nonlinearities in the calculation of the scale factor and makes the selection of the base aircraft a trivial issue.

Under the proposed approach, the total number of ATMs (landings) will be scaled by the proportion of the airport's average landed MTOW with respect to the base aircraft's MTOW. In most cases, the airport's average aircraft can be calculated from the information of the airport's aircraft mix, and hence the scale factor will be known as the "aircraft mix index" (M). In order to simplify the calculations, two of the most successful commercial airliners[18] were chosen as the base aircraft, the Boeing 737-400 and the McDonnell-Douglas MD80 series, both with an MTOW of 68 metric tons:

$$M = \frac{Landed\ Tonnes}{Landings}\frac{1}{68}.$$

The calculation of the aircraft mix index is done in two steps. First, the "airport average MTOW" is estimated by dividing the total landed tonnage by half the number of commercial ATMs (no. of landings). Next, this value is divided by 68 in order to obtain the aircraft mix index. A value higher than 1 indicates that the airport is serving aircraft on average heavier than the B737. Therefore, the total number of ATMs needs to be multiplied by M in order to find the "737-equivalent" movements[19] (ATM_{737}), which will be specified in the cost function as comparable outputs. Ultimately, the model will provide airport-specific estimations of the marginal cost of an ATM_{737} (= optimal runway charges) which could be either converted, under the linear assumption, back to any other aircraft model using weight proportions or dividing by 68 in order to obtain the optimal unit rates per metric ton MTOW. As shown in Appendix 3A, this structure agrees with the theoretical properties for the definition of output aggregates described by Jara-Díaz and Cortés (1996). However, this procedure is far from being perfect and is only intended to serve as a first approximation for the implementation of scale factors/aircraft mix indexes in this kind of study.

3.2.2 Passengers, cargo, and commercial revenues

The second output to be included in the cost function is the provision of infrastructure for *passengers and baggage* (PAX). Passengers usually consume inputs more related to the airport's landside, and there are some specific facilities that are only used by passengers and not by aircraft. At first sight, one might think that the optimal treatment

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[18] According to Boeing, the 737 is now so widely used that, at any given time, there are over 1,250 airborne worldwide, and somewhere a 737 takes off or lands every 5 seconds.

[19] This terminology is based on the standard output definition in the seaport industry: the twenty-foot *equivalent* unit (TEU). Thus, forty-foot containers are measured as 2 TEUs.

of airport cost structures would require a separate specification of both ATM and PAX partial cost functions. However, airports do not usually provide cost data disaggregated by facilities, and, most important, this approach would assume total cost independence in outputs, which is very hard to believe since they are jointly produced. Hence, the multiproduct specification seems to be the only feasible and reasonable approach to describe airport technology as imposed by microeconomic theory.

Nevertheless, the inclusion of these two variables creates a challenge regarding the basic econometrical assumptions: namely, the absence of a strong linear correlation between the explanatory variables *(w,Y).* The positive relationship between aircraft and passenger operations imposes some degree of multicollinearity in the model. Using the present database, the linear correlation between ATM_{737} and PAX was calculated as 96.67 percent. The main consequence of this near multicollinearity, as explained in any elemental econometrics manual is that estimators are optimal and unbiased but not efficient (i.e. the standard errors of the affected coefficients tend to be large), and therefore confidence intervals are increased and the model significance is reduced (Greene, 2003). In addition, the estimated coefficients are very sensitive to small changes in the data or to changes in specification. In spite of that, multicollinearity does not affect either the model fitting or the reliability of the forecast. Dropping one of the variables produces a loss of information and biased coefficients for the remaining explanatory variables. Therefore, this work keeps the multiproduct specification and assumes the presence of multicollinearity, though it also tries to minimize its impact by increasing the sample size (i.e. by obtaining more data), which can produce more precise parameter estimates[20]. Bearing that in mind, the present database was elaborated making a substantial effort of data collection and featuring 1069 observations of 161 international airports in order to provide enough variability and improve results. Further details of the database will be presented in Chapter 4.

Regarding the passengers variable, the problem of output disaggregation and heterogeneity is again present. Different passengers impose very different costs on the infrastructure and therefore the total number of PAX should be disaggregated according to terminal usage considerations. In addition, data on arriving, departing, and transit passengers is not very difficult to obtain. But the problem is that these figures are not fully comparable among airports, because security regulations (which are country-

[20] The variance of an estimator is inversely proportional to the number of observations.

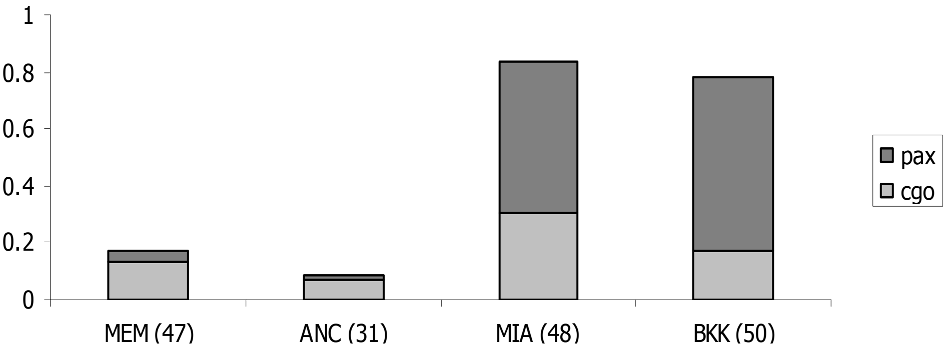
specific) and the terminal design (which is airport-specific) may affect the use of inputs that airports need to provide to each category of passenger. As a matter of fact, homogenization of PAX is much more complicated than in the ATM case, and therefore, a method to obtain “equivalent” passengers is not pursued in this work. Thus, marginal costs estimations for the PAX variable are expected to serve only as proxy first prices for each airport’s “average passenger”. The full schedule of optimal passenger charges might then be obtained by a detailed study of the airport’s flow diagrams, but this point lies for the moment beyond the scope of this work.

Freight and mail operations are the third output considered in the provision of infrastructure, the unit of observation being the metric ton (1,000 kg). Cargo operations are performed exclusively in the airport’s landside, and comprise the processing of both air and ground freight. However, this last item is only considered when the airport provides its own infrastructure for ground freight operations, hence serving as a logistic platform (e.g. SZG), and therefore assuming part of the processing costs. In cargo airports, major freight carriers operate their own on-site facilities. In these cases, ground transport tonnage should not be counted as an airport’s output.

Previous works on airport cost functions have not differentiated cargo activities from those activities related to passengers. In fact, in the best scenario, cargo has been aggregated with passengers using the variable work load units (WLUs), but freight handling is an activity that belongs to the core of airlines and, as we shall see, it has a different impact than that of passengers on the airport’s costs. Under the WLU approach, it is assumed that 100 kg of freight produce the same costs as one passenger. Taking this as true, then the operational costs of major cargo airports should be similar to other commercial airports with the same level of WLUs but more focused on passenger transportation. Figure 3.10 shows four comparable airports in terms of millions of WLUs serviced (indicated in parentheses). Bar height indicates the cost index, and the different shadings indicate the proportion of each output that has been serviced in each of the airports. It can be seen that the busiest airport in the world for cargo traffic (MEM) produced about 47 million WLUs in 2005 (of which 76 percent were cargo units). MIA presents a similar level of WLU activity, but the importance of cargo is lower (only 36 percent). The significant difference in costs between MEM and MIA provides the economic justification to disaggregate WLUs[21] into cargo and

[21] The linear correlation between cargo and the other output variables was calculated, and the value is around 54 percent.

passenger variables. As noted, the main intuition behind this concerns the higher involvement of cargo firms in the processing of parcels, by providing their own infrastructures. These costs are not imputable to the AA and hence should not be accounted for in order to calculate optimal airport prices. On the other hand, the provision of terminal space for passenger and baggage processing is almost exclusively provided directly by the airport or a related company/concessionaire. Therefore, PAX and CGO are not directly comparable, and, since they do not use the same inputs (i.e. they can be considered independent production processes), the use of a scaling factor for aggregation is not advised[22].



Source: Own elaboration.

Figure 3.10 Comparison between cargo and passenger airports

On the basis of the evidence provided by Figure 3.10 above, it should be concluded that the specification of WLUs as done in the past literature inevitably leads to a distortion of the cost frontier and hence of the efficiency estimates[23]. Besides, marginal cost pricing may produce cross-subsidization of passenger charges by cargo activities.

The last output included is the provision of infrastructure for *commercial activities* such as retail, food and beverages, parking, real estate, and many others. The unit of observation was defined as thousands of PPP USD (2006) of non-aviation revenues. As noted, financial reporting standards and cost complementarities neither allow nor advise input separation of non-aviation activities. Therefore, they should be included in order not to bias the other parameters. Otherwise marginal cost pricing for aeronautical activities may result in a significant overcharging. This is shown in Table 3.5, where the cost elasticities of the specified output vector at the average airport (i.e. the first-order output coefficients) are estimated using two different output vectors. The results of the actual model[24] are compared with those obtained when commercial revenues are

[22] In this case, we have an opposite situation to the one presented for ATMs.
[23] In this example, MEM would always be more efficient than MIA or BKK as it produces the same output with a much lower expenditure.
[24] Both estimations were made in the same conditions described for the Table 5.2.

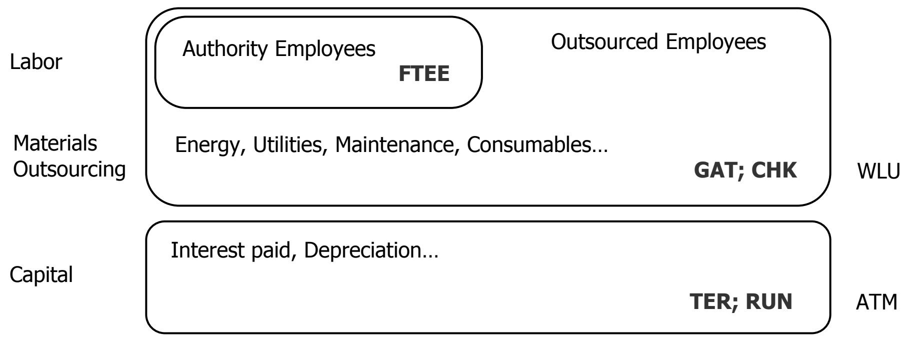
removed from the specification and thus only the aeronatical outputs remain. The parameter bias is clear, but it seems to be localized almost exclusively in the passenger variable. This makes total sense as both passenger and retail facilities are provided in the same place: the terminal building. Taking into account the direct relationship between the marginal cost and the output cost elasticity (see Chapter 8), if the commercial output is removed, the marginal cost associated to the passenger service would be overestimated, on average, by about 15 percent[25]. The reason is that the costs associated with the retail activities are lumped within it.

Table 3.5 Output cost elasticities at the average airport under different specifications

Outputs	Only aeronautical	Actual model
atm	0.10756	0.10614
pax	0.35056	0.30430
cgo	0.08283	0.07477
rev	-	0.05290

3.3 Input prices

The calculation of input prices is perhaps the most delicate part of the methodological process. Airport operations require a huge amount of different inputs, which first need to be categorized in order to serve as explanatory variables in a reasonable cost specification. This work follows the categorization presented in Doganis (1992) which identifies three major input/cost categories: namely, labor; materials/outsourcing; and capital. As each item is defined to represent a heterogeneous set of inputs, input prices are obtained by dividing the respective costs by quantity indexes, which will be constructed with the intention of correlating them with the aggregated input demands. The proposed model is represented in Figure 3.11.



Source: Own elaboration.

Note: GAT = boarding gates; CHK = check-in desks; TER = terminal surface; RUN = total runway length.

Figure 3.11 Proposed model for input price calculation

Labor costs include both payroll and retirement/health benefits. They are the most important single cost element, mainly because handling activities are particularly labor

[25] [0.35056 / 0.30430] = 1.1520

intensive. However, these activities are commonly outsourced, and, hence, a great amount of labor costs is typically recorded by the AA under "materials and OS services". As there is no practical way of determining either the number of outsourced employees or their payroll, the best estimation of an airport's labor price is obtained by dividing the recorded labor costs by the number of full-time equivalent employees (FTEE) of the AA. Note that labor prices will be affected either by each country's labor policies or by the labor union strength. In some cases, allocative inefficiencies could appear between the airport's own and OS labor (counted as materials).

Because of the scarcity of information, the calculation of both capital and materials prices have been considered a very delicate issue in the past literature, and no satisfactory solution has been proposed to date. In other works, prices were obtained by dividing the respective expenditures by an output measure, but this is widely regarded as a very imprecise method. In this work, a slightly more elaborate approach is carried out, which does not intend to be perfect but, at least, is theoretically consistent under common economic restrictions. Assuming that airports operate in competitive input markets, a well-known microeconomic result assesses that optimal input prices (profit maximizing) are given by the following expression:

$$w_j^* = P \cdot MP_j \qquad \text{where } MP_j = \partial Q \,/ x_j \qquad Q\,(x_1,\ldots,x_J)\,.$$

Therefore, optimal input prices are equal to the value of the marginal product *(MP)* for each input that is obtained by multiplying the *MP* by the output price (P_i). The next step is defining a set of proxy factors whose demand should directly explain the aggregated factor expenditure. Hence, using two inputs:

$$C_j^* = w_1^* x_1 + w_2^* x_2 = P \cdot MP_1 \cdot x_1 + P \cdot MP_2 \cdot x_2\,.$$

Then each input's marginal productivities are roughly estimated using a simple extension of a Cobb-Douglas specification of some output production frontier that needs to be highly related to the inputs included in the cost category that we are analysing, i.e.

$$Q = A x_1^b x_2^c \quad \Leftrightarrow \quad \ln Q = \ln A + b \ln x_1 + c \ln x_2$$
$$MP_j = (\partial \ln Q \,/ \partial \ln x_1) \cdot (Q \,/ x_j)$$
$$MP_2 / MP_1 = \alpha.$$

And, finally, the input price is obtained as follows:

$$C_j^* = P \cdot MP_1 \cdot (x_1 + \alpha \cdot x_2) = w_1^* (I_q)$$
$$w_1^* = C_j^* / I_q$$

Therefore, the quantity index is calculated in order to synthesize all information in a single price. Unlike the common practice of using price information to construct input aggregates (see, e.g., Caves et al., 1982), the quantities of the proxy factors are weighted according their marginal productivities (α) in order to convert them into base factor units (e.g. input 1). The more and uncorrelated proxy factors that are considered, the more precise the estimated equation will be, and therefore better estimations of marginal productivities can be obtained.

As mentioned, the category "Materials and OS Work" includes water and energy supplies, maintenance, repair and administration costs[26]. As indicated in Figure 3.11, the proxy inputs considered for the calculation of the price of materials were both the number of boarding gates[27] (GAT) and the number of check-in desks (CHK). These variables were chosen primarily because of their availability and because they were considered to be highly correlated with the airport's overall demand for energy, utilities, maintenance and OS. The reason is that every WLU served by the airport is processed by either or both of these factors. Therefore, marginal productivities were calculated with respect to this aggregated output variable. The estimated equation was:

$$Ln(WLU) = 10.66 + 1.24*Ln(GAT) + 0.40*Ln(CHK) - 0.055*[Ln(GAT)]^2 + 0.025*TIME \; ; \; R^2 = 0.87.$$

Only the statistically significant (95 percent) coefficients were left. Note that significant economies of scale for a wide range of production are present. The time parameter was included to identify the influence of technological progress in the productivity. The presence of a second degree term allows us to obtain marginal productivities and factor weights (α) which are airport-specific.

Capital costs encompass interest paid and the economic depreciation of the airport's fixed capital assets, such as landside buildings or the airside movement areas. Interest paid is said to represent the opportunity cost related mainly to unused capacity (Doganis, 1992). Therefore, these amounts will hardly belong to the cost frontier[28]. The second component is much more interesting. According to common accounting practices, fixed assets are written off by a value that represents the true economic depreciation (loss of useful life). However, for simplicity, amortization is charged on a linear basis over the acquisition cost, valued either on a historical or a current basis, plus any other (financial) costs directly attached to the acquisition. The fact that, for the sake of simplicity, they are recorded as fixed annual amounts does not mean that the actual

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[26] This cost category depends heavily on the intensity of outsourcing practices and the type of concession contracts conditions (full cost or net cost).
[27] In this case both contact and remote gates were included.

capital consumption is fixed, but it is, however, strongly related to the output level. Once the new capacity is built and enters into service, the amortization should be charged accordingly to the wear and tear strictly caused by the airport users, and hence these capital costs are as variable as any other cost category. Therefore, the collection of depreciation data directly from the airport's financial statements (intended to represent accurately the capital costs) is limited by the standard accounting practices, which might lead the researcher to carry out a short-run approach without further discussion.

As noted, the amount of depreciation charged on an infrastructure depends heavily on the valuation approach. According to Jeong (2005) and Doganis (1992), it is a major challenge to accurately value capital inputs and to collect consistent and comparable information on capital expenditures[29] because: 1) investments over many years may be "hidden" in the published figures; 2) facilities at airports may be built and operated by airlines or other enterprises (this fact is observed in some American airports); 3) some financing sources may not appear in the accounts, especially governmental aid, whose related assets may not be charged at a depreciation cost; 4) taxation and interest rates are also heterogeneous; and 5) there is no standard methodology for the quantification of opportunity costs. Book values are very different from economic value, and interest payments do not represent opportunity costs (Oum and Waters, 1996).

Once all these shortcomings have been admitted [30], the calculation of capital prices was made in a similar fashion to the previous input. The proxy variables were the total gross floor area of terminal buildings (TER) and the total commercial runway length (RUN), excluding general aviation runways where possible. In addition, the total warehouse space provided by the airport authority (WAR) was also considered, but finally removed because of the lack of significance. All these variables were chosen because they were considered to reasonably represent the airport's overall demand for capital. Marginal productivities were calculated against the ATM variable (expressed in 737-equivalent movements) because this output is specially capital intensive. The estimated equation is:

$$Ln(ATM) = -12.83 + 2.67*Ln(RUN) + 0.88*Ln(TER) - 0.12*[Ln(RUN)]^2 + 0.04*TIME - 0.007*TIME^2 \; ; \; R^2=0.86.$$

[28] Except at the very smallest production scales, where unused capacity is always present, this work considers that the efficient input demands featured in the cost function do not include unused capacity.

[29] According to Oum and Waters (1996), many researchers rely too heavily on firms' accounting data and financial reports, which are designed to save taxes and for public relations.

[30] Another alternative to avoid dealing with capital costs is to define the short-run total cost function (SRTC), given a fixed (or quasi-fixed) capital stock, and use it to derive the long-run cost function (LRTC) by minimizing the SRTC with respect to the fixed factor (Oum and Zhang, 1991). Caves et al. (1981) can be consulted for an applied case study.

As in the materials case, the function presents significant IRS for a wide range of production and the time parameter indicates that technological progress is also present.

3.4 Estimation issues

As mentioned earlier (See Chapter 2), the cost parameters will be estimated as a system of equations which include, i) the cost frontier; ii) the factor share equations; iii) those regularity restrictions imposed on the parameters; and also iv) the distributional assumptions for the technical inefficiency component of the disturbance term. This type of model is not generally supported by commercial econometric packages. The present work relies on Bayesian Methods which take parameter uncertainty into account to derive the efficiency posterior density, as economic considerations guide researchers in forming their prior ideas, but they do not provide the exact functional form of the desired parameters (Van der Broeck et al., 1994). As the model complexities make numerical methods inevitable, this work describes and applies Markov Chain Monte Carlo (MCMC) methods using an easy-to-use and freely available software, called WinBUGS (Lunn et al., 2000). According to Griffin and Steel (2007), it is a very powerful and extremely flexible tool, which allows the modeler to build any imaginable model without having to invest a lot of time coding up.

Regarding the Bayesian structure of the model, this work uses the codification proposed in Griffin and Steel (2007), which is adapted to the present case study and to the specification of Kumbhakar (1997) including allocative effects. The dependent variable (the log of the total or variable costs) is supposed to be normally distributed, with a standard translog specification as the mean and σ_v^2 as the variance representing the white noise. The parameter of technical inefficiency is allowed to vary systematically over time (Battese and Coelli, 1992), but also allows firm-specific time parameters (Cuesta, 2000). Therefore u_{it} represents the inefficiency of firm *i* at time *t*.

Focusing now on the US airport industry, neither the Battese nor the Cuesta formulation seem to be the most appropriate model to study how technical efficiency has evolved over time for the period between 2000 and 2006 because of the effect of the 9/11 traffic shock, which is more likely to impose a U-shaped evolution rather than a linear one. In these cases, González et al. (2008) propose a “back-door” approach which consists of labelling the pre-shock observations as different firms, because the traffic shock has had a major impact on US airports’ operations, such that the same firm must be considered as an independent decision-making unit before and after 9/11.

The firm-specific average technical inefficiency u_i is assumed to be exponentially distributed with mean λ^{-1}, and a negative η_i indicates increasing efficiency over time of the firm *i*. The choice of an exponential distribution for u_i among other alternatives will be further discussed in Chapter 7 using the deviance information criterion (DIC) as presented in Spiegelhalter et al. (2002).

$$\ln C_i^a \sim N(\ln C_i^o + \ln C_i^{al} + u_{it}, \sigma_v^2) \qquad u_{it} \sim \exp\{\eta_i(t-T)\}u_i, \quad \text{where } u_i \sim \exp(\lambda).$$

Prior distributions are assigned to the parameters, such as the multivariate normal with mean zero to the vector of regressors *β*, a gamma distribution (a0,a1) for the white noise precision (σ_v^{-2}), and another exponential for the λ parameter which allows us to impose our prior ideas about mean efficiency (r^*) in the airport industry. Allocative distortions ξ were specified as normal variables with zero mean representing the prior notion that average allocative inefficiency (AI) is likely to be small (Kumbhakar and Tsionas, 2005a) and a known variance representing the reasonable spread within allocative distortions may appear in the airport industry. The presence of $ln(G_i)$ (see Chapter 2) in the specification of C^{al} requires the use of very tight priors for ξ_j in order not to sample negative values for G_i, which may interrupt the iteration process. The prior distribution of η_i was also chosen to be a zero mean normal distribution representing the prior indifference between increasing and decreasing efficiency. Finally, firm-specific efficiency estimates (r_i) were calculated as functions of the inefficiency terms. The justification for all prior values will be given in Chapter 5 when explaining the model.

$$\beta \sim N(0,\Sigma) \qquad \sigma_v^{-2} \sim G(a0,a1) \qquad \lambda \sim \exp(-\log r^*)$$

$$\xi_j \sim N(0,\sigma_\xi^2) \qquad \eta_i \sim N(0,\sigma_\eta^2) \qquad r_{it} = \exp(-u_{it})$$

Factor share equations and linear restrictions are specified in a similar fashion as the cost frontier (see full code in Appendix 5B), being also normally distributed and assuming (as SURE does) that their errors are likely to be highly correlated[31]. As Bayesian estimators benefit from the addition of all available information to the system, all J factor share equations were included[32]:

$$S_j^a \sim N(S_j^o + \lambda_j, \sigma_v^2) \qquad j = 1, \ldots, J.$$

[31] Technical inefficiency does not affect factor shares, since all inputs are used excessively in the same proportion.
[32] In Bayesian methods, there is no risk of finding singular matrix problems.

Appendix 3A Scale elasticities obtained from output aggregates

The delicate issue of output aggregation has been addressed notably by Jara-Díaz and Cortés (1996), who provide a very easy method to evaluate the suitability of most common output aggregates ($\tilde{y}_j$) for the calculation of scale economies. Assuming that $\tilde{y}_j$ are implicit functions of the real outputs (y_i), then the estimated $\tilde{C}(w,\tilde{Y})$ is also an implicit representation of the real cost function $\hat{C}(w,Y)$. Therefore, although C can not be directly estimated, its microeconomic properties can be recovered from $\tilde{C}(w,\tilde{Y})$. In particular, the scale elasticity:

$$\hat{S} = \left[\sum_{j=1}^{n} \frac{\partial \tilde{C}}{\partial \tilde{y}_j} \frac{\tilde{y}_j}{C} \sum_{i=1}^{k} \frac{\partial \tilde{y}_j}{\partial y_i} \frac{y_i}{\tilde{y}_j} \right]^{-1} = \left[\sum_{j=1}^{n} \tilde{\eta}_j \left(\sum_{i=1}^{k} \frac{\partial \tilde{y}_j}{\partial y_i} \frac{y_i}{\tilde{y}_j} \right) \right]^{-1} = \left[\sum_{j=1}^{n} \tilde{\eta}_j \alpha_j \right]^{-1},$$

where $\tilde{\eta}_j$ represents the cost elasticity with respect to $\tilde{y}_j$. This elasticity is weighted by a homogeneity term[33] α_j that involves all elasticities of the corresponding aggregate output with respect to each disaggregate component. If this value equals 1, then the aggregate output specification leads to an accurate estimation of scale economies. Jara-Díaz and Cortés (1996) provide a comprehensive list of nearly all forms of output description for transportation studies including the calculation of their homogeneity terms. Regarding the proposed approach, the specification of ATM_{737} is equivalent to the specification of the airport's total landed tonnage (LT)[34]. Considering the disaggregated vector of aircraft categories as y_i:

$$LT = \sum_i y_i m_i$$

$$\alpha_{LT} = \sum_i \frac{\partial LT}{\partial y_i} \frac{y_i}{LT} = \sum_i m_i \frac{y_i}{LT} = 1,$$

where m_i, the average MTOW of the aircraft category i has been assumed to be a constant value which is also aircraft-specific. These results indicate that $\tilde{\eta}_{LT}$ fully contributes to the calculation of the disaggregate scale elasticity $\hat{S}$ if LT or alternatively ATM_{737} is included in the specification.

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[33] α_j represents the local degree of homogeneity with respect to the disaggregated output vector Y.

[34] ATM_{737} = LT x 2/68.

CHAPTER 4

DATABASE DESCRIPTION AND SOURCES

The nature of the data determines the utility of the results and, in this case, the analysis is clearly limited by data restrictions. The database is mostly composed of financial information directly collected from balance sheets and income statements published by the Airport Authorities (AAs). No external effects such as noise and congestion are featured in the data and thus results can hardly be interpreted in terms of social costs. Hence, it should be made clear that this analysis is limited to the financial component. In spite of that, it is certainly of major interest for the AAs and for public regulators.

4.1. General overview

According to Oum and Waters (1996), the quality of data can be more important than applying the most sophisticated methodologies. Regarding the airport industry, data collection represents a very serious obstacle to researchers, which explains the relative scarcity of airport cost function studies in the past literature and their inconsistent findings. The database used in this work is an unbalanced pool of 161 airports from all over the world. It was intended to comprise airports of all sizes, and hence it features many of the world busiest ones in terms of passengers/ATMs or cargo tonnage.

The geographical breakdown of 161 sample airports is as follows: 94 from Europe, 45 from North America, 11 from the Asia-Pacific region and 9 from Australia and New Zealand. The only African airport is Johannesburg (JNB) and Central America is represented by PTY (see Appendix 4A). South American airports are mostly owned and operated by national agencies which do not provide financial information disaggregated by airports. Therefore, no single airport in that continent could be included in the database. However, in the case of Europe, 36 Spanish airports were included using a database for a period (1991-1997) which was provided by the national operator AENA. Thus the number of observations is increased and therefore the parameters' significance will be improved in the estimation process.

Data collection was completed for the following variables: a) Total costs: labor, materials and capital expenditures (amortization and interest); b) Output: Passengers

(PAX), commercial ATMs, metric tons of cargo (CGO) and commercial (non-aviation) revenues (REV); c) Fixed factors: gross floor area of terminal buildings (TER-m^2), total runway length (RUN-m), warehouse space provided by the airport authority (WAR-m^2), number of gates (GAT), baggage claim belts (BEL), and check-in desks (CHK); d) Other: time (t), full-time equivalent employees (FTEE), and total landed MTOW (mix).

All the variables related to costs and revenues were converted to 2006 Purchasing Power Parity (PPP) USD using OCDE published indicators. Table 4.1 provides the range, mean and std. deviation of each variable. Airport size ranges between 1,000 passengers at ODB (Spain) in 1993 and 85 million at ATL in 2005. The mean airport serves about 155,000 ATM_{737}, 11.3 mppa, and 253,000 metric tons of cargo. Nevertheless, because of the logarithmic transformation, relevant values for a proper interpretation of parameter estimates are the geometric means (Gm), which are much lower. Therefore, it can be said that the representative average airport of the sample is really small in comparison with the busiest airports in the world. Regarding input prices, the extreme diversity of airports and countries featured explains the significant variability of input prices, which were calculated using the methodology explained in Chapter 3. With respect to the price of materials, a great share of this variability is because of the level of outsourcing, which is airport-specific.

Table 4.1 Database overview (monetary variables expressed in 000's PPP USD)

	Total Cost	PAX	ATM737	CGO metric tons	REV	FTEE	TER sqm	RUN m	Wc	Wm	Wp
Max.	1,739,326	85,907,423	1,190,887	3,692,081	690,051	13,979	761,300	24,505	65.7	8,947	191.6
Min.	692	1,000	66	0	0	8	918	1,127	0.02	3.9	15.6
Mean	151,036	11,339,733	155,299	253,847	66,005	651	112,391	5,847	3.59	727.3	52.99
Gm	-	4,703,044	48,764	28,496	15,543	-	-	-	-	-	-
Sd	219,379	14,417,880	207,709	534,132	97,777	1,069	140,278	4,017	6.33	776.3	23.32

Source:Own elaboration.

As noted, the total number of ATMs was transformed using an aircraft mix index in order to re-express this variable in terms of "base aircraft" operations (B737). Very interesting results about this mix variable were obtained as it was found to be closely related to the airport's geographical location, Hence, further comments will be given in each continental subsection. Apart from that, global results are also interesting as they allow us to revise current "world busiest airport" claims in terms of commercial ATMs[1]. As seen in Table 4.2, LHR, which does not even appear in the left table, would be the busiest airport in the world in terms of ATM_{737}. Its privileged geographical location and the fact that LHR is currently (2007) the world's busiest airport in terms of international passengers (of which 46 percent are long-haul) may explain these figures, as the average aircraft should be significantly heavier than, for example, those in major US hubs, where short- and medium-haul domestic traffic is more important. The same applies to the Asia-Pacific airports where the relative importance of very heavy freighter aircraft is much higher than in the rest of the world. .

Table 4.2 World busiest airports by passengers, aircraft operations, and cargo metric tons (CY2006)

Airport	PAX	Airport	ATM	Airport	ATM_{737}	Airport	CGO
ATL	84,846,639	ATL	965,496	LHR	940,767	MEM	3,692,681
ORD	77,028,134	ORD	926,731	ATL	915,993	HKG	3,609,780
LHR	67,530,197	DFW	693,139	HKG	909,185	ANC	2,691,395
HND	65,810,672	LAX	633,813	ORD	905,767	ICN	2,336,572
LAX	61,041,066	DEN	596,769	LAX	898,476	NRT	2,280,830
DFW	60,226,138	IAH	590,618	BKK	866,464	PVG	2,168,122
CDG	56,849,567	LAS	554,040	FRA	822,774	CDG	2,130,724
FRA	52,810,683	CDG	541,566	PEK	754,615	FRA	2,127,646
PEK	48,654,770	PHL	500,392	CDG	738,282	SDF	1,983,032
DEN	47,325,016	PHX	499,280	NRT	733,338	SIN	1,931,881

Source: ACI, IATA, own elaboration.

Regarding general data sources, for other than US airports, financial data comes directly from their published annual reports or financial statements. In most cases, airports' web sites include enough detailed information of traffic activity, such as ATMs, passenger enplanements, landed MTOW, and cargo. Regarding this last variable, some official statistics of governmental offices were also consulted, especially foreign trade records. In other cases, the AAs have been directly contacted to request additional information in order to complete the database. For the US airports, the main source is the CATS financial database provided online by the Federal Aviation Administration (FAA, 2006). The traffic figures were collected from the ICAO/ATI Airport Traffic Summary reports (ICAO, 2004b), which provide data for airports around the world between 1992 and 2004. Operational data for 2005 was obtained from the FAA Airport Master Records, and further details were available in the 2003 edition of IATA/ACI/ATAG Airport Capacity and Demand profiles (IATA/ACI/ATAG, 2003). Other interesting sources were *Wikipedia* or the *Google Earth* software.

4.2. European sample

Good financial data on European airports is scarce and very restricted, and it is difficult to find a unique source to gather all the necessary information to estimate cost functions. Therefore an extensive survey was conducted for 3 years and almost every commercial airport in Europe was considered for inclusion. Most of them were rejected because of the lack of financial data, and many others because their published accounts

[1] Because of the greater importance of GA in the US, the total number of ATMs is not directly comparable across the world.

were found to be too difficult to understand. Apart from financial statements, the standard annual report of the European AAs provides enough information about traffic results, fixed factors, projected airport expansions, or the number of employees. These reports were typically found available to download from the official airport websites, and, if not, hard copies were requested directly from Press Relations Departments. In addition, old hard copies back to 1990 (i.e. MAN, GVA, DUS, AMS, CPH) could be consulted at the Center of Documentation of the Spanish Airport Authority (AENA) in Madrid. This allowed extended time spans for several key airports.

Table 4.3 summarizes the European sample (94). Regarding the old Spanish database (36), it includes both MAD and BCN as the primary airports with the highest traffic turnover. Other important airports are dominated by a high percentage of non-scheduled tourist flights. These are mainly located on the Canary Islands, the Balearic Islands and Malaga. The rest of the sample is composed of medium-size airports in which the normal traffic consists of scheduled domestic and European charter flights, with connections to MAD being the predominant characteristic. As noted, these airports will not be considered for structural analysis.

Apart from them, the most comprehensive geographic cluster features 15 German airports, ranging from Rostock (0.2 mppa) to Frankfurt (50+ mppa). Financial reporting in Central European countries was found to be of a very high quality and homogeneity, especially taking into account the transition from national currencies to the euro in 2000. In addition, German airports are characterized by a very low level of outsourcing, and most concessionary companies are included within the AA's consolidation perimeter. Fraport AG, owner and operator of FRA, provides an excellent segmental report[2] by activities, allowing the separation of aeronautical and non-aeronautical costs. This will be incredibly useful when determining the degree of scale for the subset of aeronautical outputs. Old annual reports for HAM or DUS were found at the major shareholder *HOCHTIEF AirPort* website[3]. Smaller airports such as HHN do not publish their own annual reports. However, the accounts could be found in the *elektronische bundesanzeiger*, which is the official site where both the balance sheets and the income statements of German companies are published. In the case of FMO, all the required data was found by chance at the municipality website, as part of the annual meeting proceedings. The only objection to German airport reporting standards at regional

[2] The information provided by the Schiphol Group is also very precise.
[3] This website also provides good financial information for ATH and DUS

airports is the lack of data on total landed tonnage as an airport's output. However, in these cases, information about either the "average MTOW" or the traffic share of the most common aircraft was directly requested to the AAs, with a very satisfactory 100 percent response.

Table 4.3 European sample: data overview

Country	Airport	Time span	Country	Airport	Time span
Austria	Graz	00-06	Spain	Alicante	91-97
	Klagenfurt	02-05		Almería	91-97
	Linz	99-06		Asturias	91-97
	Salzburg	02-06		Badajoz	91-97
	Vienna	99-06		Barcelona	91-97
Belgium	Brussels	00-06		Bilbao	91-97
	Liege	01-05		Cordoba	91-97
	Ostend	02-06		Fuerteventura	91-97
Croatia	Zagreb	98-04		Girona	91-97
Czech Republic	Prague	00-06		Gran Canaria	91-97
Denkmark	Aarhus	00-06		Granada	91-97
	Billund	97-06		El Hierro	91-97
	Copenhagen	91-06		Ibiza	91-97
Estonia	Tallinn	02-06		Jerez	91-97
France	BSL/MLH/FRE	02-06		La Coruña	91-97
	Nantes	04-05		La Palma	91-97
Germany	Bremen	01-06		Lanzarote	91-97
	Dortmund	04-06		Madrid	91-97
	Dresden	04-06		Málaga	91-97
	Dusseldorf	90-06		Melilla	91-97
	Frankfurt	03-06		Menorca	91-97
	Hahn	05-06		Murcia	91-97
	Hamburg	99-06		Palma de Mallorca	91-97
	Hannover	99-06		Pamplona	91-97
	Cologne/Bonn	02-06		Reus	91-97
	Munich	92-06		San Sebastián	91-97
	Munster	03-06		Santander	91-97
	Nuremberg	97-06		Santiago	91-97
	Paderborn	02-04		Sevilla	91-97
	Rostock	03-04		Tenerife Norte	91-97
	Stuttgart	94-06		Tenerife Sur	91-97
Greece	Athens	04-06		Valencia	91-97
Italy	Bologna	05-06		Valladolid	91-97
	Brescia	05-06		Vigo	91-97
	Florence	99-06		Vitoria	91-97
	Orio al Serio	01-06		Zaragoza	91-97
	Palermo	03-06	Switzerland	Geneva	90-06
	Pisa	02-06		Zurich	96-06
	Turin	99-06	United Kingdom	Birmingham	01-06
	Venice	03-06		Bournemotuh	03-06
	Verona	05-06		Bristol	03-04
Latvia	Riga	01-06		Cardiff	01-04
Malta	Malta	03-06		East Midlands	03-06
Netherlands	Amsterdam	96-06		Humberside	03-06
	Eindhoven	01-06		London Luton	00-05
Norway	Oslo	99-06		Manchester	90-06
Slovenia	Ljubljana	98-06		Newcastle	01-04

	Total Cost	PAX	ATM_{737}	mix	CGO	REV	Wc	Wm	Wp
Max.	1,739,326	52,821,778	822,774	1.71	2,127,797	468,372	29.11	4,971.35	94.93
Min.	692	1,000	66	0.32	0	0	0.02	3.90	20.14
Arithmetic Mean	102,395	6,040,620	69,378	0.70	98,895	42,114	2.36	739.19	42.02
Std. dev.	188,182	8,413,262	112,366	0.21	248,227	75,456	3.07	671.74	12.03

Source: Own elaboration.

Another interesting case is BRU airport, as financial data for this privately-owned company comes from two different sources. Before privatization (2005) the airport issued its own annual report and accounts. However, it stopped doing so after being purchased by Macquaire, changing its name and brand logo. Financial data from thereon was collected directly at the Macquaire Airports (MAp) website, where the major accounts of BRU and all other participated airports such as SYD, BHX or CPH are released quarterly, as required by the Australian Stock Exchange (ASX). With respect to the traffic figures, BRU publishes one of the best traffic reports available online: BRUTRENDS, which features an extremely detailed analysis of passengers, ATMs, and cargo.

The second major cluster is Italy, which features 11 airports, though of a considerably smaller size than German ones. Airport size ranges from 0.23 (VBS) to 6.34 (VCE) mppa, including the fastest growing airport in Italy, BGY, which serves the low-cost traffic of Milan. Like German airports, financial reporting standards in this country were found very satisfactory, offering most of the required operational and financial information without having to search the accompanying notes. Especially remarkable is the specification of the *tonnelaggio aeromobili* as a reporting standard. In addition, Italian airports are mostly public-owned and managed, and therefore there is also a high chance of obtaining financial data via the municipalities, e.g. BLQ's accounts were not available online, but were included in the city's annual report (*commune di Bologna*).

Finally, another 11 airports in the UK were included, featuring MAN as the biggest airport. Furthermore, the Manchester Airport Group (MAG) offered very good segmental information which allowed the consideration of the group's regional airports (EMA, BOH and HUY) in the database. An additional data source for LTN was its *Annual Monitoring Report*, where a full breakdown of aircraft operations is provided.

As a last note, another problem concerns the language of published reports: for example, the annual report of TLL for the year 2006 was only available in Estonian at the time of request, and therefore numerical figures were identified by comparing the tables with the English version for the year 2005.

The mix variable for the European sample presents an average value of 0.70, which corresponds to an average aircraft of 47.6 metric tons MTOW. This is explained by the relative smallness of the featured European airports, which are mostly in regional service. In addition, larger airports with a higher share of intra-European service do not need to operate large aircraft because traveling distances within Western Europe range between short- and medium-haul.

Note that, except for AMS and FRA, average airport size in the European sample is very small. The busiest airports, such as LHR or CDG, could not be included as single observations, because neither BAA nor Aéroports de Paris (AdP) publish enough segmental information in their accounts to allow cost allocation within the respective multi-airport systems they manage. BAA owns and operates (among many others) the three major airports serving the London metropolitan area (LHR, GTW and STN). The same applies to AdP with CDG and ORY. Obtaining disaggregated data for these five international airports was originally a major objective of the collection process. Nevertheless, as this was impossible to achieve, an alternative approach was devised, so that these significant airports could still be included in the analysis. As noted, the existence of scale economies would provide economic justification for airport expansion as opposed to multi-airport systems (MAS). Therefore, aggregated data for five European cities was collected (apart from the aforementioned London and Paris systems, also Rome, Milan and Berlin). This information will be used in the later stages of this work in order to check the validity and consistency of the results, because, under the likely presence of significant returns to scale, these multi-airport systems considered as a whole[4] should present an important degree of cost inefficiency. This is especially relevant for the London case. Taking into account that LHR, LGW and STN altogether make 120 mppa and 1.5 million ATM_{737}, this case represents the biggest scale of production that is subject to analysis.

4.3. American sample

The American sample (46) is clearly dominated by the United States: with 37 airports, it is the most numerous group in the database. As of 2007, the US airport industry is the most important in the world, along with its domestic market, and it is almost completely composed of public airports, owned and managed directly by the municipalities[5]. In addition, financial data is significantly easier to obtain using the CATS financial database provided online by the Federal Aviation Administration (FAA 2006). The CATS reporting program provides both a balance sheet and an income statement for any airport under the FAA regulations. Therefore, contrary to European airports, data availability was not the main criterion for inclusion. In this case, the busiest airports were selected in order to increase the mean airport size of the whole database. With this intention, the top 30 busiest airports in terms of passenger movements were selected (28

[4] The calculation of input prices follows the methodology explained in Chapter 3.
[5] Among the major airports, only IND, which is leased to BAA, is entirely operated by a private entity.

finally included), and MEM, ANC and SDF as major cargo airports. However, in order to keep comparability with other geographical samples, other small regional airports, such as DAY, RSW or CMH, featured in the 2003 edition of IATA/ACI/ATAG Airport Capacity and Demand profiles, were also included. In spite of that, US airport overall scale of production is significantly higher than the European cluster: as a matter of fact, the mean airport produces almost 21 mppa, 300 thousand ATM_{737} and more than 450,000 metric tons of cargo.

Table 4.4 American sample: data overview

Country	Airport	Time span	Country	Airport	Time span
Canada	Calgary	93-06	United States	Kansas City	00-06
	Halifax	02-06		Knoxville	00-06
	Ottawa	98-06		Las Vegas	00-06
	Toronto	99-06		Los Ángeles	00-06
	Vancouver	99-06		Louisville	00-06
	Victoria	99-06		Memphis	00-06
	Winnipeg	99-06		Miami	00-06
Mexico	Mexico City	03-06		Chicago Midway	00-06
Panama	Panama City	04-05		Minneapolis-S.P.	00-06
United States	Anchorage	00-06		Chicago O`Hare	00-06
	Atlanta	00-06		Orlando	00-06
	Baltimore/Washington	00-06		Phoenix	00-06
	Charlotte	00-06		Pittsburgh	00-06
	Cincinnati	00-06		Portland	00-06
	Dallas–FW	00-06		Pt. Columbus	00-06
	Dayton	00-06		Washington Reagan	00-06
	Denver	00-06		Reno	00-06
	Detroit	00-06		Salt Lake City	00-06
	Washington Dulles	00-06		San Francisco	00-06
	Fort Lauderdale	00-06		Seattle	00-06
	Honolulu	00-06		SW Florida	00-06
	Indianapolis	00-06		Tampa	00-06
	Jacksonville	00-06		Tucson	00-06

	Total Cost	PAX	ATM_{737}	mix	CGO	REV	Wc	Wm	Wp
Max.	927,867	85,907,423	1,190,887	3.14	3,692,081	328,526	13.43	1,736.79	120.78
Min.	5,368	1,102,547	11,892	0.39	354	3,423	0.18	111.95	15.57
Arithmetic Mean	200,031	20,786,991	296,167	0.96	456,473	80,897	3.28	533.27	67.66
Std. dev.	188,635	18,639,970	244,784	0.37	680,980	66,439	2.47	332.76	18.32

Source: Own elaboration.

Apart from the above-mentioned data sources, all financial figures were double checked with the respective published annual reports. Many airports issue two versions of this document – the normal version and a comprehensive annual financial report (CAFR) – which was found very useful as it provides detailed information about the airport staff, and current or projected facilities. Only in a few cases was other precise information, such as the number of FTEE, directly requested.

The quality of information on US airports is really impressive, but one of the most surprising facts is the breakdown of expenditures by source, as shown in Table 4.5. The use of such disaggregated information would be the first step for the estimation of partial cost functions (airside vs. landside), with the objective of avoiding the presence of multicollinearity in the output vector. Unfortunately, no similar information was found for any airport outside the US. Hence, this hypothetical experiment should be carried out with the limited set of American airports, which are currently offering these very detailed accounts. Looking into the future, any improvement which could be made to the present methodology would be highly dependent on the information provided by airports. The last section of this chapter deals with the proposition of homogeneous financial/operational reporting standards, and the model proposed is largely based on this kind of CAFR report.

Another excellent data source for the calculation of aircraft mixes was the Air Carrier Statistics (BTS, 2007). This database allows us to obtain a full breakdown of aircraft operations by aircraft types (up to 350 different ones) at each US airport back to 1990. Therefore, the estimation of equivalent ATMs at these airports could be considered as exact under the earlier mentioned methodological assumptions (see Section 3.2.1). The average value of the mix variable yields 0.96, which corresponds to an average aircraft of 65.28 metric tons MTOW. Note that it is significantly higher than the previous cluster, but considering the huge size difference between both groups, the average MTOW is not as high as expected. The reason is the extreme importance of the US domestic market[6] in comparison with major European hubs, where the share of international traffic is somewhat higher.

Table 4.5 Breakdown of expenditures by source at DFW

	2006	2005	2004
Landing area	$ 20,396	$ 17,629	$ 13,684
Terminal area	75,121	36,874	11,210
Transit system	26,914	15,322	6,835
Parking	32,431	30,340	27,506
Ground rentals/outside concessions	4,435	2,857	3,541
Utility services	21,670	17,851	13,524
Ground transportation	5,694	5,018	4,778
General aviation complex	2,344	1,215	918
Airport Services	128,813	111,040	106,970
Other operating expenses	17,112	11,739	6,903
Depreciation / amortization	214,622	123,060	81,682
Total operating expenses	$ 549,552	$ 372,946	$ 277,558

Source: DFW (2006).

Regarding specific industry features, it was found that the Port Authority Police were considered as airport staff, and, in some cases, the estimated labor prices, which included a huge amount of retirement benefits, were much too high to be realistic. In this case, important outliers were obtained for the 3 major airports serving New York's

[6] e.g. ATL ranks 7th as an international gateway to the US, JFK being the 1st.

metropolitan area (JFK, LGA and EWR), and for this reason it was decided not to include them in the database[7].

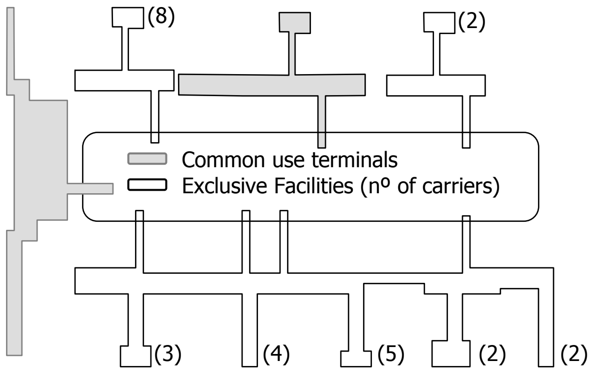
But the most interesting characteristic of the US airport industry, as pointed out in Graham (2003), is related to the close airline-airport relationship where carriers take part directly in airport capacity expansion and even in determining charging systems. This led to a very important question: Are reported financial figures truly representative of the overall operating costs of the airport? It is quite common in the US that airport food, beverages, news and gift concessionaires are awarded contracts for a certain period of time (7-12 years is common) to operate in the terminal. The concessionaires pay the airport a percentage of sales as rent, but are required to pay upfront 100 percent of the cost of building on the leased space. They then hire their own construction contractor and pay for the construction work directly and this cost is never shown as part of the airport's capital improvements. Any additional improvements made over the term of the agreement are also paid directly by the concessionaire. Airlines also pay directly for many capital improvements that they make to terminal space they lease from the airport. Each airport is different, depending on its situation in terms of how much airport capital developments are actually paid for by airlines or concessionaires, and how much is paid by the airport and then included in rent or use fees. At many large airports, certain airlines will pay directly to build their own terminals. This cost would also not be reflected in the airport's capital improvements or depreciation expenditures (TUS, 2007).

In other words, if a single terminal building at certain airport is dedicated to a major carrier, possibly a significant part of the utilities/depreciation/financing costs of these facilities were not recorded in the Authority's financial report but in the carrier's. In this case, the level of expenditure recorded from the CATS database will not represent the true expenditure that corresponds to the airport's declared output level, and therefore, the results would be biased, showing this kind of airport to be more efficient[8]. As this characteristic may introduce an important source of noise in the data, a survey was made among all major US sample airports. At SFO, for example, the City owns and operates all terminals. In contrast, at LAX, many facilities are currently on long-term leases to airlines who would bear a certain degree of the operational, financial and

[7] NYAA was contacted in order to exclude the costs of the police or to obtain the number of FTEE but our request was politely rejected for obvious security reasons.

[8] As an example, ATL airport authority has reported about USD 250 million of operating expenditures for the year 2006, while both DFW and ORD report about USD 700 million.

depreciation costs (see Figure 4.1). As this situation may clearly compromise the estimation of the degree of scale, a little transformation (on both sides of the cost function) was applied in order not to eliminate these important airports (ATL, LAX, DFW and ORD) from the database.



Source: Los Angeles World Airports (LAWA) website.

Figure 4.1 Terminal buildings at LAX

Regarding the explanatory variables, the calculation of input prices was corrected. Using the information contained in both annual reports and IATA (2003), the output figures and fixed factors used in the calculation of input prices (estimation of marginal productivities) were adjusted in order to roughly represent the infrastructures accounted for directly by the AA. In the case of capital prices, runway length was weighted according to the relevant terminal floor area. Regarding materials, only the gates and desks of non-dedicated terminals were considered. This allows a fair calculation of the vector input prices.

Total costs (labor + materials + capital) were also increased according to a dedicated/non-dedicated terminal surface proportion. Nevertheless, the capital component still needs further consideration, as the expenditures related to the runway/airside areas are more likely to be exclusively recorded by the Authority itself, and hence do not need to be corrected. For that reason, capital costs were only altered in proportion to the share they constituted in landside infrastructures. This proportion was estimated linearly[9], ranging between 55 and 80 percent for the affected airports. The main underlying assumption is that both the airport and dedicated carrier are equally efficient, i.e. they will have the same operational expenditure per unit of managed terminal surface. It is expected that this change may help to minimize the impact of dedicated terminals in the estimation of scale economies. In spite of that, technical

[9] Capital Costs=0.453*TER+3.390*RUN (R^2=0.68). The estimating sample did not include the affected airports.

efficiency and marginal cost estimations for these airports will be labeled as approximations in the corresponding chapters.

As seen in Table 4.4, seven Canadian airports are also included. The airports of this cluster present a specific peculiarity regarding their cost structure, known as the "Canada lease". These AAs are not-for-profit corporations that operate the facilities under a long-term lease from the Government of Canada. Hence, these payments were considered as capital costs. Apart of that, the only relevant data source worth citing is Stats Canada (2005), where highly detailed data on commercial aircraft operations and fleet mixes was available back to 2002. As usual, the lack of disaggregated information explains the absence of Montreal's Airports, which were a major objective of the data collection. Finally, the American database was completed with MEX and PTY, whose financial and operational data was available online. At PTY, however, there was no published data on FTEE. These figures were finally found in the financial records of the *Panamanian Ministry of Transport*, where a full breakdown of public employees' (including airport staff) average salaries was detailed.

4.4. Oceania sample

The Oceania sample consists of six Australian and the three major New Zealand airports. For this geographic region, the main data collection objective was to include almost every major city in the database. However, some airports such as Melbourne could not be finally included, again for reasons of disaggregation. In spite of that, airport size ranges from ASP with 0.6mppa to SYD with more than 29 mppa. A major source of information for the Australian group was BTRE (2006). This publication presents time-series data on scheduled transport services at selected airports by financial year from 1996 to 2006. Regarding NZ, the official web page of *Stats New Zealand* was found very helpful when assessing total cargo tonnages. As seen in Table 4.6, the average size of Oceania airports is between 7 and 8 mppa and 100,000 equivalent operations. As expected, the mean value for the mix variable is significantly higher than it is for the European cluster, and is clearly justified by the territorial isolation which increases the average length of haul, especially for trans-Pacific flights to the US.

Table 4.6 Oceania sample: data overview

Country	Airport	Timespan	Country	Airport	Time span
Australia	Adelaide	99-06	Australia	Sydney	01-06
	Alice Springs	02-06	New Zealand	Auckland	96-06
	Brisbane	98-06		Christchurch	99-06
	Darwin	02-06		Wellington	99-06
	Perth	99-06			

	Total Cost	PAX	ATM_{737}	mix	CGO	REV	Wc	Wm	Wp
Max.	600,643	29,108,466	396,971	1.56	578,000	235,411	22.05	1,291.62	87.41
Min.	6,947	561,509	6,000	0.23	1	478	0.76	88.65	35.67
Arithmetic Mean	86,889	7,607,651	101,800	0.87	111,443	45,716	4.36	400.74	53.92
Std. dev.	131,536	6,707,971	92,672	0.35	132,914	56,184	4.67	219.75	13.1

Source: Own elaboration.

4.5. Asia-Pacific sample

As mentioned in the introduction, the Asia-Pacific airports are expected to be rapidly expanded to accommodate the rapid increase of travel demand. Therefore, scale results are especially relevant for this geographic cluster, as they may provide economic justification for these huge investment projects. However, it would also be crucial to know if these returns to scale were exhausted for any hypothetical scale of production, highlighting in this way the maximum airport size that would be reasonable to design within the actual technological frontier. Taking into account most recent land reclamation projects for Asiatic airports, any hypothetical limit to airport size and expansion could be of great significance in the future. Table 4.7 summarizes the Asiatic sample (11). Airport size ranges from 0.7 mppa at CEI (Thailand) to 48 mppa at PEK. The average scale of production is the greatest of the four continental samples, serving almost 23 mppa and 420,000 equivalent movements. Especially significant are the values of the mix variable, whose mean is 2.33, indicating an average aircraft of 158 metric tons MTOW. As noted (in Section 4.4), this is mainly because of the greater importance of long-haul freighter aircraft at these airports which rank among the world's busiest in terms of cargo traffic.

The best financial information was provided from both PEK and HKG, whose financial statements fully meet international reporting standards. In addition, detailed information about airport development projects was easily found at their respective websites. Surprisingly, the mid-size HAK airport, located on the Chinese island of Hainan, provided both Chinese and English financial reports, and, additionally, a full infrastructure and operational review was found in a Public Share Offering document (HAK, 2002). In contrast, availability of detailed financial data in English for Japanese airports is very restricted. Therefore, only two major airports could be included, NRT and KIX, although in the second case the English report was not available online but requested and received by mail. In addition, a very detailed infrastructure report was kindly added to the financial statements. This document (KIX, 2007) was already cited earlier in the Chapter 1 as it provides very interesting information about the process of land reclamation and also about major expansion plans for Asia-Pacific leading airports.

The Japanese *Ministry of Finance* also issues an English document which includes a brief financial report of any company which benefits from the Fiscal Investment and Loan Program (FILP) funds, such as both NRT and KIX. The busiest airport in Asia is Tokyo HND (65 mppa), even though nearly all of its flights are to destinations within Japan. It was considered for inclusion, but its mixed managerial structure[10] was found not to fit very well with the other sample airports, so it was excluded.

In order to be consistent with the other clusters, some further variability was needed (i.e. more small airports). Taking into account data scarcity, the Thailand airport system and its segmental financial reporting was perfect for this purpose. It includes the major hub BKK[11], but also four smaller regional airports. Nevertheless, aircraft mix data for the latter had to be approximated based on the figures for other similar sample airports.

Table 4.7 Asia-Pacific sample / data overview

Country	Airport	Timespan	Country	Airport	Timespan
China	Beijing	00-06	Thailand	Bangkok	05-06
	Haikou	03-06		Chiang Mai	05-06
	Hong Kong	99-06		Chiang Rai	05-06
Japan	Osaka kansai	99-06		Hat Yai	05-06
	Tokio Narita	01-06		Phuket	05-06
South Korea	Incheon	04-05			

	Total Cost	PAX	ATM_{737}	mix	CGO	REV	Wc	Wm	Wp
Max.	1,101,682	48,654,770	909,185	4.22	3,600,000	690,051	65.69	8,947.43	191.63
Min.	11,214	676,352	1,636	0.31	4,698	1,944	0.48	225.11	20.98
Arithmetic Mean	572,501	22,793,445	419,454	2.33	1,177,247	316,411	21.66	2,441.29	98.15
Std. dev.	367,967	14,178,064	294,117	1.22	1,032,796	194,514	20.04	1,958.86	54.87

Source: Own elaboration.

4.6. Proposed reporting form

As noted in Wells and Young (2004), accounting procedures in airports differ considerably from other business firms because airports vary considerably in terms of goals, size, and operational characteristics. Therefore, it is very difficult to define a unified accounting system that can be used by all airports, but this is not the aim of this section. Instead, this section aims to propose a new standard form for airport data collection. It is similar to ICAO's form-J, whose use was stopped in 2004, when airports introduced the form electronically and it was stored in a database available online under subscription. The form-J required airports to provide a very brief income statement and a summary of the year's investments. Nevertheless, no detailed information was provided of many other important variables, such as retail and parking revenues or the number of employees. In addition, the electronic version of this database (ICAO,

[10] The Ministry of Transport operates the airfield and a private company the terminal buildings.

[11] Note that BKK refers to the former Bangkok Intl. not Suvarnabhumi.

2004b) does not even provide the full financial information requested but only total amounts of income and expenditures. On the other hand, the operational data was found to be more complete, providing a full disaggregation of the most common output categories (*atm*, *pax* and *cgo*) by types of traffic. However, it did not feature landed tonnages, which has proven to be a very important variable for this type of study, and no infrastructure report was provided.

Therefore, this section has three objectives. First, proposing a *financial* reporting form, which requests all the necessary information for airport efficiency and productivity analysis. This will enable a fair calculation of marginal costs and optimal airport charges. As mentioned in Chapter 3, this requires the adoption of an "activities" instead of a "firm" approach. In other words, there is a need to provide consolidated financial information of the full transport perimeter of each airport, regardless of whether it is already included in the AA's consolidation perimeter[12]. This implies that financial reporting forms should no longer be sent only to the AA but also to any other major concessionaire whose financial records may represent a significant part of the airport's operating revenues/expenditures as, for example, in the case of dedicated terminals.

The second part features an *infrastructure* report. The objective is to provide detailed capacity information, which can serve as input data for productivity analysis. In addition, it will be necessary to establish a standard procedure for capital assets valuation. Therefore, this part should collect detailed information about each airport's valuation principles for common infrastructures in order to apply a uniform criterion when calculating depreciation costs. Finally, the third part is the *operational* report, which should provide enough information for output separation and standardization.

The proposed reporting form can be found in Appendix 4B. It consists of three parts. The operational report needs only to be sent to the AA and requests information on: i) aircraft operations by type of traffic, and commercial operations by type of carrier – this last item was included in order to test empirically whether secondary airports serving low-cost airlines (ORY, GRO, BGY) are more/less efficient that their full-service competitors; ii) total landed tonnages, in order to allow the calculation of "equivalent aircraft movements". Note that the disaggregation of both i) and ii) would allow GA to be incorporated into the specification as a differentiated output in order to analyze the potential economies (or diseconomies) of scope of offering GA services at major

[12] This only occurs at a few airports, for example in Germany.

airports. This kind of analysis would be especially relevant in the US; iii) passenger information is requested in terms of three different variables: the origin/destination and the passenger's itinerary. This would allow the airport's "passenger mix" to be defined, and, with the appropriate information about the terminal(s) layout and security procedures, then passenger-specific charges with respect to the itinerary[13] could be calculated in conformity with the user-pays principle; iv) the most common indicators of cargo activity are also included but the airport is requested to indicate the weight units in order to facilitate conversions; and v) a detailed breakdown of aircraft movements by weight categories is also necessary in order to improve the aircraft mix methodology. Combined with the airside incremental costs requested on the financial form, any hypothetical combination of the aircraft's MTOW (or alternative specification) could be tested. This work proposes a linear approach for simplicity, but the existence of non-linear MTOW pricing schemes at major airports puts the optimality of this approach in doubt.

The infrastructure report is the second part of the form, which, as noted, has also to be sent to major concessionaires with a significant participation in airport building or renovation and therefore in depreciation/financing expenditures. Note that this form refers only to already-operating facilities, and includes the most common capacity indicators which serve to perform either DEA or SFA. The reason for requesting some financial data on this form (items E-I) is the necessity to make a survey of valuation principles as they may be not only country-specific or airport-specific but also firm-specific, and there is a need for a uniform criterion for depreciation. Regarding financial expenditures, it is very important that any remaining debt should be reported on this form, because it allows us to check that it is not bigger than the book value, and therefore, financial debt on assets under construction is not included[14]. In the same way, facility upgrades and renovations affect depreciation values only if they increase the book value (i.e. they are already operating). The disaggregation of output figures among facilities is also very important because it allows us to use any partial information received in the case of not getting a 100 percent response. In addition, the availability of disaggregated information on low-cost terminals with their specific traffic figures is of the utmost importance in order to calculate the low-cost passengers' marginal costs and

[13] A full schedule of charges for domestic/intl.; arr/dep; and all transit/terminal combinations.
[14] They should not be included because these inputs have not produced any output, and, if included, the efficiency analysis could be misleading, as under this approach all expanding airports would be likely to be reported as less efficient.

hence their optimal service charges, which are expected to be much lower than those of the full-service terminal[15].

The third part is the financial form which is largely based on both ICAO's form-J and the aforementioned CAFR. As long as it has to be forwarded to the same operators as in the previous case, the blank spaces for identification are provided at the beginning of the report. Each part of the report has to be filled in by the corresponding firm, and enough information about the "transport perimeter" has to be given by the AA so that all financial information can be consolidated as a single fictitious airport company, which, in the end, will be the true unit of observation. Finally, the full breakdown of airport expenditures by location allows the separate cost functions for either airside or landside activities to be estimated, thus simplifying some of the existing multicollinearity problems and enabling us to draw a number of very important conclusions about output disaggregation, and economies of scale and scope.

[15] Marseilles Airport has dropped passenger service charges to EUR 1 for low-cost terminal users, as against the current EUR 6 fee for the full-service terminals.

Appendix 4A Sample airports

Figure 4A.1 European airports

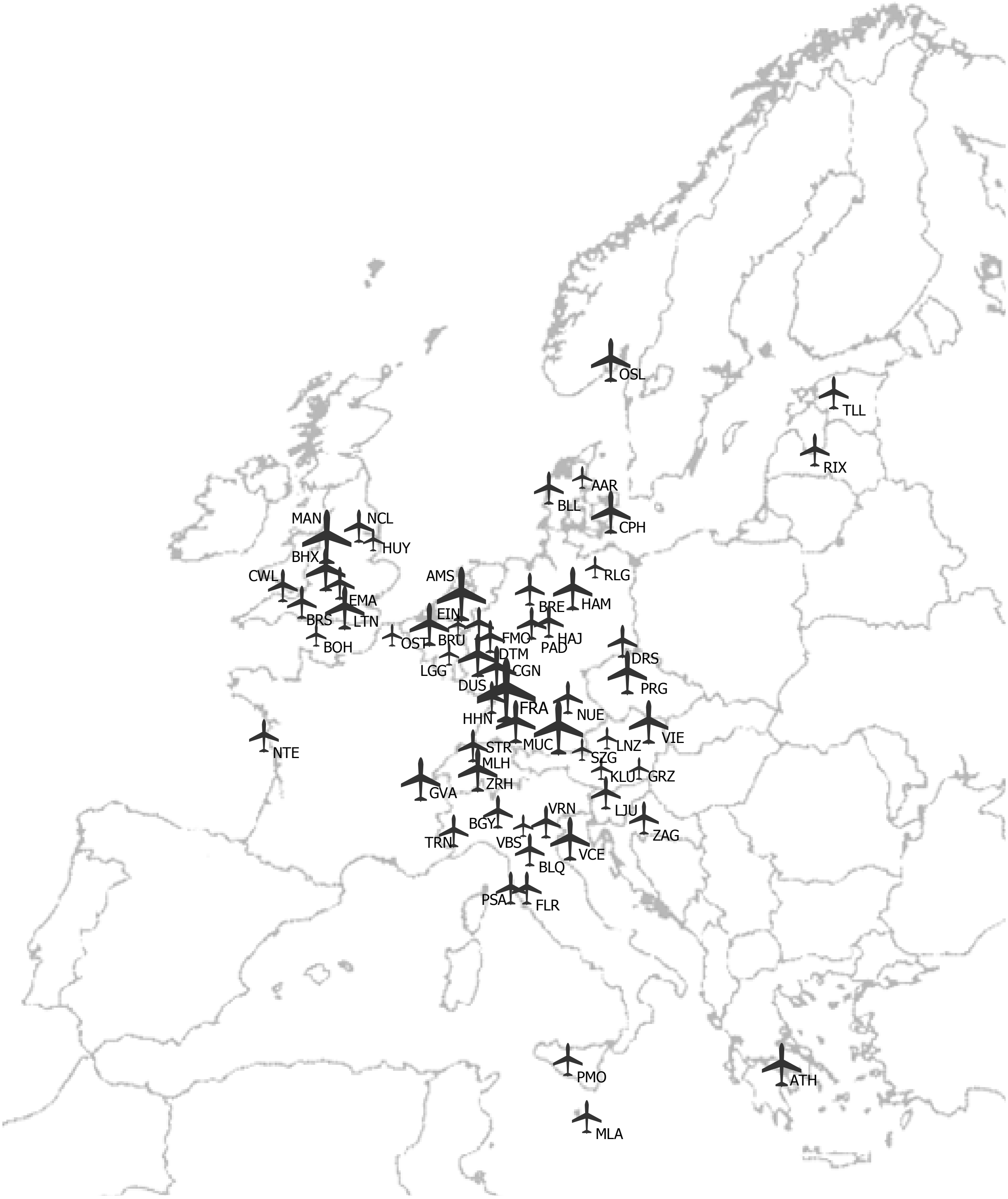


Figure 4A.2 North American and Caribbean airports

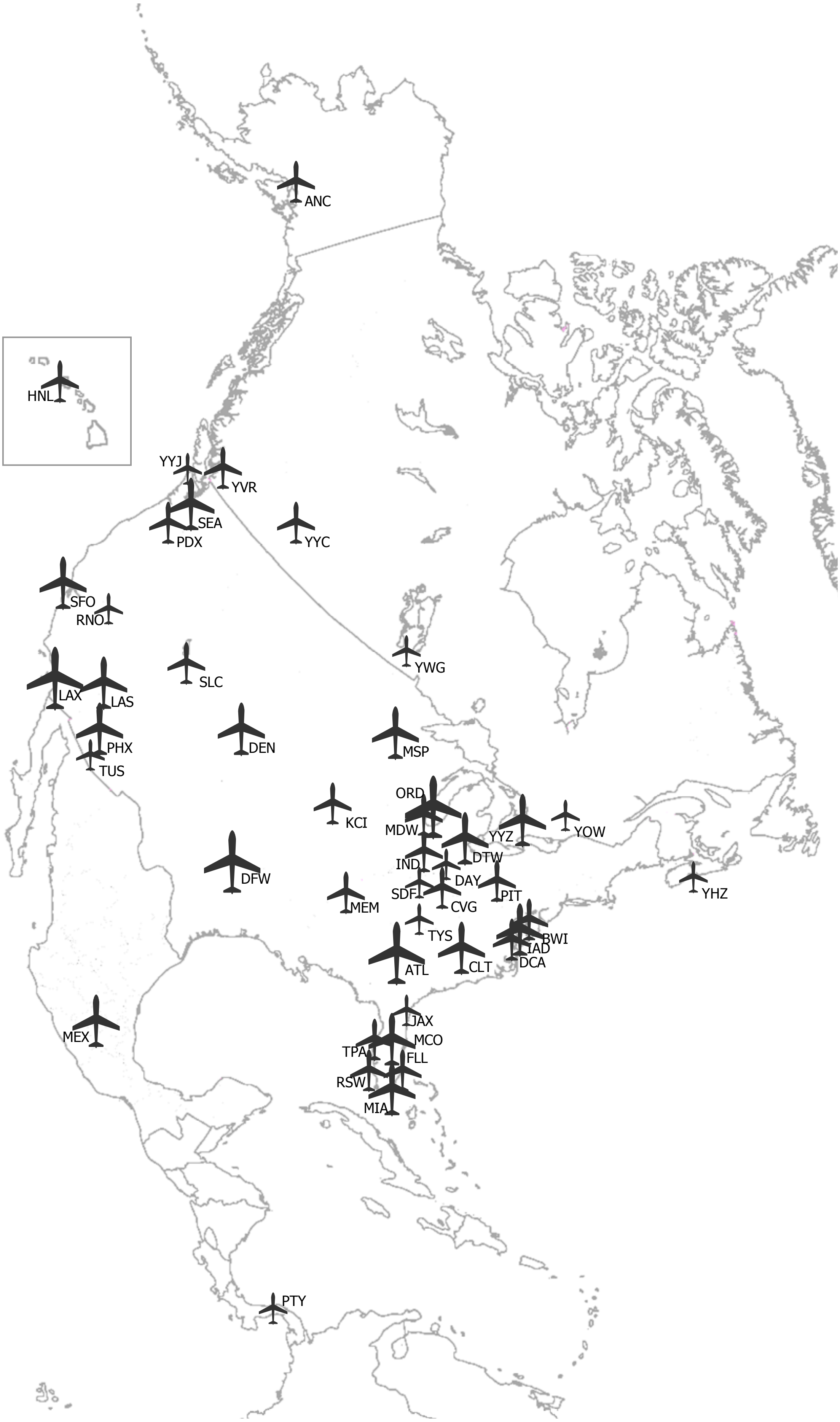


Figure 4A.3 Asia-Pacific airports

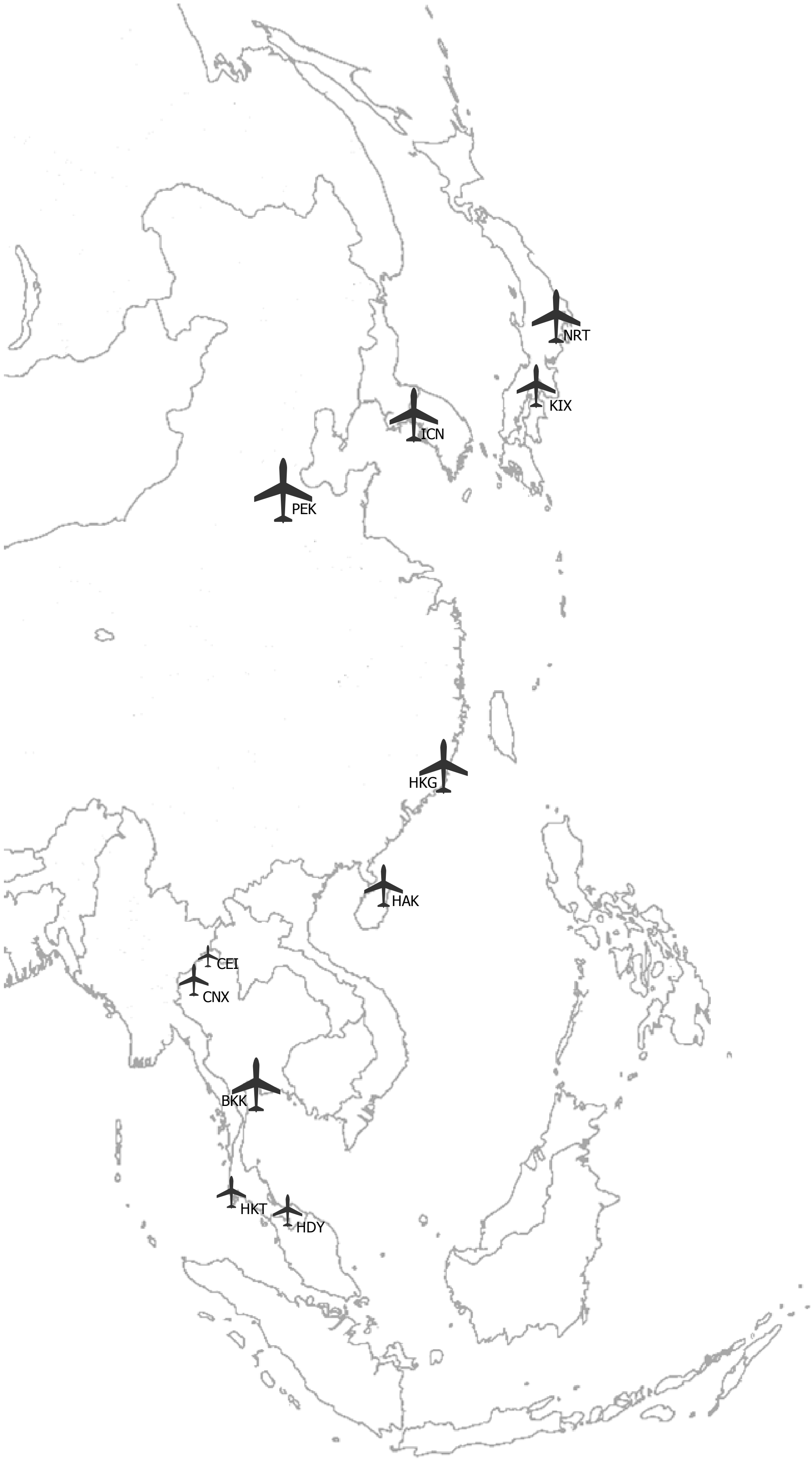
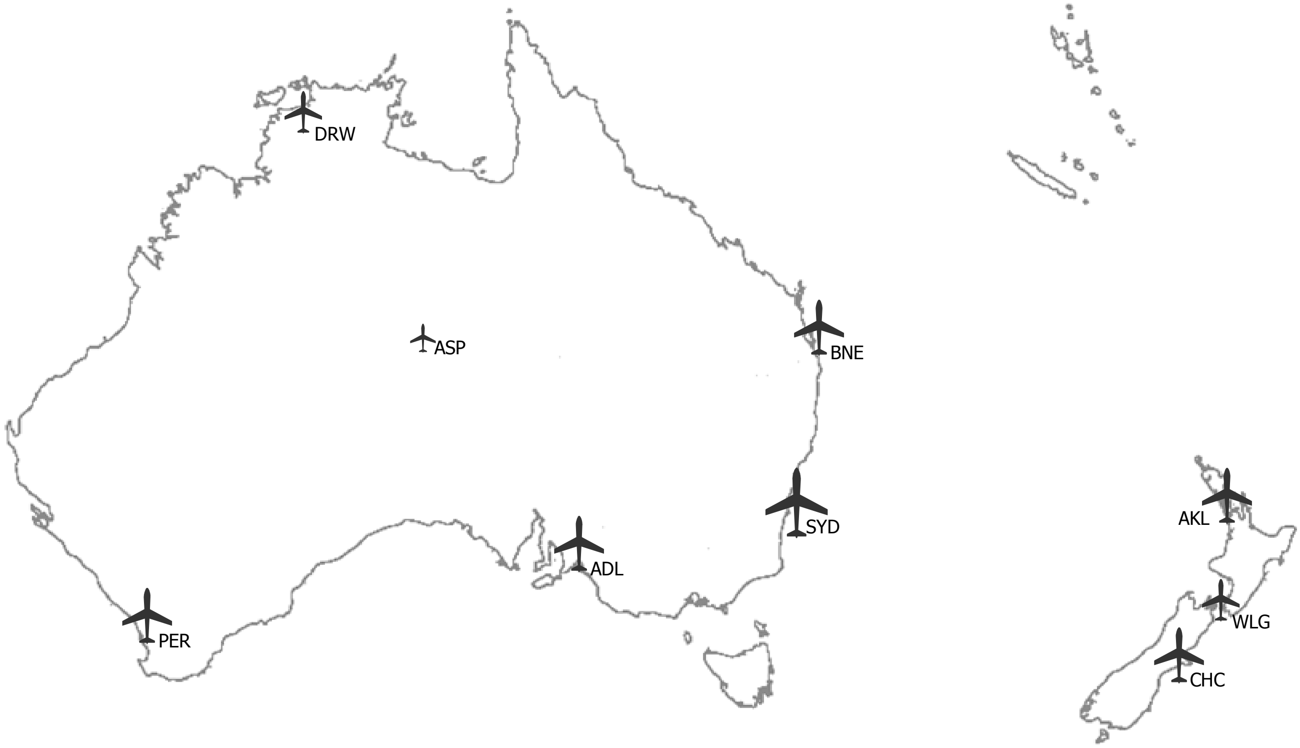


Figure 4A.4 Oceania airports



Appendix 4B Proposed airport operational and financial reporting form.

AIR TRANSPORT REPORTING FORM

AIRPORT OPERATIONAL DATA

Airport:________________________ Period Covered:____________________
Country:________________________ Weight unit: ________________________

AIRCRAFT MOVEMENTS, PASSENGERS AND CARGO

DESCRIPTION	AMOUNTS	
	SUBTOTAL	TOTAL
1. Aircraft Movements		____________
1.1 Commercial		....
1.1.1 Full Service	....	
1.1.1 Low Cost	....	
1.2 General Aviation	....	
1.3 Military/others	....	
2. Total landed tonnage		____________
2.1 Commercial	....	
2.2 General Aviation	....	
3. Passengers		____________
3.1.1 Domestic	....	
3.1.1 International	....	
3.2.1 Arriving	....	
3.2.2 Departing	....	
3.2.3 Transit (counted once)	....	
4. Cargo tonnage		____________
4.1 Air Cargo	....	
4.2 Trucking	....	

AIRCRAFT MIX

DESCRIPTION		AMOUNTS	
		SUBTOTAL	TOTAL
1. Aircraft Movements	(alternative categories)		____________
1-9 t. MTOW	....	....	
10-19 t.	....	....	
20-49 t	....	....	
50-74 t	....	....	
75-150 t	....	....	
160-199 t	....	....	
200-249 t	....	....	
250-299 t	....	....	
300-349 t	....	....	
350+t	....	....	

AIR TRANSPORT REPORTING FORM

AIRPORT INFRASTRUCTURE DATA

Airport:________________________ Period Covered:____________________
Country:________________________ Length unit: ________________________
Currency:_______________________ Surface unit: ________________________
Valuation basis[1]: ________________ Weight unit: ________________________

LANDSIDE FACILITIES

DESCRIPTION	AMOUNTS			
	SUBTOTAL			TOTAL
Terminal/Facility name	Domestic	...	(planned)[2]	current facilities
1. Gross floor area,	………………	………………	………………	………………
of which:	………………	………………	………………	………………
1.1 Retail	………………	………………	………………	………………
1.2 Office	………………	………………	………………	………………
	………………	………………	………………	………………
2. No. of gates	………………	………………	………………	………………
2.1 Contact	………………	………………	………………	………………
2.2 Remote	………………	………………	………………	………………
	………………	………………	………………	………………
3. Check in positions	………………	………………	………………	………………
3.1 Desks	………………	………………	………………	………………
3.2 Automatic	………………	………………	………………	………………
	………………	………………	………………	………………
4. Length of baggage belts	………………	………………	………………	………………
	………………	………………	………………	………………
5. No. of parking spaces	………………	………………	………………	………………
5.1 Long-term	………………	………………	………………	………………
5.2 Short-term	………………	………………	………………	………………
	………………	………………	………………	………………
6. Warehouse area	………………	………………	………………	………………
A. Passengers	………………	………………	………………	………………
B Pax. annual capacity	………………	………………	………………	………………
C. Cargo tonnage	………………	………………	………………	………………
D. Cgo. annual capacity	………………	………………	………………	………………
E. Year of acquisition	………………	………………	………………	………………
F. Book value	………………	………………	………………	………………
G. Lifespan	………………	………………	………………	………………
H. Remaining debt	………………	………………	………………	………………
I. Avg. interest rate	………………	………………	………………	………………
J. Common use Yes/No	………………	………………	………………	………………

[1] Historic, Current, other…

[2] Low-cost terminals should be reported separately, because they will be charged at different rates than FSC terminals. Common infrastructures such as people movers or parking/ground transport facilities should also be included in a separate column filling E-I. Note that only operating infrastructures should be reported.

AIRSIDE INFRASTRUCTURES

DESCRIPTION	AMOUNTS			
	SUBTOTAL			TOTAL
Runway denomination	9L-27R	...	(planned)	current facilities
1. Length	………………	………………	………………	………………
2. Surface[1]	………………	………………	………………	………………
3. C/G/M[2]	………………	………………	………………	………………
A. Aircraft operations	………………	………………	………………	………………
B. Peak hour capacity	………………	………………	………………	………………
E. Year of acquisition	………………	………………	………………	………………
F. Book value	………………	………………	………………	………………
G. Lifespan	………………	………………	………………	………………
H. Remaining Debt	………………	………………	………………	………………
I. Avg. interest rate	………………	………………	………………	………………
Apron denomination[3]	Contact	...	(planned)	current facilities
1. Total apron area	………………	………………	………………	………………
E. Year of acquisition	………………	………………	………………	………………
F. Book value	………………	………………	………………	………………
G. Lifespan	………………	………………	………………	………………
H. Remaining Debt	………………	………………	………………	………………
I. Avg. interest rate	………………	………………	………………	………………
Other Facilities[4]	Tower	...	(planned)	current facilities
1. Gross floor area	………………	………………	………………	………………
E. Year of acquisition	………………	………………	………………	………………
F. Book value	………………	………………	………………	………………
G. Lifespan	………………	………………	………………	………………
H. Remaining Debt	………………	………………	………………	………………
I. Avg. interest rate	………………	………………	………………	………………

[1] Asphalt, concrete, grass , etc…
[2] Indicates runway's primary utilisation : Commercial, General aviation, Military. i.e. CG indicates both uses.
[3] Contact, Remote, Cargo, GA …
[4] ATC tower, Hangars, emergency bases, Equipment and vehicles, etc…

AIR TRANSPORT REPORTING FORM

AIRPORT FINANCIAL DATA

Airport:________________________ Period Covered:____________________
Country: _______________________ Currency:_________________________

Company:______________________ Activity[1]:___________________________
Location[2]:_______________________ FTEE: __________________________

REVENUES

DESCRIPTION	AMOUNTS	
	SUBTOTAL	TOTAL
1. Air traffic operations		___________
1.1 Aircraft-related	....	
1.2 Passenger-related	....	
1.3 Other charges on air traffic operations	....	
2. Ground handling		___________
3. Concessions		___________
of which:		
3.1 Parking	....	
3.2 Retail	....	
3.3 Fuel and oil	....	
4. Rentals		___________
5. Other revenues		___________
6. Operating subsidies		___________
7. TOTAL INCOME		___________

EXPENSES[3]

DESCRIPTION	AMOUNTS	
	SUBTOTAL	TOTAL
8. Operation and maintenance		___________
8.1 Personnel costs		___________
of which:		
8.1.1 Administration	....	
8.1.2 Maintenance	....	
8.1.3 Security/Police	....	
8.2 Supplies		___________
8.3 Services (contracted)		___________
8.3.1 Maintenance	....	
8.3.2 Security	....	
9. Administrative overhead / other		___________
11. Capital costs		___________
11.1 Depreciation and/or amortization	....	
11.2 Interest	....	
12. TOTAL EXPENSES		___________

[1] Airport Authority, Air Carrier, Ground Handling, Parking, Retail …
[2] It refers to the company's location in the airport premises.
[3] Only airport-related expenses.

INVESTMENTS

DESCRIPTION	AMOUNTS	
	SUBTOTAL	TOTAL
13. Airside areas (under construction)[1]		___________
14. Terminal buildings (under construction)		___________
14.1 Airport Authority	…………………………..	
14.2 Concessionaires	....	
15. Equipment and vehicles		___________
16. Other facilities (under construction)		___________
16.1 Airport Authority	…………………………..	
16.2 Concessionaires	....	
17. Land		___________
18. TOTAL INVESTMENTS		___________

BREAKDOWN OF EXPENSES BY LOCATION[2]

DESCRIPTION	AMOUNTS	
	SUBTOTAL	TOTAL
1. Landing Area	....	
2. Terminal Area	....	
3. Transit System	....	
4. Parking	....	
5. Ground Rentals	....	
6. Utility services	....	
7. Ground Transportation	....	
8. General Aviation	....	
9. Air Traffic Control	....	
10. Other (Emergency/Meteorological)	....	
10. Depreciation / Amortization	....	
11. TOTAL		___________

NOTES[3]

[1] Only already-operating infrastructures are to be reported in the infrastructure report.
[2] The concessionaire should only report in its corresponding category.
[3] This section is intended to ease the consolidation of the "transport perimeter". The AA should provide details on the airport's organizative structure. Non-related companies should provide further details on their activities and contract obligations, especially regarding ownership and investment issues.

CHAPTER 5

MODEL SPECIFICATION AND ESTIMATION

In spite of the extensive review of airport operations and technology carried out in the previous chapters, the decision on whether a long- or a short-run specification should be estimated has not yet been taken. The previous literature does not provide any further help on this issue. Except for Tolofari et al.(1990), which clearly decided for a short-run model, all other studies simply estimated both equations, though the capital costs were always given special treatment.

On the one hand, most airports' capital assets are planned and built to accommodate the forecasted traffic demand well into the future. Airport capacity remains clearly fixed for long periods of time. Hence the cost function analysis should be, at first sight, more appropriately based on a short-run specification that takes into account the capital stock as a fixed factor. On the other hand, the capital costs as defined by Doganis (1992) mainly consist of the economic depreciation of the fixed assets and thus, capital costs are fully related to the level of production, i.e. they cannot be considered as fixed costs[1]. The fact that accounting practices allow structures to be written off in fixed amounts at the end of each financial year does not imply that the economic depreciation is faithfully represented by these figures. Thus the specification of a capital stock variable in a short-run model may lead to significant parameters, but a wrong interpretation is induced by the poor quality of the data.

In order to clarify this issue, Oum et al. (2008b) state that a good knowledge of the database is the best guide to assess the real nature of the estimated elasticities. The use of time-series data on airports should lead to obtaining short-run estimates if the observed data on capital costs is most likely linked to the existing capital stock and does not provide enough variability to support a functional relationship with the output vector. The present database provides time series up to 17 years for certain airports, though the average time span is eight observations per firm (99-06). Nevertheless, a little investigation on sample airports indicates that this short-run assumption does not

[1] Note that fixed assets should not be depreciated if they are not used or until they enter into service.

hold for all observations in the database: 57 out of the featured 161 airports have expanded either their runway system or the terminal buildings (or both) during the time span considered. Furthermore, most of these expansions are justified by a significant development in both aircraft and passenger operations. The weighted average annual growth rate for the airports that have been expanded is 6.9 percent compared with 4.1 percent for those whose capacity has not been expanded.

On the contrary, if the data features cross-sectional observations on a wide range of traffic levels, output mixes and infrastructures, the estimated elasticities should be interpreted as long-run. The wide variation across firms allows the consideration of all factors as variable. Hence, even the capital expenditures can be assumed to be fairly adjusted to their output vector. In other words, given the variability among the sample firms, it is more likely that the cost function will find a long-run efficient observation for every scale of production.

For quantitative reasons, the pooled database used in this work should be regarded as a cross-section rather than time-series. Therefore, the long-run model will be the chosen approach when analysing the industry structure and the technical efficiency. The long-run estimated output cost elasticities may provide very interesting conclusions about the industry's minimum efficient scale if, as expected, increasing returns to scale are present. A short-run model will also be estimated because some airlines' managers argue that this approach should be chosen in order to find optimal prices. Utilization of short-run parameter estimates is restricted to the calculation of marginal costs (see Chapter 8) in order to test whether current airport pricing levels are calculated according long- or short-run considerations.

This last analysis can be used as a starting point for considering the controversy that has arisen with the recent price regulation for the London Airports approved by the Civil Aviation Authority (CAA). It proposes the adoption of new price caps of GBP 12.80 at Heathrow and GBP 6.79 at Gatwick for the year 2008, with annual increases capped at 7.5 percent above inflation for Heathrow and 2 percent above inflation for Gatwick. This new pricing regime will last for the next five years. This increase is supposed to improve airport facilities and service standards after a huge investment plan (GBP 5bn). Thus, it seems that the CAA, in order to guarantee a better service to passengers and airlines, is in favor of the long-run perspective because these investments need to be recouped with an increase in airport charges.

5.1 Long-run model

The estimation of the proposed cost frontier system cannot be easily implemented by the existing statistical packages without investing a lot of time in programming specific tasks in order to resolve the whole problem partially. The significant complexity of this approach contrasts with the extreme simplicity of the WinBUGS software. In spite of that, the estimation procedure comprises two stages.

In the first phase, a good fitting and parsimonious specification should be chosen from a simple estimation of the cost frontier system made with the Eviews software. The presence of near multicollinearity between passenger (*pax*) and aircraft operations (*atm*) makes this previous step necessary, as a great number of redundant parameters may appear. This basic model includes the cost frontier and its *(n-1)* cost share equations. Neither technical nor allocative inefficiencies are considered for the moment. Regarding the parametric restrictions, only the first-order price coefficients are restricted to sum to 1 without inducing singularity problems. This step is necessary because WinBUGS does not allow the specification to be changed easily once the code is written and the model compiled, and the execution times increase considerably with the number of parameters. In addition, the estimated values of the parameter vector *(beta)* obtained in this stage are collected in order to serve as initial values for the sampling process in WinBUGS.

Therefore, to begin with, the estimated cost frontier included 45 parameters, featuring all second-order interactions between the explanatory variables. It attained an excellent $R^2 = 0.968$, but there were a great number of non-significant parameters and many others oddly valued. For this reason, the frontier needed to be reformulated in order to get another more convincing specification. In order to do that, some control variables were selected (mostly related to the outputs), as shown in Table 5.1. Note that the first-order *atm* parameter is not significantly different from zero, and this result is not really satisfactory if the researcher wants to calculate marginal costs related to this output. Of course, this result was clearly produced by the presence of multicolinearity and the overparametrization of the complete model.

Other odd results were obtained if one compares the second order interactions between *atm* and *pax* with their respective quadratic parameters. Knowing that both variables are highly correlated and hence they have a similar explanatory power, the two negative signs of the quadratic parameters and the positive sign of the interaction make no sense at all. In spite of not affecting the model fitting, the necessity to make a structural analysis of the estimated coefficients requires the model to be recalibrated.

Hence, it was decided to keep only one out of these three second-order parameters between *atm* and *pax* in order to minimize the effect of multicollinearity. Statistically speaking, removing any of them should not have a direct effect on the overall significance of the model. Nevertheless, it seriously affects the final results in the way they will be presented, because the second-order remaining output parameter will be responsible for explaining the evolution of the scale elasticity for the whole industry. Thus the remaining variable should be a good indicator of airport size.

The passenger variable (mppa) has been widely used in master planning in order to express current and planned airport capacity considerations. On the other hand, this dissertation has focused on the definition of a new variable, equivalent aircraft operations (ATM_{737}) as a better descriptor of airport size. There are two main reasons for that: i) the database features specialized cargo airports whose capacity cannot be established in terms of mppa. In addition, major cargo hubs are typically prepared to handle very large freight aircraft. Hence the number of equivalent operations seems to be a suitable measure of the airfield capacity of both passenger and cargo airports; ii) the imminent full-scale introduction (as of 2008) of the A380 in a limited set of major hubs will have a significant impact on airport operations and planning in the near future.

Table 5.1 First specification control variables in the long-run model

	Coefficient	Std. error	t-Statistic	Prob
atm	0.012191	0.021993	0.554305	0.5794
pax	0.302167	0.021814	13.85221	0.0000
cgo	0.080699	0.006147	13.12850	0.0000
rev	0.140641	0.011012	12.77208	0.0000
0.5*atm^2	-0.254608	0.042756	-5.954961	0.0000
0.5*pax^2	-0.275698	0.034434	-8.006606	0.0000
0.5*cgo^2	0.019469	0.003332	5.842135	0.0000
0.5*rev^2	0.082867	0.006907	11.99795	0.0000
atm*pax	0.341914	0.034776	9.831897	0.0000
atm*cgo	0.061547	0.011216	5.487427	0.0000
atm*rev	-0.137347	0.025658	-5.353060	0.0000
pax*cgo	-0.047148	0.011221	-4.201598	0.0000
pax*rev	0.073453	0.025658	3.559165	0.0000
cgo*rev	-0.042312	0.007496	-5.644881	0.0000

After estimating the three different models, using in each case one of the potential second order interactions between these two variables, that is, pax^2, atm^2 or $pax*atm$, it was decided to choose the interaction between *pax* and *atm*. The reason can be found in the partial derivatives that correspond to each alternative. They are shown below[2].

[2] The final specification for both models can be seen in Appendix 5A at the end of this chapter.

These partial derivatives represent each output's cost elasticity and they are used in the calculation of the degree of scale and marginal costs. The selected option is featured on the right, where the presence of a shared parameter allows each output's cost elasticity to vary with respect to the airport size. The selection of any of the other squared parameters would have assigned all the explanatory power of both variables into the chosen output's cost elasticity, thus biasing both of them. This has no major effect when assessing the level of scale economies in the industry because all individual effects are aggregated, but, on the other hand, it distorts the use of the individual elasticities at the time of calculating marginal costs and output-specific scale economies, i.e.

$$\frac{\partial \ln C^o}{\partial atm} = \alpha_2 + w'\gamma + \rho_{27} atm \qquad \frac{\partial \ln C^o}{\partial atm} = \alpha_2 + w'\gamma \qquad \frac{\partial \ln C^o}{\partial atm} = \alpha_2 + w'\gamma + \rho_{27} pax$$

$$\frac{\partial \ln C^o}{\partial pax} = \alpha_3 + w'\gamma \qquad \frac{\partial \ln C^o}{\partial pax} = \alpha_3 + w'\gamma + \rho_{27} pax \qquad \frac{\partial \ln C^o}{\partial pax} = \alpha_3 + w'\gamma + \rho_{27} atm$$

In conclusion, both squared parameters were finally discarded from the second-order interaction coefficients leaving the *atm* and *pax* interaction and the other components of the output vector as descriptors of airport size in the evolution of scale elasticities. In this second estimation, many other parameters become non-significant and were also discarded. This set includes all specified interactions with the time *(t)* variable, which was introduced as a proxy for technical change in the industry. For that reason, its explanatory power will be used exclusively in the estimation of the time-varying technical inefficiency (u_{it}) using the Cuesta formulation.

The reduction in the number of parameters has negatively affected the R^2 coefficient of the model. However, as many of them were redundant, the measure of goodness-of-fit was only reduced by less than 1 percent (R^2 = 0.961). Hence the final long-run specification features 29 variables. A first approximation of what will be obtained in the Bayesian estimation is shown in Table 5.2. The model performs very well and the most relevant parameters are significantly different from zero. The inverse of the sum of the first-order output parameters gives the average elasticity of scale[3]. This yields 1.86, which seems to be a very reasonable value because of the small size of the geometric mean airport (4.7 mppa; 48,000 ATM_{737}). Nevertheless, the positive sign of some of the featured second-order output parameters indicates that scale economies are going to be exhausted at a certain, yet still unknown, level of production.

[3] Note that each variable is in logarithms and deviated with respect to its average. For example, *atm* means [ln atm_i – average(ln *atm*)]

Table 5.2 Initial values for the WinBUGS sampling in the long-run model

	Coefficient	Std. error	t-Statistic	Prob
constant	10.70048	0.01450	738.117	0.0000
atm	0.10614	0.03018	3.51720	0.0004
pax	0.30430	0.02756	11.0402	0.0000
cgo	0.07477	0.00938	7.96782	0.0000
rev	0.05290	0.01564	3.38309	0.0007
wc	0.37379	0.00346	108.001	0.0000
wm	0.30498	0.00314	97.0965	0.0000
wp	0.32117	0.00312	103.005	0.0000
atm*wc	0.03227	0.00889	3.62985	0.0003
atm*wm	0.01235	0.02678	0.46106	0.6448
atm*wp	-0.04404	0.00848	-5.19203	0.0000
pax*wc	-0.03907	0.00777	-5.02819	0.0000
pax*wm	0.04737	0.02143	2.21030	0.0271
pax*wp	0.02863	0.00731	3.91843	0.0001
cgo*wc	-0.00175	0.00268	-0.65286	0.5139
cgo*wm	-0.02679	0.01046	-2.56109	0.0105
cgo*wp	0.00755	0.00248	3.04843	0.0023
rev*wc	0.00621	0.00417	1.48921	0.1365
rev*wm	0.00950	0.00947	1.00359	0.3157
rev*wp	-0.02364	0.00373	-6.34461	0.0000
wm*wc	-0.10656	0.00493	-21.6228	0.0000
0.5*wm*wm	0.11806	0.02912	4.05429	0.0001
0.5*wc*wc	0.10042	0.00535	18.7592	0.0000
wm*wp	-0.01318	0.00443	-2.97406	0.0030
wc*wp	-0.01789	0.00456	-3.92259	0.0001
0.5*wp*wp	-0.02607	0.00958	-2.72254	0.0065
atm*pax	0.02656	0.00375	7.07701	0.0000
0.5*cgo*cgo	0.00651	0.00265	2.45270	0.0142
0.5*rev*rev	0.02067	0.00473	4.36863	0.0000

The next step, once the specification has been chosen, is to formulate the whole system taking into account primarily the allocative effects defined across the input price vector, as in Kumbhakar (1997). Following this shadow price approach, one input category is chosen as the reference, and the allocative effects are defined with respect to it. In this work, capital has been chosen as the base input, hence the relevant input price vector for the allocatively inefficient cost minimizing airport is:

$$w^{*}=[w_c, w_m \exp(\xi_m), w_p \exp(\xi_p)],$$

where ξ_j indicates the allocative inefficiency (AI) for the input pair (*j*, capital). For ease of exposition, the polynomial expression containing all ξ_j parameters *(ln C^{al})* is separated from the efficient cost frontier *(ln C^{o})*. This expression represents the percentage increase in total costs because of AI. In a very similar way, the input share equations are directly derived from the cost frontier, thus adapting the λ_i factor (see Chapter 2) to this more convenient expression:

$$S_i^a = \frac{S_i^o(w,y) + S_i^{al}(\xi,w,y)}{G_i \exp(\xi_i)}.$$

As noted, the system will benefit from any additional information the data can provide. Hence, as no singularity problems exist when Bayesian methods are used, the three factor share equations are included in the system. The expression of G_i is derived directly from theory (see Kumbhakar, 1997), and it is closely related to the factor share equations. Finally, up to eight regularity restrictions to the parameters were imposed to comply with the linear homogeneity in input prices. The symmetry of the Hessian matrices is also imposed to liberate some degrees of freedom. The final specification of the long-run system can be seen in Appendix 5A.1, and the transcription into WinBUGS code is presented in Appendix 5B.1.

The first part of this code relates to the k = 161 different airports and the estimation of the firm-specific effects. The second part accounts for the n = 1069 observations. The total costs (*tc[i])* are said to be normally distributed (*dnorm)* with the whole frontier expression as the mean (*mu[i])*. WinBUGS imposes an upper limit in the length of the polynomial expressions that can be defined. Hence the codification of $ln\ C^o$ is conveniently shortened using the vectorial expression *inprod*. The *beta* vector includes all cost frontier parameters, and the *data* vector comprises the p = 29 explanatory variables including the constant term (a vector of 1's) and all interactions between outputs and input prices (explicitly calculated)[4].

A second set of data includes the natural logarithm of total costs as the dependent variable, the factor shares, the time proxy as it is not featured in the cost frontier, a vector of *zeros* for imposing linear regularity restrictions and an additional vector (*id[i])*, which labels each different airport (1-161) in order to facilitate the estimation of both technical and allocative inefficiencies. Factor share equations are specified in a similar fashion as the cost frontier, being also normally distributed and assuming (as SURE does) that their errors are highly correlated. Finally, the Cuesta formulation for the time-varying technical inefficiency is implemented so that it allows us to obtain the firm-specific efficiency estimates (eff_{it}) as functions of the inefficiency terms.

$$eff_{it} = \exp\left(u_i \exp\{\eta_i (t - T)\}\right).$$

The last detail before running the model is to establish reasonable values for all fixed parameters in the prior distributions. Informative priors considerably reduce the range of values that the software is allowed to sample for any stochastic node. Hence a good prior elicitation increases the efficiency of the sampling process, though the researcher is required to provide proper justification for the selected values. A first estimation attempt was made using non-informative priors. However, the specification of $ln(G_i)$ in

[4] Formatting of data files to WinBUGS format can be done using BAUW code (Zhang and Wang, 2006).

the cost frontier was a major source of problems, as the procedure inevitably crashed after several hours of sampling when the first negative value appears. This indicates the necessity of setting very tight prior distributions. The precision of the *eta* parameter (σ_η^{-2}) was set at 10 because changes in firm technical efficiency are not expected to present a high variability in the database. The same applies to both allocative effects (σ_ξ^{-2}) where prior precisions were set at 18 allowing only for a narrow variability. This value was roughly calculated in order to prevent allocative distortions higher than ±2. This is considered to be a reasonable spread for describing AI in the airport industry[5].

The white noise for both cost frontier and factor share equations (σ_v^{-2}) was given a Gamma distribution with shape parameter a_0 and mean a_0/a_1. They were set ($a_0 = a_1 = 0.001$), as shown in Griffin and Steel (2007). This ensures very diffuse prior information. The last parameter to be set is perhaps the most interesting. As noted, technical inefficiency was assumed to be exponentially distributed with parameter λ. Prior ideas on the industry's median efficiency can be added to the system by means of the r^* parameter in the distribution of *lambda*. This was set at 0.82, as obtained in a previous study (Martín and Voltes-Dorta, 2008) using a very similar but smaller database. Finally, as the most important outcome of the estimation process, the prior distribution for the *beta* parameter vector was intended to remain absolutely non-informative, and hence its precision was set at 0.01. Because of the nonlinear complexities of the proposed system, the sampling may crash even after imposing such tight distributional assumptions. In this particular estimation, convergence was more easily achieved once a complete set of initial values was also added to the model. Hence, the initial values for the *beta* vector obtained from the Eviews estimation (Table 5.2) were used. In addition, it is highly advisable that other variables such as *eta* or the allocative effects be initialized at zero.

Once the syntax of the model is checked by WinBUGS, and all data and initial values are compiled, the software allows the model to be updated. In order to avoid additional correlation problems, a burn-in of 4,000 iterations was made, i.e. these draws are not used to derive posterior densities. Finally, the chain was successfully run with 30,000 retained draws that were more than enough to achieve convergence. The results are shown in Table 5.3, which reports the posterior mean, standard deviation, and a 95 percent posterior confidence interval for the *beta* parameter vector.

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[5] Note that prior means for both *eta* and *xi* parameters were set at zero.

The estimation performs well, showing correct signs, and significance of the most important parameters. As expected, many parameters related to input prices become non-significant because of the presence of allocative effects. In addition, it is very easy to check that the homogeneity of degree 1 with respect to the input price vector *(w)* effectively holds as it was imposed in the model.

Table 5.3 Long-run cost function parameter estimates

	mean	*sd*	*MC*	*2.5%*	*median*	*97.5%*	*start*	*sample*
constant	10.4700	0.0234	1.37E-04	10.4200	10.4700	10.5200	4001	30000
atm	0.1261	0.0364	2.22E-04	0.0544	0.1261	0.1970	4001	30000
pax	0.2742	0.0425	2.42E-04	0.1904	0.2744	0.3572	4001	30000
cgo	0.0730	0.0155	8.82E-05	0.0427	0.0731	0.1031	4001	30000
rev	0.0644	0.0282	1.62E-04	0.0091	0.0644	0.1197	4001	30000
wc	0.3701	0.0061	3.50E-05	0.3581	0.3701	0.3821	4001	30000
wm	0.2918	0.0065	3.97E-05	0.2789	0.2918	0.3045	4001	30000
wp	0.3085	0.0088	5.02E-05	0.2912	0.3084	0.3257	4001	30000
atm*wc	-0.0003	0.0014	7.95E-06	-0.0031	-0.0003	0.0024	4001	30000
atm*wm	-0.0025	0.0014	8.66E-06	-0.0052	-0.0025	0.0003	4001	30000
atm*wp	0.0036	0.0095	5.23E-05	-0.0148	0.0036	0.0223	4001	30000
pax*wc	0.0022	0.0078	4.43E-05	-0.0132	0.0022	0.0177	4001	30000
pax*wm	0.0317	0.0069	3.93E-05	0.0183	0.0317	0.0451	4001	30000
pax*wp	0.0071	0.0126	7.66E-05	-0.0176	0.0071	0.0316	4001	30000
cgo*wc	-0.0008	0.0034	1.79E-05	-0.0074	-0.0008	0.0060	4001	30000
cgo*wm	-0.0082	0.0026	1.36E-05	-0.0133	-0.0082	-0.0031	4001	30000
cgo*wp	0.0014	0.0054	2.77E-05	-0.0092	0.0014	0.0121	4001	30000
rev*wc	0.0014	0.0068	3.68E-05	-0.0120	0.0014	0.0149	4001	30000
rev*wm	0.0241	0.0049	2.52E-05	0.0145	0.0241	0.0338	4001	30000
rev*wp	-0.0366	0.0107	5.77E-05	-0.0575	-0.0365	-0.0158	4001	30000
wm*wc	-0.0949	0.0059	3.46E-05	-0.1064	-0.0949	-0.0833	4001	30000
0.5*wm*wm	0.1089	0.0078	3.95E-05	0.0936	0.1089	0.1241	4001	30000
0.5*wc*wc	0.0876	0.0090	5.30E-05	0.0701	0.0875	0.1054	4001	30000
wm*wp	-0.0117	0.0097	5.91E-05	-0.0308	-0.0117	0.0073	4001	30000
wc*wp	-0.0021	0.0093	5.15E-05	-0.0203	-0.0021	0.0162	4001	30000
0.5*wp*wp	-0.0388	0.0222	1.24E-04	-0.0822	-0.0388	0.0049	4001	30000
atm*pax	0.0316	0.0033	1.88E-05	0.0252	0.0316	0.0381	4001	30000
0.5*cgo*cgo	0.0066	0.0033	1.89E-05	0.0002	0.0066	0.0131	4001	30000
0.5*rev*rev	-0.0032	0.0110	6.40E-05	-0.0247	-0.0032	0.0182	4001	30000

Finally, the robustness of the first-order *atm* and *pax* parameters has been also checked. The same specification was kept and the model was re-estimated using several different data samples, but always keeping the same range of airport sizes and a comparable approximation point.

Table 5.4 Robustness of the long-run cost function parameter estimates

no. Obs	800	825	850	875	900	925	950	975	1000	1025	1050	1069
atm	0.0977	0.1022	0.1015	0.0949	0.0999	0.1045	0.1180	0.1277	0.1267	0.1303	0.1319	0.1261
pax	0.2905	0.2880	0.2865	0.2904	0.2825	0.2771	0.2695	0.2678	0.2629	0.2615	0.2615	0.2742

Table 5.4 shows some degree of variation in the estimated coefficients. However, these average values are consistent with the posterior distributions presented in Annex 3.1, where the estimated confidence interval for the *atm* parameter ranges between [0.05-0.20] and between [0.19-0.36] for the *pax* coefficient. For that reason, the conclusion is

that the use of a very broad database provides enough variability to allow the identification of the individual coefficients in spite of the presence of multicollinearity.

5.2 Short-run model

The estimation of the short-run model follows the same straightforward strategy. Only the prices of the variable factors (materials and labor) remain on the cost frontier, while the capital price is changed by one or more indicators of capital stock. Data on the airport's fixed factors are relatively easy to gather, either from published sources or by direct request. The four fixed factors considered are the gross floor area of terminal buildings (TER-m^2), total runway length (RUN-m), number of boarding gates (GAT), and check-in desks (CHK). The correlation matrix was calculated and is shown in Table 5.5. It is observed that, as expected, a great degree of correlation is present and, therefore, it is highly advisable to discard a few of these factors in order to avoid additional multicollinearity problems. As the number of boarding gates and check in desks are obviously explained by the total surface of the terminal buildings (TER), these two variables were finally discarded from the model specification, as well as the capital price, leaving only TER and RUN as indicators of the fixed capital stock.

Table 5.5 Correlations between fixed factors

	TER	RUN	GAT	CHK
TER	1	0,791	0,924	0,924
RUN	0,791	1	0,822	0,753
GAT	0,924	0,822	1	0,932
CHK	0,924	0,753	0,932	1

The final equation shown in Table 5.6 includes 23 variables (R^2 = 0.939). The model performs well and the most relevant parameters are significantly different from zero. The major difference in comparison with the long-run specification is the absence of the commercial revenues among the first-order output parameters. This variable became non-significant mainly because of its high correlation with the terminal surface variable (0.86). It should be taken into account that: i) the AA's financial statements were the primary source for information; ii) most retail firms are not related companies and operate under rental lease agreements; and iii) these firms are usually not included in the consolidation perimeter of the AA. Therefore neither labor nor material costs for these firms are expected to be featured in the data[6]. Thus, they can be considered to be fixed given a certain terminal surface. They were included, however, in a second-order

[6] The inclusion of the REV variable in the long-run model was mainly related to the capital/depreciation of the leased facilities (fixed costs in the short run) which are usually recorded in the AA's financial statements, as the AA remains the owner. The issue of dedicated facilities was addressed in Chapter 4.

interaction with the terminal surface in order to catch some (weak) complementarity effect, as in the long-run model.

The final parameter is the interaction between ATM and RUN. This very interesting variable determines the evolution of the variable cost elasticity with respect to the airport size. The positive sign indicates that the evident cost savings for serving a higher number of aircraft in the same infrastructure will become exhausted at a certain point. The inverse of the sum of the first-order output parameters gives the average elasticity with respect to variable costs. In the short-run case, this elasticity is expected to be significantly higher than in the long-run case, mainly because in the short-run model the assumption is that the capital (runways and terminal) of most recently expanded airports cannot be easily adapted to demand conditions, and they will be operating with an evident excess of capacity. The average elasticity yields 2.32, indicating that the mean airport is far from utilizing its fixed infrastructure optimally.

Table 5.6 Initial values for the WinBUGS sampling in the short-run model

	Coefficient	Std. error	t-Statistic	Prob
constant	10.29979	0.010141	1015.692	0.0000
atm	0.059584	0.019752	3.016578	0.0026
pax	0.303645	0.017755	17.10216	0.0000
cgo	0.067628	0.005630	12.01213	0.0000
ter	0.201881	0.012922	15.62251	0.0000
run	0.045259	0.021374	2.117487	0.0343
wm	0.534688	0.004670	114.4906	0.0000
wp	0.468532	0.005211	89.90446	0.0000
atm*wm	0.022950	0.013812	1.661627	0.0967
atm*wp	-0.050757	0.018370	-2.762990	0.0058
pax*wm	0.071536	0.010964	6.524723	0.0000
pax*wp	0.046667	0.015465	3.017502	0.0026
cgo*wm	-0.004427	0.004088	-1.082877	0.2789
cgo*wp	0.007442	0.005089	1.462329	0.1437
ter*wm	-0.009520	0.009791	-0.972272	0.3310
ter*wp	-0.040007	0.011611	-3.445703	0.0006
run*wm	-0.060530	0.014391	-4.206095	0.0000
run*wp	-0.005030	0.018679	-0.269310	0.7877
0.5*wm*wm	0.087433	0.006827	12.80612	0.0000
wm*wp	-0.097908	0.007879	-12.42724	0.0000
0.5*wp*wp	-0.062347	0.022788	-2.735939	0.0062
atm*run	0.075798	0.009847	7.697797	0.0000
ter*rev	-0.006057	0.003591	-1.686507	0.0918

Finally, once the final specification has been chosen, the full system is formulated, taking into account the allocative effects in the variable input price vector. In the short-run case, the materials are chosen as the reference input. Thus,

$$w^{*}=[w_m, w_p \exp(\xi_p)],$$

where ξ_p indicates the AI for the labor input with respect to the materials. Regarding the hyper-parameters of the model, the only variation from the long-run is that this labor allocative effect was allowed much more variability because of its new definition.

Hence, it was defined as a standard normal. The final specification of the short-run system can be seen at the end of this chapter in Appendix 5A.2 and the transcription into WinBUGS code is presented in Appendix 5B.2. The chain was run with a burn-in of 4,000 iterations and 30,000 retained draws. The results are shown in Table 5.7, which reports the posterior mean, median and standard deviation with a 95 percent posterior confidence interval.

Table 5.7 Short-run cost function parameter estimates

	mean	*sd*	*MC error*	*2.5%*	*median*	*97.5%*	*start*	*sample*
constant	9.8271	0.03697	0.001507	9.7513	9.8275	9.8975	4001	30000
atm	0.05594	0.01822	2,24E-01	0.02031	0.05618	0.09115	4001	30000
pax	0.26132	0.03127	5,75E-01	0.20063	0.26185	0.32173	4001	30000
cgo	0.03618	0.01111	1,44E-01	0.01478	0.03615	0.05796	4001	30000
ter	0.25893	0.03224	5,41E-01	0.19614	0.25882	0.32331	4001	30000
run	0.12363	0.04934	8,18E-01	0.02799	0.12343	0.22032	4001	30000
wm	0.50817	0.00843	1,01E-01	0.49167	0.50839	0.52455	4001	30000
wp	0.49191	0.00843	1,01E-01	0.47553	0.49170	0.50843	4001	30000
atm*wm	0.06994	0.02229	2,41E-01	0.02601	0.06986	0.11399	4001	30000
atm*wp	-0.06994	0.02229	2,41E-01	-0.11399	-0.06985	-0.02598	4001	30000
pax*wm	-0.01074	0.02057	2,63E-01	-0.05171	-0.01076	0.02971	4001	30000
pax*wp	0.03639	0.02358	2,33E-01	-0.00943	0.03643	0.08195	4001	30000
cgo*wm	-0.01473	0.00777	9,13E-02	-0.03011	-0.01469	4,89E-04	4001	30000
cgo*wp	0.01378	0.00883	9,26E-02	-0.00376	0.01387	0.03128	4001	30000
ter*wm	0.03061	0.01166	2,35E-01	0.00766	0.03091	0.05277	4001	30000
ter*wp	-0.03223	0.01693	2,30E-01	-0.06222	-0.03198	-0.00120	4001	30000
run*wm	0.01451	0.02168	3,48E-01	-0.03099	0.01523	0.05642	4001	30000
run*wp	-0.00351	0.03468	3,48E-01	-0.07148	-0.00357	0.06455	4001	30000
0.5*wm*wm	0.07317	0.01475	2,37E-01	0.04404	0.07339	0.10226	4001	30000
wm*wp	-0.07517	0.01488	3,43E-01	-0.10478	-0.07504	-0.04571	4001	30000
0.5*wp*wp	-0.08749	0.04267	4,18E-01	-0.17243	-0.08731	-0.00352	4001	30000
atm*run	0.05483	0.00909	1,06E-01	0.03702	0.05485	0.07271	4001	30000
ter*rev	-0.03481	0.00530	8,35E-02	-0.04529	-0.03481	-0.02439	4001	30000

The estimation performs well, showing correct signs and significance of the most important parameters. Note that the intercept is significantly lower than the proposed initial value, and that both interactions between runway length and input prices become non-significant. In spite of that, the estimated cost function satisfies all specified theoretical restrictions expected for a short-run specification.

Appendix 5A Model specifications

Appendix 5A.1 Long-run model specification

$$
\begin{aligned}
\ln TC_{it}^{a} = {} & \alpha_1+\alpha_2 atm+\alpha_3 pax+\alpha_4 cgo+\alpha_5 rev+\beta_6 wc+\beta_7 wm+\beta_8 wp+\gamma_9 atm*wc+\\
& +\gamma_{10} atm*wm+\gamma_{11} atm*wp+\gamma_{12} pax*wc+\gamma_{13} pax*wm+\gamma_{14} pax*wp+\\
& +\gamma_{15} cgo*wc+\gamma_{16} cgo*wm+\gamma_{17} cgo*wp+\gamma_{18} rev*wc+\gamma_{19} rev*wm+\gamma_{20} rev*wp+\\
& +\delta_{21} wm*wc+\delta_{22} 0.5*wm*wm+\delta_{23} 0.5*wc*wc+\delta_{24} wm*wp+\delta_{25} wc*wp+\\
& +\delta_{26} 0.5*wp*wp+\rho_{27} atm*pax+\rho_{28} 0.5*cgo*cgo+\rho_{29} 0.5*rev*rev+\\
& +\beta_7\xi_m+\beta_8\xi_p+\gamma_{10} atm*\xi_m+\gamma_{11} atm*\xi_p+\gamma_{13} pax*\xi_m+\gamma_{14} pax*\xi_p+\gamma_{16} cgo*\xi_m+\\
& +\gamma_{17} cgo*\xi_p+\gamma_{19} rev*\xi_m+\gamma_{20} rev*\xi_p+\delta_{21}\xi_m*wc+\delta_{22} wm*\xi_m+\delta_{22} 0.5*\xi_m*\xi_m+\\
& +\delta_{24}\xi_m*wp+\delta_{24} wm*\xi_p+\delta_{24}\xi_m*\xi_p+\delta_{25} wc*\xi_p+\delta_{26} wp*\xi_p+\delta_{26} 0.5*\xi_p*\xi_p+\\
& +\ln(G_{it})+u_{it}+v_{it}
\end{aligned}
$$

$$S_C^a=\frac{\beta_6+\gamma_9 atm+\gamma_{12} pax+\gamma_{15} cgo+\gamma_{18} rev+\delta_{21} wm+\delta_{23} wc+\delta_{25} wp+\delta_{21}\xi_m+\delta_{25}\xi_p}{G_{it}}$$

$$S_M^a=\frac{\beta_7+\gamma_{10} atm+\gamma_{13} pax+\gamma_{16} cgo+\gamma_{19} rev+\delta_{22} wm+\delta_{21} wc+\delta_{24} wp+\delta_{22}\xi_m+\delta_{24}\xi_p}{G_{it}*e^{\xi m}}$$

$$S_P^a=\frac{\beta_8+\gamma_{11} atm+\gamma_{14} pax+\gamma_{17} cgo+\gamma_{20} rev+\delta_{24} wm+\delta_{25} wc+\delta_{26} wp+\delta_{24}\xi_m+\delta_{26}\xi_p}{G_{it}*e^{\xi p}}$$

$$
\begin{aligned}
G_{it} = {} & [\beta_6+\gamma_9 atm+\gamma_{12} pax+\gamma_{15} cgo+\gamma_{18} rev+\delta_{21} wm+\delta_{23} wc+\delta_{25} wp+\delta_{21}\xi_m+\delta_{25}\xi_p]+\\
& +[\beta_7+\gamma_{10} atm+\gamma_{13} pax+\gamma_{16} cgo+\gamma_{19} rev+\delta_{22} wm+\delta_{21} wc+\delta_{24} wp+\delta_{22}\xi_m+\delta_{24}\xi_p]/e^{\xi m}+\\
& +[\beta_8+\gamma_{11} atm+\gamma_{14} pax+\gamma_{17} cgo+\gamma_{20} rev+\delta_{24} wm+\delta_{25} wc+\delta_{26} wp+\delta_{24}\xi_m+\delta_{26}\xi_p]/e^{\xi p}
\end{aligned}
$$

$$\beta_6+\beta_7+\beta_8=1$$

$$
\begin{aligned}
&\gamma_9+\gamma_{10}+\gamma_{11}=0\\
&\gamma_{12}+\gamma_{13}+\gamma_{14}=0\\
&\gamma_{15}+\gamma_{16}+\gamma_{17}=0\\
&\gamma_{18}+\gamma_{19}+\gamma_{20}=0
\end{aligned}
$$

$$
\begin{aligned}
&\delta_{21}+\delta_{23}+\delta_{25}=0\\
&\delta_{21}+\delta_{22}+\delta_{24}=0\\
&\delta_{24}+\delta_{25}+\delta_{26}=0
\end{aligned}
$$

Appendix 5A.2 Short-run model specification

$$
\begin{aligned}
\ln VC_{it}^{a} = {} & \alpha_1 + \alpha_2 atm + \alpha_3 pax + \alpha_4 cgo + \varphi_5 ter + \varphi_6 run + \beta_7 wm + \beta_8 wp + \gamma_9 atm*wm + \\
& + \gamma_{10} atm*wp + \gamma_{11} pax*wm + \gamma_{12} pax*wp + \gamma_{13} cgo*wm + \gamma_{14} cgo*wp + \gamma_{15} ter*wm + \\
& + \gamma_{16} ter*wp + \gamma_{17} run*wm + \gamma_{18} run*wp + \delta_{19} 0.5*wm*wm + \delta_{20} wm*wp + \\
& + \delta_{21} 0.5*wp*wp + \rho_{22} atm*run + \rho_{23} ter*rev + \\
& + \beta_8 \xi_p + \gamma_{10} atm*\xi_p + \gamma_{12} pax*\xi_p + \gamma_{14} cgo*\xi_p + \gamma_{16} ter*\xi_p + \gamma_{18} run*\xi_p + \delta_{20} wm*\xi_p + \\
& + \delta_{21} wp*\xi_p + \delta_{21} 0.5*\xi_p*\xi_p + \ln(G_{it}) + u_{it} + v_{it}
\end{aligned}
$$

$$
S_M^a = \frac{\beta_7 + \gamma_9 atm + \gamma_{11} pax + \gamma_{13} cgo + \gamma_{15} ter + \gamma_{17} run + \delta_{19} wm + \delta_{20} wp + \delta_{20} \xi_p}{G_{it}}
$$

$$
S_P^a = \frac{\beta_8 + \gamma_{10} atm + \gamma_{12} pax + \gamma_{14} cgo + \gamma_{16} ter + \gamma_{18} run + \delta_{20} wm + \delta_{21} wp + \delta_{21} \xi_p}{G_{it} * e^{\xi p}}
$$

$$
\begin{aligned}
G_{it} = {} & [\beta_7 + \gamma_9 atm + \gamma_{11} pax + \gamma_{13} cgo + \gamma_{15} ter + \gamma_{17} run + \delta_{19} wm + \delta_{20} wp + \delta_{20} \xi_p] + \\
& + [\beta_8 + \gamma_{10} atm + \gamma_{12} pax + \gamma_{14} cgo + \gamma_{16} ter + \gamma_{18} run + \delta_{20} wm + \delta_{21} wp + \delta_{21} \xi_p] \big/ e^{\xi p}
\end{aligned}
$$

$$\beta_7 + \beta_8 = 1$$

$$\gamma_9 + \gamma_{10} = 0$$
$$\gamma_{11} + \gamma_{12} = 0$$
$$\gamma_{13} + \gamma_{14} = 0$$
$$\gamma_{15} + \gamma_{16} = 0$$
$$\gamma_{17} + \gamma_{18} = 0$$

$$\delta_{19} + \delta_{20} = 0$$
$$\delta_{20} + \delta_{21} = 0$$

Appendix 5B WinBUGS estimation codes

Appendix 5B.1 WinBUGS code for the long-run model

```
model
{for (k in 1:K){
		u[k] ~ dexp(lambda)
		eta[k] ~ dnorm(0.0,etasigma)
		allm[k] ~ dnorm(0.0, allmsigma)
		allp[k] ~ dnorm(0.0, allpsigma)}

for ( i in 1:N ) {
		tc[i] ~ dnorm(mu[i], prec)
		scale[i]<-1/(beta[2]+beta[3]+beta[4]+beta[5])
		eff[i] <- exp(-u[id[i]]*exp(eta[id[i]]*(t[i]-T)))
		mu[i] <- u[id[i]]*exp(eta[id[i]]*(t[i]-T)) + inprod(beta[], data[i, 1:p]) + beta[7]*allm[id[i]] +
beta[8]*allp[id[i]] + beta[10]*data[i,2]*allm[id[i]] +  beta[11]*data[i,2]*allp[id[i]] + beta[13]*data[i,3]*allm[id[i]] +
beta[14]*data[i,3]*allp[id[i]] + beta[16]*data[i,4]*allm[id[i]] +  beta[17]*data[i,4]*allp[id[i]] +
beta[19]*data[i,5]*allm[id[i]] + beta[20]*data[i,5]*allp[id[i]] + beta[21]*data[i,6]*allm[id[i]] +
beta[22]*data[i,7]*allm[id[i]] + beta[22]*0.5*allm[id[i]]*allm[id[i]] + beta[24]*data[i,7]*allp[id[i]] +
beta[24]*data[i,8]*allm[id[i]] + beta[24]*allm[id[i]]*allp[id[i]] + beta[25]*data[i,6]*allp[id[i]] +
beta[26]*data[i,8]*allp[id[i]] + beta[26]*0.5*allp[id[i]]*allp[id[i]] + log(g[i])

g[i] <- g1[i] + g2[i] + g3[i]
g1[i]<- beta[6] + beta[9]*data[i,2] + beta[12]*data[i,3] + beta[15]*data[i,4] + beta[18]*data[i,5] +
  beta[21]*data[i,7] + beta[23]*data[i,6] + beta[25]*data[i,8] + beta[21]*allm[id[i]] + beta[25]*allp[id[i]]
g2[i] <- (beta[7] + beta[10]*data[i,2] + beta[13]*data[i,3] + beta[16]*data[i,4] + beta[19]*data[i,5] +
  beta[21]*data[i,6] + beta[22]*data[i,7] + beta[24]*data[i,8] + beta[22]*allm[id[i]] +
  beta[24]*allp[id[i]])/exp(allm[id[i]])
g3[i] <- (beta[8] + beta[11]*data[i,2] + beta[14]*data[i,3] + beta[17]*data[i,4] + beta[20]*data[i,5] +
  beta[24]*data[i,7] + beta[25]*data[i,6] + beta[26]*data[i,8] + beta[24]*allm[id[i]] +
  beta[26]*allp[id[i]])/exp(allp[id[i]])

sc[i] ~ dnorm(nu[i], prec)
sm[i] ~ dnorm(pi[i], prec)
sp[i] ~ dnorm(phi[i], prec)

nu[i]<- g1[i]/g[i]
pi[i]<- g2[i]/g[i]
phi[i]<- g3[i]/g[i]

lin[i]<-beta[6] + beta[7] + beta[8]
a[i]<-beta[9] + beta[10] + beta[11]
b[i]<-beta[12] + beta[13] + beta[14]
c[i]<-beta[15] + beta[16] + beta[17]
d[i]<-beta[18] + beta[19] + beta[20]
e[i]<-beta[21] + beta[23] + beta[25]
f[i]<-beta[21] + beta[22] + beta[24]
h[i]<-beta[24] + beta[25] + beta[26]

data[i,1] ~ dnorm(lin[i], 1000000)
zero[i] ~ dnorm(a[i], 1000000)
zero[i] ~ dnorm(b[i], 1000000)
zero[i] ~ dnorm(c[i], 1000000)
zero[i] ~ dnorm(d[i], 1000000)
zero[i] ~ dnorm(e[i], 1000000)
zero[i] ~ dnorm(f[i], 1000000)
zero[i] ~ dnorm(h[i], 1000000)
						}
lambda ~ dexp(lambda0)
lambda0 <- -log(rstar)

for (i in 1:p) {beta[i] ~ dnorm(0.0, betasigma)}
		prec ~ dgamma(a0, a1)}}
```

Appendix 5B.2 WinBUGS code for the short-run model

```
model
{for (k in 1:K) {
		u[k] ~ dexp(lambda)
		eta[k] ~ dnorm(0.0, etasigma)
		allp[k] ~ dnorm(0.0, allpsigma)}

for ( i in 1:N ) {
		tc[i] ~ dnorm(mu[i], prec)
		eff[i] <- exp(-u[id[i]]*exp(eta[id[i]]*(t[i]-T)))
		mu[i] <- u[id[i]]*exp(eta[id[i]]*(t[i]-T)) + inprod(beta[], data[i, 1:p]) + beta[8]*allp[id[i]] +
beta[10]*data[i,2]*allp[id[i]] + beta[12]*data[i,3]*allp[id[i]] +  beta[14]*data[i,4]*allp[id[i]] +
beta[16]*data[i,5]*allp[id[i]] + beta[18]*data[i,6]*allp[id[i]] + beta[20]*data[i,7]*allp[id[i]] +
beta[21]*data[i,8]*allp[id[i]] + beta[21]*0.5*allp[id[i]]*allp[id[i]] + log(g[i])

g[i] <- g1[i] + g2[i]
g1[i] <- beta[7] + beta[9]*data[i,2] + beta[11]*data[i,3] + beta[13]*data[i,4] + beta[15]*data[i,5] +
  beta[17]*data[i,6] + beta[19]*data[i,7] + beta[20]*data[i,8] + beta[20]*allp[id[i]]
g2[i] <- (beta[8] + beta[10]*data[i,2] + beta[12]*data[i,3] + beta[14]*data[i,4] + beta[16]*data[i,5] +
  beta[18]*data[i,6] + beta[20]*data[i,7] + beta[21]*data[i,8] + beta[21]*allp[id[i]])/exp(allp[id[i]])

ssm[i] ~ dnorm(pi[i], prec)
ssp[i] ~ dnorm(phi[i], prec)

pi[i]<- g1[i]/g[i]
phi[i]<- g2[i]/g[i]

lin[i]<-beta[7] + beta[8]
a[i]<-beta[9] + beta[10]
b[i]<-beta[11] + beta[12]
c[i]<-beta[13] + beta[14]
d[i]<-beta[15] + beta[16]
e[i]<-beta[17] + beta[18]
f[i]<-beta[19] + beta[20]
h[i]<-beta[20] + beta[21]

data[i,1] ~ dnorm(lin[i], 1000000)
zero[i] ~ dnorm(a[i], 1000000)
zero[i] ~ dnorm(b[i], 1000000)
zero[i] ~ dnorm(c[i], 1000000)
zero[i] ~ dnorm(d[i], 1000000)
zero[i] ~ dnorm(e[i], 1000000)
zero[i] ~ dnorm(f[i], 1000000)
zero[i] ~ dnorm(h[i], 1000000) }

lambda0 <- -log(rstar)
lambda ~ dexp(lambda0)

for (i in 1:p) {beta[i] ~ dnorm(0.0, betasigma)}
prec ~ dgamma(a0, a1)}}
```

CHAPTER 6

ANALYSIS OF THE INDUSTRY STRUCTURE

Although most of the biggest airports in the world are undertaking huge investments in new infrastructures, which will increase their capacity in the future, there is no proper empirical evidence on the existence of scale economies in airport operations which can provide economic justification for these expansion programs. Apart from the cited literature on the estimation of airport cost functions, which did not recognize the presence of increasing returns to scale (IRS) further than 3 or 4 mppa, many other publications have drawn their own conclusions on this issue. Walters (1978) and Starkie and Thompson (1985) support the common intuition that aircraft operations enjoy scale economies, even for the operation of very small aircraft, because of lumpiness in airside investments. On the contrary, diseconomies of scale may exist in passenger/baggage operations, since large expenditures are needed to accommodate increasing throughput levels. The construction and maintenance of, for example, a rapid transit system between terminal buildings and the provision of enough parking spaces for travellers and visitors requires a greater financial effort that certainly increases with the scale of production. The validation of these economic intuitions through empirical evidence is the main objective of this chapter.

6.1 Scale economies

The analysis of the economies of scale is based on the first- and second-order output parameters of the estimated cost frontier (lnC^0), without including the interactions related to the two specified allocative effects (lnC^{al}). The logarithmic transformation allows us to obtain the expression of each output's cost elasticity directly from their partial derivatives. Note that the explanatory variables to be used in these calculations still remain logged and deviate from their average values, i.e.

$$S = \frac{1}{\sum_{i=1}^{n} \frac{\partial \ln C(\omega, Y)}{\partial \ln Y_i}} = \frac{1}{\sum_{i=1}^{n} \eta_i} .$$

$$\frac{\partial \ln C^o}{\partial atm} = \alpha_2 + \gamma_9 wc + \gamma_{10} wm + \gamma_{11} wp + \rho_{27} pax$$
$$\frac{\partial \ln C^o}{\partial pax} = \alpha_3 + \gamma_{12} wc + \gamma_{13} wm + \gamma_{14} wp + \rho_{27} atm$$
$$\frac{\partial \ln C^o}{\partial cgo} = \alpha_4 + \gamma_{15} wc + \gamma_{16} wm + \gamma_{17} wp + \rho_{28} cgo$$
$$\frac{\partial \ln C^o}{\partial rev} = \alpha_5 + \gamma_{18} wc + \gamma_{19} wm + \gamma_{20} wp + \rho_{29} rev.$$

The scale elasticity at the geometric mean airport (4.7 mppa; 48,000 ATM_{737}) is obtained directly as the inverse of the sum of the first-order output parameters ($\alpha_2 + \alpha_3 + \alpha_4 + \alpha_5$). It yields 1.85, a very significant value indeed. However, in order to definitely reject the presence of constant returns to scale (CRS) in the average airport, an alternative approach to the classic Wald test will be carried out. This interesting WinBUGS feature consists of obtaining the posterior density pictures for any defined stochastic node. As seen in the full code featured in Appendix 5B.1, the node *scale* was created to measure the scale elasticity at the mean airport (Table 6.1). In addition, a graphic representation of the standard 95 percent confidence interval is also provided. As seen in the Figure 6.1[1], all probability mass lies in the IRS zone around the 1.85 value, clearly rejecting CRS, as expected.

Table 6.1 Posterior statistics of the *scale* node

	mean	sd	2.5%	median	97.5 %
scale	1.854	0.07597	1.705	1.853	2.003

Looking back at the estimated cost frontier, it is clear that the cost elasticity of the whole output vector increases with the scale of production. The positive sign of the interaction between *atm* and *pax* indicates that these IRS are going to be exhausted at a certain output level. The cgo^2 variable also has a small effect in the same direction. However, the negative sign of the rev^2 parameter is of much more interest. In spite of not being significantly distinct from zero, the fact that a higher probability density (see Annex 3.1 for the kernel density picture) is located on the negative side can be clearly interpreted as a cost complementarity between aviation and non-aviation activities at major commercial airports. This negative sign indicates that the range of operations where airports enjoy IRS could be expanded if airport regulation allows the joint production of aeronautical and commercial activities. Thus it would be possible to observe in the real world that airports with control of commercial activities will grow

[1] All the figures in this chapter (Figures 6.1 to 6.10) are presented in Appendix 6A.

more than simple airfields to become large "shopping malls". In order to provide empirical evidence for this intuition, the industry's Minimum Efficient Scale (MES) [2] will first be calculated for the whole output vector, as specified on the cost frontier, and then only for the aeronautical outputs (see Section 6.1.2).

A basic procedure to determine the industry's MES will be used. First, the airport's specific scale elasticities (for the year 2006) are calculated using the partial derivatives shown above. Second, these values will then be plotted against the most representative variable of airport size (as explained in the previous chapter): the number of 737-equivalent aircraft operations (ATM_{737}). Third, one of the standard nonlinear equations provided by Excel will be fitted to the pairs (Figure 6.2). Finally, the production level where the economies of scale are fully exhausted will be calculated by solving the equation of the L-shaped scale elasticity curve for CRS, thus obtaining the MES.

The airport-specific estimations of the scale elasticities for the year 2006 are detailed in Annex 4. However, Table 6.2 summarizes this information by presenting the average estimations for a wide range of output levels.

Table 6.2 Scale elasticities at different production levels

PAX (mil.)	Avg. Scale	ATM737 (thousands)	Avg. Scale
0 to 0.5	4.032	0 to 5	4.430
0.5 to 1	2.756	5 to 15	2.467
1 to 5	2.086	15 to 75	1.917
5 to 20	1.685	75 to 200	1.636
20 to 40	1.475	200 to 500	1.515
40+	1.430	500+	1.374

The scale elasticities vary between 4.36 at AAR and 1.23 at PEK. These values are plotted against the number of ATM_{737}. It can be clearly observed that the estimated values tend to decrease with airport size, as expected (Figure 6.2). The adjusted potential equation presents a better fit than the logarithmic one. However, solving for CRS using the first equation does not provide any finite result, which could only be explained if the economies of scale in airport operations were not exhausted at any output level. Using the second alternative, an approximate value could be obtained. The MES is not reached until roughly 2,275,000 ATM_{737} per year. This result provides a strong economic justification for the actual expansion trend observed in the industry because there is still considerable scope for future expansions, as the biggest scales of production currently serve almost a million annual ATM_{737} (ATL, ORD, LHR). Hence,

[2] The MES is the output level in the long run at which the economies of scale have been fully exploited.

within the current technological frontier, the world's leading airports will continue to benefit from scale economies in the provision of infrastructure for air transportation and commercial activities until they reach between two or three times their current scales.

However, the question which output will be responsible for slowly exhausting the scale economies in the future still remains unanswered. The aforementioned studies argued that the passenger service is the most likely suspect because of the progressively larger investments in landside infrastructures, which are related to the steady increase in annual passenger throughput. This intuition will be empirically validated by estimating the output-specific degree of scale for the passenger service. The calculation of the degree of scale economies for a subset R of outputs was introduced in Chapter 2, i.e.

$$S_R(\omega,Y)=\frac{C(\omega,Y)-C(\omega,Y_{N-R})}{\sum_{j\in R}Y_j\dfrac{\partial C(\omega,Y)}{\partial Y_j}}=\frac{IC_R(\omega,Y)}{\sum_{j\in R}Y_j\dfrac{\partial C(\omega,Y)}{\partial Y_j}}.$$

As a technical note, the incremental costs of the passenger output were estimated using a "small value" approach[3], because the translog is not analytic at zero.

The results are shown in Figure 6.3. It can be seen that most major airports are currently experiencing diseconomies of scale in the provision of infrastructure for passenger and baggage operations. As an approximate value, DRS may appear over 61.5 mppa, which is roughly the current scale of, for example, LHR or DFW. The explosive passenger growth requires the adoption of new operational procedures (many of them never seen before) and large capital investments, which are progressively incorporated into the cost data. Therefore, the future estimation of a new cost frontier with renovated data is absolutely necessary and will probably lead to a dramatic downward revision of the industry MES. The expected scenario for the near future is that the increasing average airport size will probably meet the decreasing MES for the effect of the increased passenger traffic on the airport's operational expenditures.

In addition, given these results, airport regulation could also play an important role in order to determine the optimal size of airports. In the event that airport activities (*atm*, *pax*, *cgo*, *rev*) were unbundled, and each activity was regulated and managed independently, the optimal size could be totally different than in an environment in which all the activities are under the umbrella of the Airport Authority.

[3] The small value was considered to be 0.5 mppa in order not to deviate too much from the approximation point. In addition, all airports serving under 1 mppa were excluded from the calculation of the MES.

All these scale results should, however, be considered by their real content, i.e. a simple measure of the financial savings for the AA derived from production increases. In this context, it is insufficient in order to establish the final benefit of an airport expansion project, if any other agent is (most likely) affected by the project. Therefore, conclusions and policy implications, especially concerning public agents and resources, should be treated with caution, as this analysis is clearly limited by the absence of environmental/externality costs and benefits in the specification (see Chapter 9). Taking into account all these external factors, the industry's real (social) MES might possibly be located in smaller levels of production. In this same line of reasoning, the effect of the airport size and the scale of production on the airport's organizational complexity[4] may also play a very important role in the validation of these results. And, finally, other aspects such as the quality of the service should also be taken into account, as many of the world's leading airports, such as LHR or CDG, are consistently ranked bottom in passenger surveys related to the overall service quality (Rosenthal, 2008).

6.1.1 Temporal evolution

It has been shown that economies of scale decrease with airport size because of the industry's own technological features. However, as is common in other transport activities, the main airport capital assets have significant indivisibilities, so it is not always possible to adjust capacity and demand in an optimal manner. In the airport industry, especially at major commercial airports, this can be hardly achieved as runways and terminal buildings need to be projected, taking into account future and not present capacity requirements, thus revealing very important capacity gaps and hence departing from the (minimum) cost function to a higher level of technical inefficiency. This idle capacity increases the distance between average and (efficient) marginal costs generating the appearance of new scale economies and potential cost savings. Therefore, the temporal evolution of the scale elasticity when compared with both traffic and infrastructure development can serve as a descriptor of actual investment/development practices in the industry. The database provides some very interesting case studies concerning this topic.

As noted, optimal airport development (without capacity gaps) may not be achieved at major hubs. In fact, it can only be seen in those small and middle-size airports which are

[4] In this case, other considerations such as the number of carriers and even the diversity of aircraft served should be taken into account, using some sort of hedonic approach.

currently experiencing explosive growth. Development of RIX airport, for example, could be an excellent example of optimal infrastructure investment, as it seems to be well adjusted to its increasing capacity requirements, shifting through the long-run average cost curve. RIX is Latvia's major airport, and in recent years it has experienced an unprecedented increase in demand levels with an inter-annual growth rate of 52 percent in passenger traffic (04-06). In view of this trend, the AA approved an investment program which included the expansion of the terminal building. In spite of this important investment, the new additional capacity was rapidly consumed, and therefore, the development of a new terminal building and a further runway expansion has been recently approved. This evolution is clearly seen in Figure 6.4, which represents the evolution of the scale elasticity (*S*) at two rapidly growing small airports (RIX and BGY). The persistent decrease of *S* clearly indicates a very good adjustment of capacity and demand, successfully consuming part of their scale potential to reduce average costs. The same applies to BGY, which is one of Italy's fastest growing airports with an average 37.5 percent annual increase in passenger traffic (01-06). During these years, the movement areas have been equipped with a new lighting system, and both new passenger and cargo terminals have been expanded. Nevertheless, there is no significant evidence of idle capacity.

According to Buyck (2004) this development is representative of a trend that is surfacing all over Europe, as regional airports are overtaking main hubs in terms of passenger growth rates because of the dynamism of the low-cost carrier sector, which has attached itself to smaller and basic facilities[5] that can be easily expanded allowing the airports (in this case BGY) to consume their scale potential in the long-run by avoiding idle capacity.

Nevertheless, these expansion solutions can not be indefinitely applied because of the unavoidable indivisibilities tied to major airside expansion projects, which commonly require land purchases. In addition, full-service terminals at major airports may not allow such flexibility and expandability and, even if the new-built capacity remains largely idle, the depreciation and financing costs (capital costs) for the whole airport infrastructure will increase at a very significant level, thus increasing the scale elasticity. For this reason, even though most airports show steady increases in aircraft and

[5] These low-cost terminals are commonly adapted from hangars and cargo terminals, providing a single-floor operation area. Thus, the necessary investments are not so important because, normally, travelators, escalators and aerobridges are not provided.

passenger operations, the temporal evolution of the scale elasticity is not always downwards. The traffic expansion periods (scale-consuming) alternate with capacity-expanding periods (scale-creating) which allow the airports to exploit their scale potential in a higher output range. However, in the long run, the overall scale tendency should always point downwards if the traffic evolution meets the projected capacity.

In order to provide empirical evidence in support of this economic intuition, the evolution of the scale elasticity should be analyzed for a wide variety of scales of production, and if possible through the whole life of the airport that serves as the case study. However, this task presents many difficult problems, and, in this case, the database does not feature such broad time spans. In fact, for most of the airports, the average observation period is 8 years (99-06); however, both MAN and CPH are two exceptional cases with 15 observations each (92-06) which provide illustrative examples of this typical development trend (Figure 6.5). As of 2007, MAN is the busiest public airport in the UK. Its Terminal 2 opened in 1993, and was designed to be easily expanded allowing more gates and a larger apron area. From that year, MAN experienced an average 5 percent annual growth in aircraft operations. In 2001, the second runway was inaugurated and traffic growth has continued ever since. The same applies to CPH, which significantly expanded the terminal buildings in 1998.

Because of the data restrictions, this analysis cannot be carried out with the rest of the sample airports, yet these short-run trends may be identified in the recently or currently expanded airports (Figure 6.6). The most representative example of this is PEK. It has registered double-digit growth annually since 2003. In that financial year, it was observed that the traffic expansion was actually higher than the increase in costs, hence the scale elasticity decreased. However, PEK started a very ambitious expansion project that year, which included a third runway and a new terminal with a rail link to the city center, becoming one of the largest airports in the world in terms of land area. This project has created new scale economies derived from this idle capacity, allowing the airport to exploit its cost advantages within the (forecast) higher output range. Because of the inauguration of the new Terminal 3 at PEK during 2007, the predicted value for the scale elasticity was even higher. However, once the projected capacity is reached, PEK should present a scale-consuming development trend like that observed at FRA, where no major expansions have been carried out, and average costs have been reduced primarily by the increase of the average MTOW and, hence of the number of ATM_{737}.

At the other extreme is LAX, whose increasing scale potential is not related to expansion trends but to the persistent decrease in equivalent aircraft operations, artificially creating idle capacity[6]. Another airport which was severely affected by the 9/11 events was DFW, which served as Delta Airlines' second largest hub, but was finally de-hubbed in early 2005. The scale evolution at this airport is very interesting as it shows both scale-creating and -consuming behavior simultaneously. Between 2001 and 2003 DFW lost about 12 percent of its total traffic, but also reduced its operating costs, and hence the moderate increase in the scale elasticity (see Appendix 7B). Note also the flexibility of the capital costs which were adjusted in line with the evolution of traffic. However, in 2004 the traffic figures began to recover, reaching in 2006 the same passenger level as back in 2000. In conjunction with this expansion, three runways were extended and a new international terminal was opened in 2005. From the estimated results, it seems that this huge investment effort has had a very significant effect on operating costs, overcoming the scale-consuming effect with all this new idle capacity.

6.1.2 Aviation-specific returns to scale

The question about the effect of the commercial activities' cost complementarities on the estimation of scale elasticities still remains unresolved. It would be of great interest to know to what extent the provision of infrastructure for air transportation can be expanded without encountering DRS.

As in the previous section, the delicate part of this procedure is how to calculate the non-aviation specific costs, which will be used to estimate the incremental costs for the aviation production subset (*pax*, *atm* and *cgo*). The non-aviation share of total costs was calculated by simply dividing the airport's total predicted (efficient) costs by the prediction obtained using a "small value" approach. As in the PAX case, the first "small value" that came to mind was 1. This represents USD 1,000 at 2006 PPP of commercial revenues, which can be considered a negligible revenue level for almost every airport in the database. Considering both logarithmic transformation and deviation around the mean, the value to be entered into the cost function was:

$$\ln(1) - avg.\ln(rev) = -9.709\,.$$

This value is too far from the cost function's approximation point (i.e. the sample's geometric mean. Note that the translog equation is a second-order Taylor expansion).

[6] LAX ranked as the busiest airport in the world in the year 2000 by ATM_{737} (approx. 1,200,000). In 2006 it comes in 6th place.

This extreme value produced very odd results, including negative scale elasticities at several airports. Hence, in a second approach, the *rev* variable was directly truncated at the approximation point, i.e. allowing the commercial revenues to vary from their minimum value to the geometric mean (around USD 15 million). This procedure, of course, produced biased results, and reasonable estimates are only obtained at major airports, where the above-mentioned value represents a negligible revenue. However, this shortcoming is not really important because the scale effect of commercial activities is only of interest at major hubs. Therefore, the calculation of an approximate value of the aeronautical MES will depend almost exclusively on the values obtained at the set of big hub airports. It was finally observed that, over 50,000 ATM_{737}, all airports were producing commercial revenues significantly over the sample's geometric mean. Hence, only these airports will be used to calculate the MES (see Figure 6.7). Using a logarithmic fit, the aeronautical MES was found to be located between 1.54 and 1.76 million ATM_{737}, with a mean value of 1.65 million[7]. As an example, ORD's modernization program (OMP, 2005) will expand the airport's capacity to over 1.36 million ATM_{737} a year (holding its current average MTOW at 66.6 metric tons).

The same regression was made using the *pax* variable as the output to explain the scale elasticity, obtaining a confidence interval for the MES from 117.8 to 134.6 mppa, with a mean value of 126.4 mppa[8]. As in the ORD case, these values are not very far from projected capacities at many of the world's leading airports. The new JXB airport at Dubai has been planned to serve 120 mppa, and ATL is being expanded with the same figure in mind. Therefore, the main conclusion is that the upcoming generation of major airports will still be enjoying scale economies in their aeronautical activities in the long run. However, as offered capacities are approaching the MES, it is possible that some airports experience DRS created by temporary lack of capacity. In these cases, major airports may draw on their commercial activities in order to increase their own short-run efficient scale, though at some degree of inefficiency in transport provision[9].

A nice example of such a congested airport can be found at AMS (Figure 6.8). The aeronautical activities are so constrained for the fixed capacity that they are dangerously approaching their aeronautical MES, located at around 688,000 annual ATM_{737} or 56

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[7] Confidence intervals were obtained using Eviews software.

[8] Scale = -0.2667Ln(PAX) + 5.9752 [R^2 = 0.6832].

[9] Beesley (1999) argued that the important complementarities between aviation and non-aviation services at major airports provides an adequate incentive for dominant airports to increase their output beyond the level that would be expected from profit-maximization behavior obtained only from aeronautical services.

mppa. However, with the important support of its leading non-aviation sector[10], AMS can theoretically serve much more traffic even though it is already congested. In spite of that, AMS is consistently ranked by Skytrax among the world's best airports in terms of punctuality and passenger service. Again, the validation of these econometrical outcomes depends heavily on the consideration of congestion/delays and other external effects in the specification.

6.1.3 Unweighted ATM variable

In this section, the estimation of the scale elasticities using ATMs without converting them into equivalent units will be discussed. The aggregation of aircraft operations without holding a base aircraft constant was said to bias the estimation of the cost frontier parameters, leading to an underestimation of the degree of scale. The same long-run specification presented in chapter 5 was reestimated using a plain aggregation of ATMs instead of equivalent ones. The results are shown in Table 6.3 (R^2=0.968).

Table 6.3 Long-run cost frontier parameters using an unweighted aggregation of ATM

	Coefficient	Std. error	t-Statistic	Prob
constant	10.69837	0.013127	814.9744	0.0000
atm	0.167743	0.023903	7.017624	0.0000
pax	0.242060	0.025689	9.422784	0.0000
cgo	0.083763	0.007075	11.83900	0.0000
rev	0.093429	0.014385	6.494656	0.0000
wc	0.374864	0.003214	116.6524	0.0000
wm	0.305340	0.002574	118.6445	0.0000
wp	0.319790	0.003023	105.7966	0.0000
....	....	....	....	....
atm*pax	0.042213	0.004518	9.344150	0.0000
0.5*cgo*cgo	0.008957	0.002202	4.067674	0.0000
0.5*rev*rev	-0.007679	0.007934	-0.967792	0.3332

The scale elasticity at the mean airport is now slightly lower at 1.69. However, the most important effect is related to the quadratic ATM parameter, which is now significantly larger. This implies that the airport's total operating costs are now more elastic to variations in the scale of production, reaching the MES at a much smaller output level. This is a direct consequence of the close relationship between the ATM production level and the average aircraft size.

The determination of the MES was carried out using a similar procedure as in the previous subsection. All airport-specific scale elasticities were calculated and plotted against a representative variable of airport size: the aggregated ATM in this case. In

[10] The Schiphol group is well known for being one of the most profitable airport companies, and has successfully expanded it scope of activities out of AMS.

order to obtain the area where the economies of scale are exhausted, both approximation fitting equations are used: the logarithmic and the potential. Figure 6.9 shows that the estimated MES ranges between 500 and 750 thousand ATMs.

As of 2007, most major international hubs in both the US and the EU can be found around this level of production: for example, FRA, CDG, DFW or LAX. However, all these airports have recently been expanded, or are currently undertaking expansion programs (Table 1.4). This result would contradict such practices, as economies of scale would have been exhausted, and there is no economic reason to increase the size of the airport, thus providing economic justification for the existence of multi-airport systems in those areas capable of attracting and generating such an amount of traffic [11].

As noted, the size of the critical aircraft is the major determinant of the airfield size. Hence, this ambiguous result may correspond to a very wide set of different airport sizes and configurations. As an illustrative example, the average aircraft weight at all sample airports within the mentioned CRS range is almost linearly distributed from 55 (DTW) to 116 metric tons MTOW (FRA). The results for the passenger variable do not provide further clarifying evidence because the same airports are featured in the CRS range (from 41.3 to 62.3 mppa). As expected, the misspecification of a heterogeneous variable as airports' output provides an extremely confusing panorama at the time of discussing the optimal industry structure.

Furthermore, the best evidence of the underestimation of the MES is obtained without the support of commercial activities. Therefore, the output range, over which airports enjoy IRS, is still more reduced. As seen in Figure 6.10, the MES is now located around 400,000 annual ATM. Most major international hubs (commercially-oriented) would now be operating in the area of DRS. The scale elasticity of both FRA and PEK is approximately 0.5, which indicates that a 1 percent increase in aeronautical production will result in a 2 percent increase in operating costs. Most Asia-Pacific airports will be also in the DRS area (KIX, NRT or HKG). This is clearly a result of the predominance of very large passenger and freighter aircraft which artificially biases the results.

6.2 Factor substitutability

The estimated parameters for input prices and their interactions provide very interesting information related to the extent to which the technology allows substitution between

[11] The technical efficiency of multi-airport systems will be discussed next in Chapter 7.

production factors. Whether AI exists or not (Chapter 7), the importance of the problem will be exacerbated when production factors are not good substitutes. Since the cost function describes the technology, the degree of substitutability between the production factors can be analyzed by means of Allen partial elasticities of substitution (AES), which are defined as:

$$\sigma_{AES\,ij} = \frac{\lambda_{ij}}{s_j} \text{ where } \lambda_{ij} = \frac{\partial x_i}{\partial w_j}\frac{w_j}{x_i} \text{ and } s_j = \frac{w_j x_j}{C}$$

$$\sigma_{ii} = -\frac{1}{S_i} + 1 + \frac{\delta_{ii}}{S_i S_i} \quad ; \quad \sigma_{ij} = 1 + \frac{\delta_{ij}}{S_i S_j},$$

where δ_{ij} is the parameter of the second-order interaction between input prices i and j, as specified in the translog frontier. These elasticities of substitution have been reported and used in the past to characterize the relationship between production factors[12]. The results are reported in Table 6.4a,b.

Table 6.4a Allen elasticities of substitution (long-run)

	wc	wm	wp
wc	-1.069	0.1886	0.9853
wm	0.1886	-1.1094	0.8853
wp	0.9853	0.8853	-2.5621

Table 6.4b Allen elasticities of substitution (short-run)

	-	wm	wp
-	-	-	-
wm	-	-0.6534	0.6083
wp	-	0.6083	-1.2432

It can be seen that these elasticities allow us to characterize whether the production factors are gross substitutes or complements. In the long-run model, the estimated AES suggest very limited possibilities for substitution between the materials/OS services and capital. In fact, materials are a gross complement for capital for some of the airports. Apart from this value, all point estimates are significantly high. The cross-elasticity between labor and capital is close to 1. Perhaps, in these cases, some capital operations (e.g. automatized baggage handling) are substituted by labor. The same patterns hold for the estimated cross-price elasticity between labor and materials which is slightly lower, though still indicating a high degree of substitutability. Looking at the factors' own price elasticities, it can be seen that the expected signs are correct and that all factor demands are elastic, though demand for labor is by far the most elastic one.

In the short run, only materials and labor costs are considered. The cross-elasticity indicates the existence of some degree of substitutability between the two factors, though it is more limited than in the long run. Considering the demand for materials as a

[12] AES also provide useful information about the curvature of the Hessian matrix of second-order partial derivatives of the translog cost function with respect to input prices.

proxy for the demand for outsourced labor, this result is clearly a consequence of the lack of flexibility of labor markets in many countries. Thus, very important allocative inefficiencies may appear if airports are not allowed to minimize their operating costs through outsourcing minor activities, such as ground handling or maintenance. The factors' own price elasticities also present the correct signs, and again the demand for labor is by far the most elastic, although as expected it is more inelastic than in the long run. The demand for materials becomes inelastic. Most of these services are provided under long-term agreements with the AA. Hence the price of many of them is established beforehand, and the demand is clearly fixed to the level of production which, in most cases, does not change dramatically from year to year.

Appendix 6A Chapter 6 figures

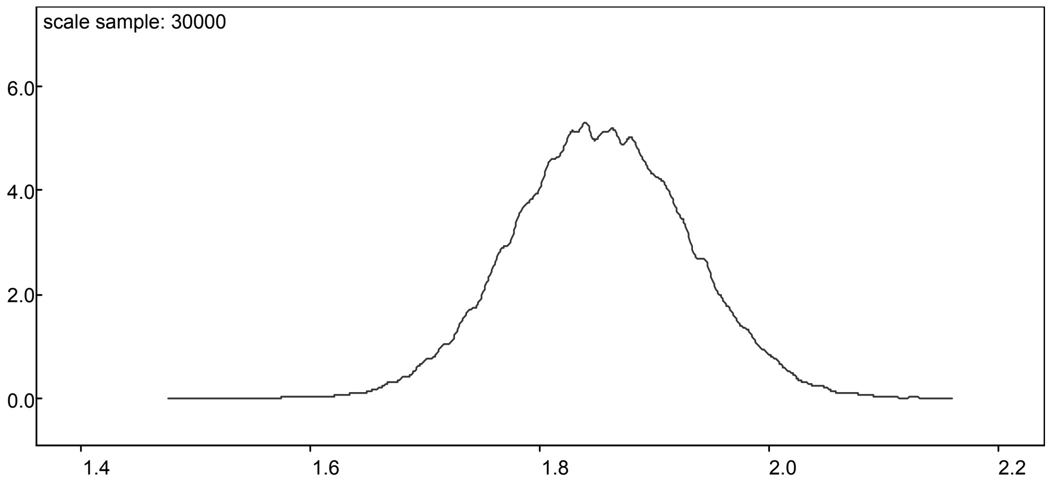

Figure 6.1 Kernel density picture of the scale elasticity node at the mean airport

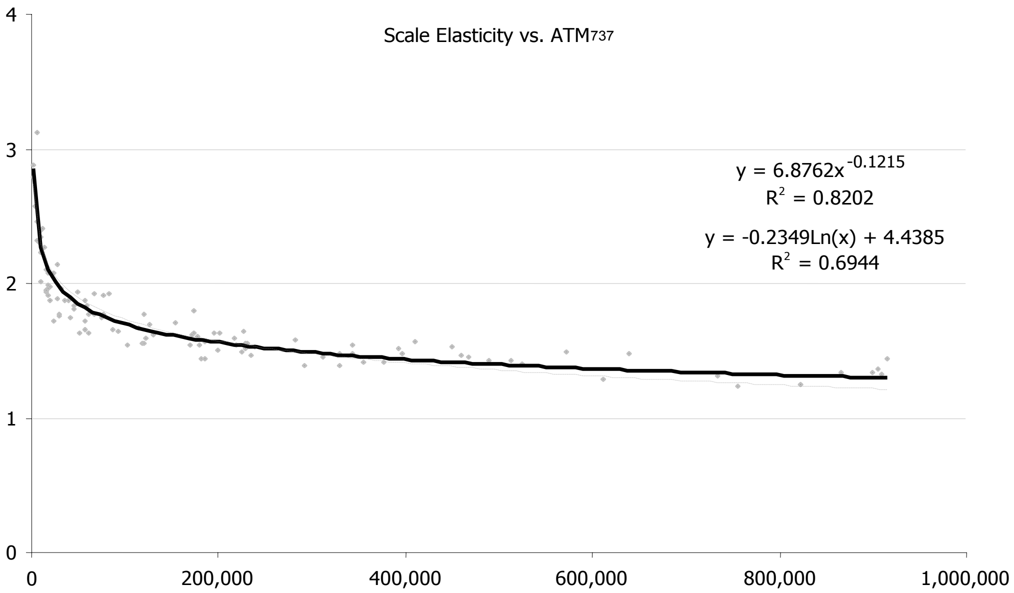

Figure 6.2 Scale elasticities for both aeronautical and non-aeronautical production

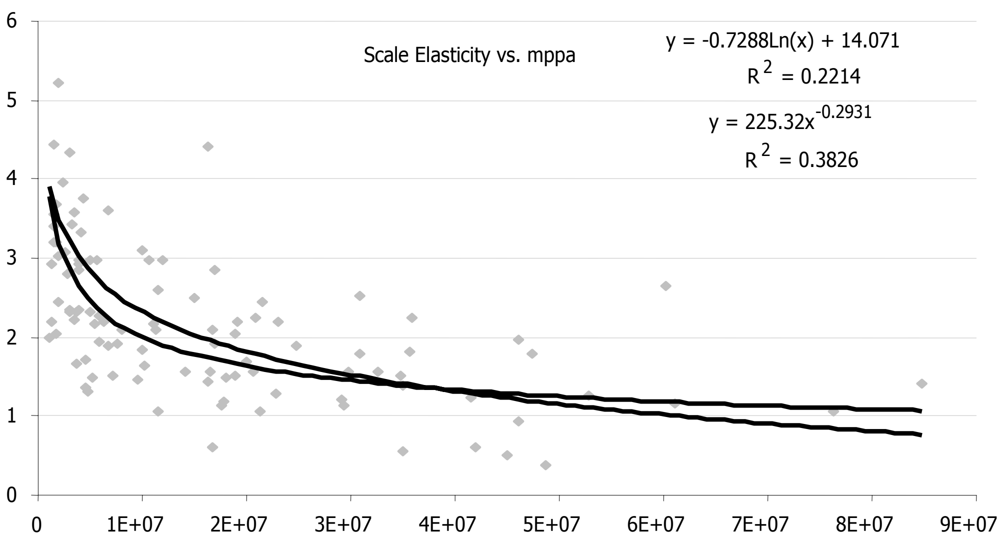

Figure 6.3 Scale elasticities in passenger operations (mppa)

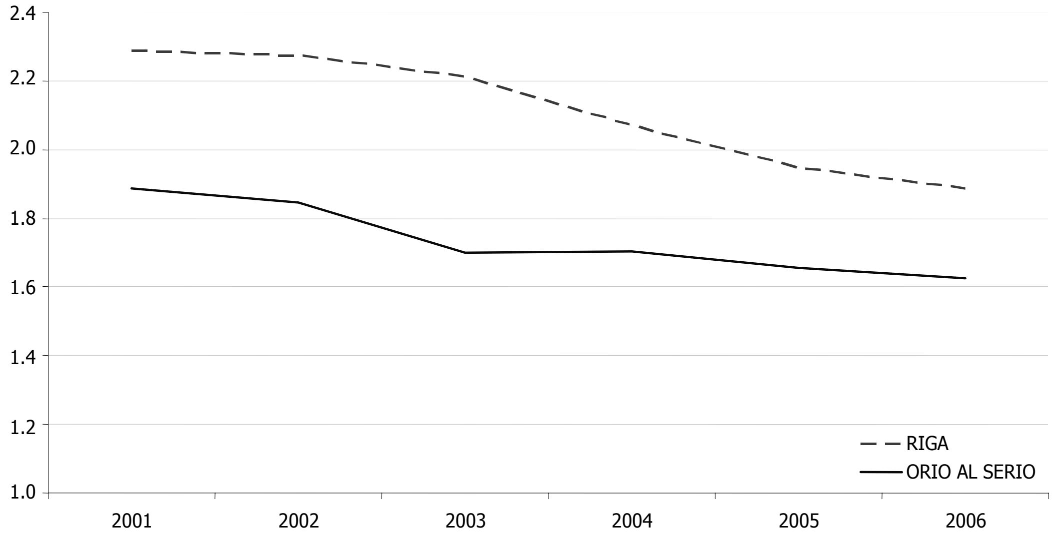

Figure 6.4 Evolution of scale elasticities at rapidly growing small airports

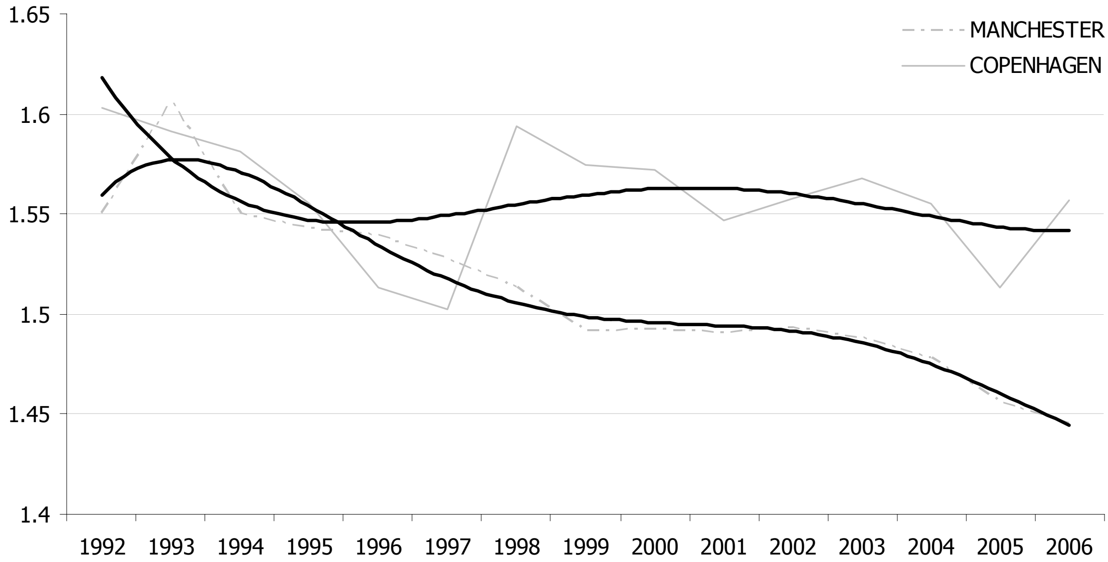

Figure 6.5 Evolution of scale elasticities in the long run at MAN and CPH

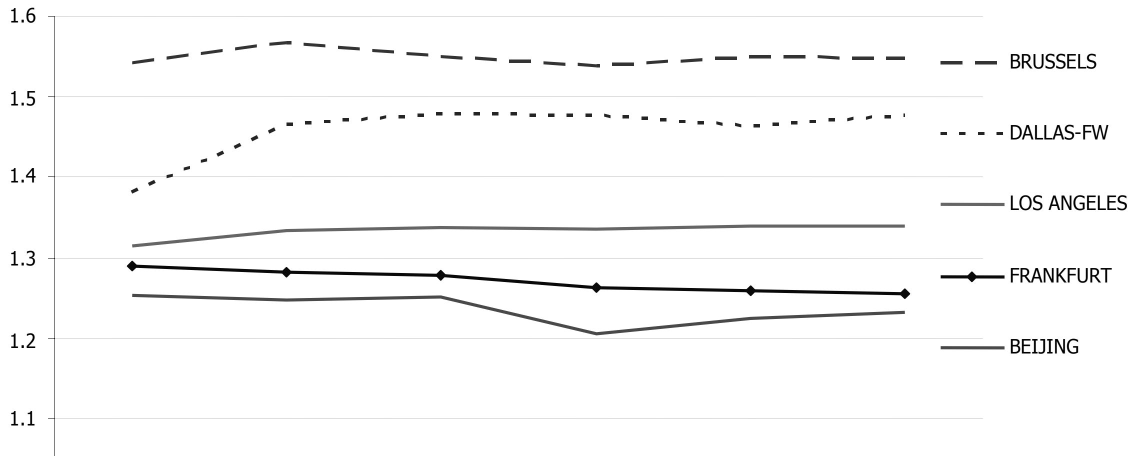

Figure 6.6 Evolution of scale elasticities at major hubs

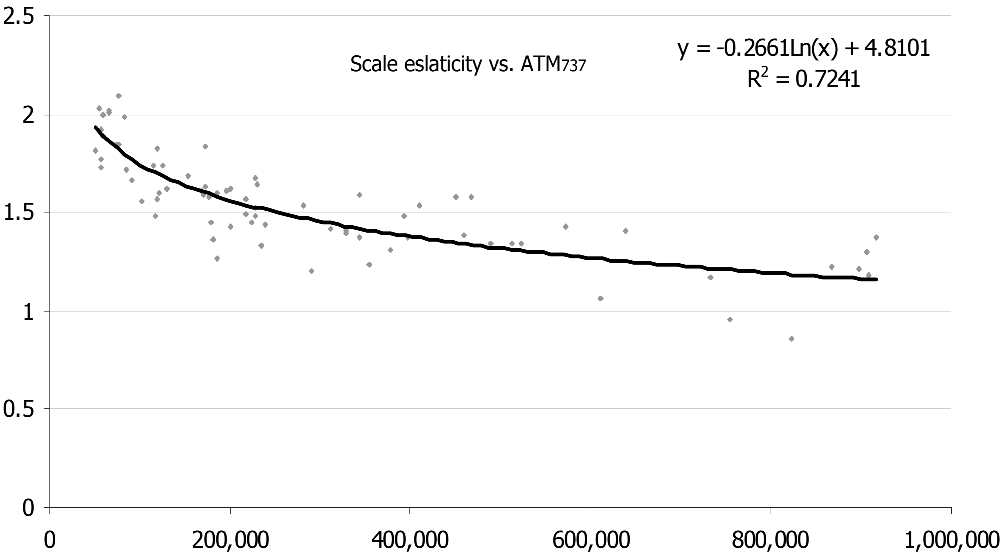

Figure 6.7 Scale elasticities for aeronautical operations (ATM_{737})

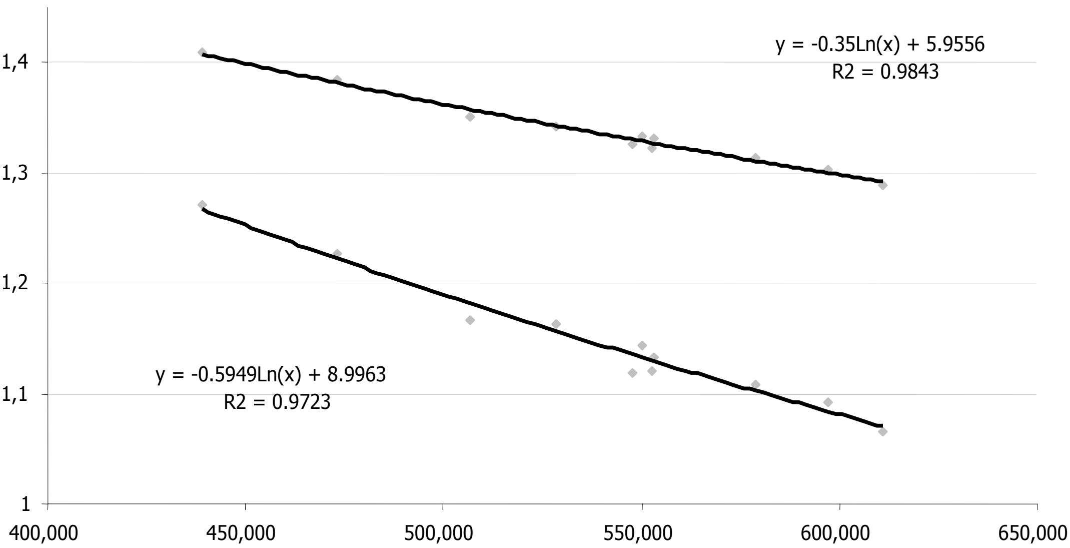

Figure 6.8 Evolution of scale elasticities at AMS (ATM_{737})

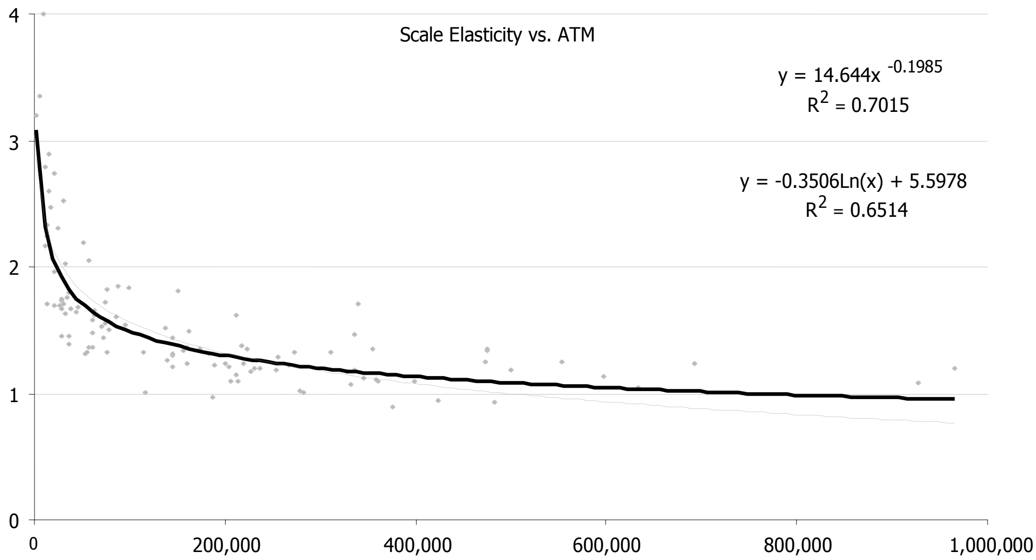

Figure 6.9 Scale elasticities for both aeronautical and non-aeronautical production using ATM

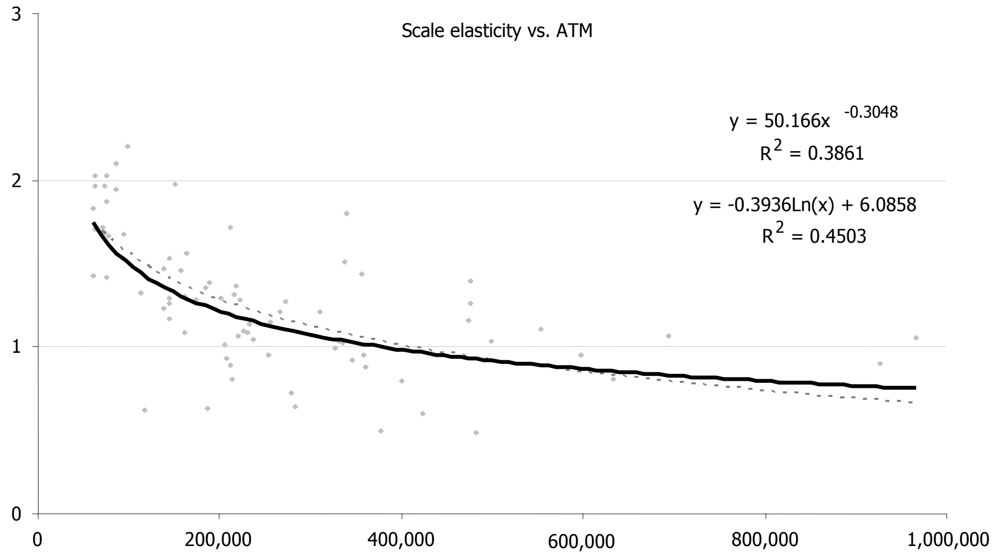

Figure 6.10 Scale elasticities for aeronautical production using ATM

CHAPTER 7

EFFICIENCY RESULTS

One of the most controversial issues regarding the estimation of technical efficiency (TE) is related to the distribution of the u_{it} parameter. Many distributions have been proposed and discussed in the literature, the most used being the exponential, gamma and truncated normal. The choice between these three distributions will be briefly discussed using the Deviance Information Criterion (DIC) (Spiegelhalter et al., 2002) which is automatically implemented by WinBUGS. The DIC was developed as a generalization of the Akaike's Information Criterion (AIC). It is a portable information criterion that trades off the model fit against a complexity penalty, computed as:

$$DIC = \bar{D} + p_D \,,$$

where p_D is the effective number of parameters in the model and $\bar{D}$ is the posterior mean of the deviance[1]. The model with the smallest DIC is regarded as the model that would best predict a replicated data set of the same observed structure.

Coding any feasible distributions is very simple and intuitive in WinBUGS. For further details on the code and prior elicitation, see Griffin and Steel (2007). The results for the total cost stochastic node (*tc[i]*) are shown in Table 7.1. The criterion favors the use of the more general gamma specification rather than the exponential, which is a specific case of this distribution. The least-preferred distribution for this data is the truncated normal. However, the difference between the gamma and the exponential is very small, so the latter was finally chosen as it allows the easiest and most intuitive elicitation of prior ideas and direct interpretation of its single parameter[2].

Table 7.1 Comparison of models with different distributional assumptions using the DIC criterion

Distribution	DIC
Exponential	-111.221
Truncated Normal	-101.853
Gamma	-112.672

[1] D = (-2*log likelihood).

[2] In the early stages of this work, a truncated normal was first chosen, and the TE estimates were consistently lower (1-2 percent) than the exponential ones. In spite of that, the ranking of airports regarding their TE has remained basically unaltered. The rank correlation test yielded a result of 83%.

In addition, before presenting the results, it should be clear that the efficiency estimation is the weakest part of the analysis as it depends on the distributional assumptions and prior knowledge added to the system. The main reason for the inclusion of both technical and allocative effects in the model is to reduce the bias of the cost frontier parameters under the most likely existence of some inefficient behavior which causes the conduct of the airport to deviate from the neo-classic paradigm. This allows a more precise estimation of the output cost elasticities upon which the whole analysis of industry structure and marginal costs is based. Furthermore, the aggregated data on costs, and especially the approach used in this dissertation to estimate the input price vector, do not provide enough information to allow a proper quantitative estimation of many variables related to the efficiency analysis.

Taking these shortcomings into account, it is highly advisable that neither the individual estimations of the *eta* parameter nor the single allocative effects be interpreted in terms of quantity. Hence, in this chapter, the analysis of these features is mainly based on the positive or negative sign of the respective parameter's mean. This average value is located on the side that accumulates more probability density, and hence it indicates the result of the underlying hypothesis test related to each single parameter. In the case of the parameter *eta* we will discuss whether the TE is increasing or decreasing over time. The signs of the ξ_j parameters will allow us to determine whether the airport is underusing or overusing some production input.

7.1 General overview

Technical efficiency results based on the selected exponential distribution are shown in Annex 4. The first conclusion is that technical inefficiency is roughly in the range about 15-18 percent for the mean airport. This average value is basically the same as that obtained in Martín and Voltes-Dorta (2008), but its robustness was checked using a reasonable range of initial values for the r^* parameter[3]. According to the lambda node statistics shown in Table 7.2, the exact average technical inefficiency is $6.82^{-1} = 0.146$. The posterior kernel density of the lambda parameter is shown in Figure 7.1[4].

Table 7.2 Posterior statistics of the *lambda* node

node	mean	sd	2.5%	median	97.5%
lambda	6.826	6.884	0.1708	4.711	25.72

[3] In fact, the average value used in Martín and Voltes-Dorta (2008) was 0.75 based on the previous estimations made for the GRACE project. (Martín et al., 2006)

[4] All the figures in this chapter (Figures 7.1 to 7.6) are presented in Appendix 7A.

Another important result is the absence of a significant correlation between airport size and operational efficiency, as shown in Figure 7.2. It would be expected that either major airports presented better results, because their higher traffic levels compel them to push up performance, or, conversely, the increasing operational complexities hindered efficiency. Surprisingly, the results indicate that they can be considered independent variables, i.e. the coefficient of linear correlation between TE and the number of mppa was estimated at 0.16. In spite of that, the average TE calculated by size groups shows a steady increasing trend and decreasing variability (Table 7.3).

In order to evaluate airports' performance under different operating environments, i.e. the "uniqueness" of airport operations (Kamp et al. 2005), additional information about the sample airports was collected with regard to the type of ownership or the airports' height above sea level. In this case, the impact of private capital and geographical location has been studied. However, both variables show some kind of asymmetry regarding the number of observations, so the results have to be interpreted with caution.

One of the major interests of airport productivity and benchmarking studies is to provide useful information for public policy analysis in the ongoing process of airport privatization. Finding out whether privatized airports operate more efficiently than public ones is a major question, yet still unanswered. Only 21 out of the 161 sample airports (13 percent) are privately owned, and they score a satisfactory 86 percent (traffic-weighted) average TE. The remaining set of public airports scores slightly under this figure at an overall average of 81 percent. However, the robustness of this result can be questioned by the aforementioned asymmetry.

Regarding the influence of the airport's geographical location on the operational efficiency, a good analysis of the so-called "hot and high" airports would have been interesting. This category includes all airports located in elevated altitudes above mean sea level. The lower air pressure requires the provision of longer runways for safe aircraft operations, and thus a financial record for these extra expenditures is expected to be featured in the data, inducing an artificially higher technical inefficiency. However, the only "hot and high" airports in the sample are MEX, JNB and DEN, with an average TE of around 79 percent. The availability of more data on South American airports, especially those from Bolivia would have certainly allowed us to obtain more empirical evidence to clarify this particular issue.

Regarding airport operations, technical inefficiency is related to many factors, but the most important is the provision of idle capacity. Recently expanded airports tend to provide temporarily idle runway and terminal capacity because forecast traffic is expected to meet the capacity in the future. However, in other cases, inefficient expenditures may persist as a result of bad planning, e.g. relying on too optimistic traffic forecasts. In order to avoid that, new airports are planned and built in different phases, each one covering a different capacity range. These phases are executed according to the revised traffic trends and current availability of funding. In spite of that, idle capacity can still appear as a consequence of any external traffic shock, such as 9/11 or the bankruptcy of dominant carriers. Identifying the main sources of technical inefficiency has always been a major issue for airport operators, though the quantification of the problem in monetary terms may give them the proper incentive to correct this malpractice. This turns the adoption of new operational procedures into an exercise in cost-benefit analysis. Because of the explicit specification of allocative effects on the cost frontier, the TE estimates offered in this section are not biased, in the sense that they truly represent the percentage of actual costs that can be saved by optimizing input usage[5] in the production of the observed output vector.

Considering only the 116 sample airports for which financial data for 2006 was available, the total losses derived from technical inefficiency in the provision of infrastructure for air transportation during 2006 amounted to PPP USD 4.37 billion[6]. In order to put this figure into perspective, this is approximately the estimated cost of the recently launched expansion project at PEK. Individual estimations related to each airport's potential savings can be easily calculated from the TE estimates provided in Annex 4. However, in order to provide reference values for the industry, Table 7.3 presents disaggregated results by airport category. Small-size regional airports in Europe may be losing up to USD 3.6 million each year, which represents 20 percent of their actual operational expenditures. The typical middle-size international airport in Europe (e.g. BRU, CPH, MAN, ZRH) serves around 20 mppa. According to the TE estimations, they are expected to lose between USD 33 and USD 64 million each year because of operational inefficiency. At the four above-mentioned airports, this amount represents between 56 to 112 percent of their annual payroll. The third category includes all the current and future world leading airports, featuring major international

[5] Holding the observed input proportions.
[6] Throughout this chapter the term "billion" refers to thousand million.

hubs in America, Europe and the Asia-Pacific region. Airport-specific estimates vary, but on average they may be currently spending USD 110 million per year over the cost frontier. Such a significant amount could have paid, for example, for the entire renovation works necessary for the A380 adaptation program[7].

Table 7.3 Technical inefficiency average annual costs at different production levels

PAX (mppa)	Avg. TE mean	Avg. TE s.d.	Avg. annual losses (million PPP USD) mean	Avg. annual losses (million PPP USD) range
0 to 1	0.803	0.09	3.64	0.6 - 9.4
1 to 5	0.802	0.07	8.97	1.0 - 16.5
5 to 20	0.826	0.07	33.28	4.4 - 76.6
20 to 40	0.845	0.06	67.24	18.9 - 219.3
40 +	0.842	0.05	110.23	30.6 - 284.0

This analysis, however, assumed the original input proportions as fixed. The lack of flexibility in labor markets and the usual practice of outsourcing non-core activities under long-term agreements may obscure the fact that additional efficiency gains can be achieved (for the same production level) through the optimal allocation of inputs, given the vector of prices (see Chapter 2). Thus, each airport's actual price vector (w^*), which generates all the above-mentioned technically-efficient input combinations, is compared with the underlying optimal price vector featured on the cost frontier (lnC^o). The difference represents the lnC^{al}, which are the extra costs related exclusively to the presence of allocative inefficiency (AI). Airport-specific estimations for the specified allocative effects are shown in Annex 4. The average values for these variables are ξ_m = -0.03 and ξ_p = 0.00. This indicates that, at the mean airport, the proportion of labor with respect to the capital factor is allocatively efficient while the demand for materials and outsourced services is somewhat above the optimal propotion. As in the previous case, no significant correlation between the allocative effects and airport size could be found. But most interesting is the quantification of the aggregate effects in monetary terms, which are given by the predicted values of lnC^{al}, i.e. [8]

$$\begin{aligned}\ln C_i^{al} = {} & \beta_7\xi_m+\beta_8\xi_p+\gamma_{10}atm*\xi_m+\gamma_{11}atm*\xi_p+\gamma_{13}pax*\xi_m+\gamma_{14}pax*\xi_p+\gamma_{16}cgo*\xi_m+\\ & +\gamma_{17}cgo*\xi_p+\gamma_{19}rev*\xi_m+\gamma_{20}rev*\xi_p+\delta_{21}\xi_m*wc+\delta_{22}wm*\xi_m+\delta_{22}0.5*\xi_m*\xi_m+\\ & +\delta_{24}\xi_m*wp+\delta_{24}wm*\xi_p+\delta_{24}\xi_m*\xi_p+\delta_{25}wc*\xi_p+\delta_{26}wp*\xi_p+\delta_{26}0.5*\xi_p*\xi_p+\ln(G_i).\end{aligned}$$

Airport-specific estimations for C^{al} vary between 1 and 1.16, indicating that the costs associated with the technically-efficient input demands may deviate up to 16 percent

[7] This is the average A380 investment (De Neufville and Odoni, 2003).
[8] Note that the consideration of *ln(Gi)* requires the computation of the predicted cost shares according to the original Kumbhakar (1997) formulation.

from the minimum cost frontier. In order to provide a density for the overall level of AI, the node $C^{al} = exp(lnC^{al})$ was created under a truncated normal distribution[9] with 1 as the lower bound. The mean and variation were obtained from the individual C_i^{al} estimations (Table 7.4). The density picture is shown in Figure 7.3. The average AI level in the industry was therefore estimated at 6.3 percent covering the expected range of variation[10].

Table 7.4 Posterior statistics of the C^{al} node

node	mean	sd	2.5%	median	97.5%
C^{al}	1.063	0.04232	1.004	1.057	1.159

Considering only the 116 sample airports, for which financial data for 2006 was available, the total losses derived from AI amounted to PPP USD 1.28 billion. Individual estimations related to each airport's potential savings can be easily calculated from the AI estimates provided in Annex 4. However, in order to provide reference values for the industry, Table 7.5 presents disaggregated results by airport category. In comparison with the previously reported TE losses, these are of much less significance. The European middle-size hubs are currently losing from USD 10 to USD 23 million per annum because of AI. The same applies to the world's busiest airports which can expect to reduce their annual expenditures by USD 32 million each year by simply adjusting their input demands in the proportions suggested by the sign of the AI parameters. Airport-specific case studies will be provided in the next section.

Table 7.5 Allocative inefficiency average annual costs at different production levels

PAX (mppa)	Avg. AI mean	Avg. AI s.d.	Avg. annual losses (million PPP USD) mean	Avg. annual losses (million PPP USD) range
0 to 1	1.066	0.037	0.76	0.06 - 1.23
1 to 5	1.046	0.024	1.82	0.15 - 4.24
5 to 20	1.044	0.031	10.16	0.78 - 12.94
20 to 40	1.043	0.033	23.31	1.35 - 32.01
40 +	1.039	0.037	32.73	2.56 - 95.03

As a final note, the average value for the time-varying *eta* parameter is 0.05. This indicates that the overall TE in the airport's industry has decreased during the time span considered. The main explanation for that result is the huge financial effort made by all airports in order to carry out capacity expansions. These expenditures artificially decrease the level of TE, as the presence of idle capacity makes actual costs deviate from the long-run cost frontier. In spite of that, many airports in the sample, either

[9] The truncated normal distribution was codified into WinBUGS by Lunn (2003).
[10] This mean value differs from the one shown in Annex 4 (4 percent), because in this last case all sample years have been considered.

recently expanded or not, show increasing TE, and so do some geographical clusters. This is discussed in the next subsection.

7.2 Geographical clusters

The analysis of the differences in TE among the nine major geographical clusters featured in the database generates a very interesting discussion. Europe is represented by the UK (9), Germany (15), Italy (9) and Austria (5). North America includes both the US (37) and Canada (7). Both Australia (6) and New Zealand (3) are the whole Oceanian sample, and, finally, Asia is represented by 2 Japanese hubs. This is certainly a very heterogeneous set of airports. The country-specific political background may have a very strong influence on both the type of ownership and the regulatory framework, e.g. the setting of charges or the funding of capacity expansions. Another important feature is the geographical location that causes substantial differences in the nature of traffic (passenger vs. freight) and also in the size of the aircraft served[11]. In addition, geography is a major factor regarding the existence of strong competition between airports or with other transport modes. Therefore, always under the assumption that all sample airports share the same technology, this section is focused on catching some of the "uniqueness" of airport operations by testing the influence of all the above-mentioned country-specific characteristics on airport performance. In order to do that, each country's weighted average TE coefficient was calculated according to traffic proportions. The final ranking is shown in Figure 7.4.

Austrian and German airports are the least efficient in the world. Their level of technical inefficiency ranges between 22 and 27 percent, which is significantly higher than the world average. Considering that almost every commercial airport in these countries is featured in the database, the accumulated annual losses derived from technical inefficiency can be considered to properly represent the losses of each country's entire airport industry. This amounts to PPP USD 1.15 billion in Germany[12] and USD 137 million in Austria (Table 7.6). These numbers agree with the past literature, as German (mostly public- owned) airports are said to be less efficient because of the lack of private financial incentives which push up performance. In addition, all these airports face strong competition with the rail mode which imposes very important restrictions on

[11] The amount of foreign trade is another important variable.
[12] Though not included in the estimating sample, this figure includes the multi-airport system in Berlin as featured in Section 7.4. Total losses without the Berlin airports amount to PPP USD 982 million.

the development of domestic and short-haul international traffic. This is aggravated by the existing competition between the same country's airports and with major hubs in border countries (AMS, BRU, PRH, ZRH) induced by their close proximity and the aforementioned availability of reliable rail services for short-haul passengers.

Another characteristic of the airports in central Europe is the small size of the average aircraft served, which is only 54 metric tons in Germany (not counting FRA) and 55 metric tons in Austria. As shown later, this feature has a big impact on airport performance[13]. In spite of that, not every single parameter regarding TE at German and Austrian airports provides negative results. The traffic-weighted average value for *eta* indicates that the airports in these countries show increasing TE during the time span considered. In this context, it is very interesting to notice that the average efficiency level for German airports increased by almost 1.5 percent between 2005 and 2006, clearly showing the positive influence on passenger and cargo traffic of hosting the World Cup football championship. In addition, a very significant development is observed at VIE, which will be discussed as a separate case study in the next section.

Table 7.6 Technical inefficiency estimated losses at different geographical regions

Country	Avg. TE	Expected annual losses (PPP USD)
German Airport Industry	0.73	1,150,204,450
Austrian Airport Industry	0.77	136,670,740
Italian Airport Industry	0.83	762,349,450
US top 30	0.81	1,705,846,160

Regarding AI, both countries score slightly under the global average. Germany scores 4.7 percent and Austria 5.1 percent. This translates into PPP USD 88 million and USD 10 million, respectively, for the year 2006. The main reason for this alarming result is the great lack of flexibility in labor markets that translates into higher salaries than the rest of Europe, ranging from USD 55 thousand to USD 60 thousand per year against the European average at USD 42 thousand (see Table 7.7). In addition, the share of AA labor in the total operating costs at both FRA and VIE airports in 2006 ranges between record levels of 45 and 52 percent[14] compared with the global average of 29 percent.

The interpretation is clear, there is almost no outsourcing in ground handling and other non-core activities. The AA and its related companies carry out all traffic-related procedures using their own resources (see the HAM example in Chapter 3). Taking into

[13] Givoni and Rietveld (2006) discussed the inefficiencies resulting from the trend to use smaller aircraft for short haul.
[14] Although in both cases the labor share has significantly decreased in the last ten years.

account current outsourcing practices in the rest of the countries, this apparently outdated situation generates important levels of AI. Taking again both VIE and FRA as the most representative airports in these countries, this last point is clearly seen in the positive sign of the allocative effect for the materials variable (*allm*), and the negative sign for the labor variable (*allp*) detailed in the Annex 4. Avoiding any quantitative analysis of the actual estimations, the simplest analysis indicates that both airports are demanding too much labor and too little "materials/outsourcing", i.e. the cost frontier has identified other sample airports whose input combinations yield lower total operating expenditures across the same isoquant.

North American airports are next in the ranking of performance by geographical area, with average TE levels around the sample mean (81 percent), though the Canadian cluster scores slightly higher. The quantification of the total TE losses for the US industry is based on the top 30 busiest airports in terms of passenger traffic, of which 24 are directly featured in the database. In order to provide the most accurate estimation, the average TE level was applied to the total costs of the other six airports[15] collected from the FAA (2006). The final result indicates that the elite of the US airport industry is USD 1.7 billion over the cost frontier[16].

An explanation for that can be found in the regulatory framework (Graham, 2003). The rate-of-return (ROR) regulation is the traditional mechanism used in the US to regulate natural monopolies. Under this approach, a certain ROR for the AA is fixed by law, and hence the prices can only be increased when costs also increase. Consequently, as shown empirically, the US airports have no incentives to minimize costs, and this system encourages overinvestment. In spite of that, the unique characteristic of American airports was pointed out in Chapter 4 and is related to the close airport-airline relationship. These latter two agents sign long-term lease agreements, and hence the activities of the airport cover either the net costs of running the entire airport itself (single-till) or only the aeronautical costs (dual-till). Consequently, the dominant carriers at each airport may also play a key role in airport investment decisions, thus preventing non-signatory airlines from accessing to idle terminal space and gates[17].

[15] These are the three New York Airports (JFK, EWR and LGA), PHL, BOS and SAN.
[16] As a result of the presence of dedicated terminals and the correction explained in Chapter 4, all cost estimations regarding US airports should be labeled as approximations.
[17] In order to avoid that, FAA (1999) states that the control of the assets will be returned to the airport if such anticompetitive behavior is present.

The temporal evolution of the TE indicates a steady downward trend, clearly explained by the tremendous traffic shock of 9/11. The hypothesis that the rigidity of the Battese/Cuesta linear formulation was not appropriate to describe the evolution of TE in the US between 2000 and 2006 (against a U-shaped evolution) was tested by labeling the pre-shock observations as different firms. However, the results do not provide any conclusive evidence, as the TE estimations do not significantly differ from those presented in Annex 4. Regarding allocative distortions, an additional USD 253 million per annum can be saved by optimizing input allocation, although the variability in the estimations of the corresponding parameters does not allow us to draw any particular conclusion in terms of recommended practices. In spite of that, the analysis of the individual case studies could shed some light on this topic.

The Italian sample airports also show an average TE level of 83 percent spending USD 72 million over the frontier. However, the featured nine airports only cover 26 percent of total passenger traffic in Italy during 2006. In order to get a better representation, both multi-airport systems at Rome and Milan should be considered as they carry almost two-thirds of the country's total traffic. Thus, the estimation of the total losses of the set of airports covering 84 percent of Italian traffic is ten times larger, with a total of USD 762 million because of the high inefficiency associated with the multi-airport system. As a technical note, the AI effect at the sample airports is of much lower importance, amounting only to USD 10 million.

The British sample airports show an average TE level of 86 percent. However, in this case no monetary aggregate quantification for the technical inefficiency has been given, as the featured airports are not an exhaustive sample of the whole industry in the UK. Exactly the same applies to the Australian airports with an average TE of about 87 percent. As in the American case, the collapse of Ansett[18] in 2001 was considered as an external shock, but no significant TE differences were found using the Gonzalez et al.(2008) methodology. Apart from that, the differences in the TE of both countries with respect to, for example, the aforementioned US airports can be explained by the different regulatory approaches. During recent decades there has been growing concern about the airport privatization in terms of providing the correct incentives for an efficient operation and appropriate investment policy (Graham, 2003). As noted, under a ROR mechanism, no incentive for cost minimization was given. To overcome this

[18] Ansett was Australia's second largest domestic airline by that time.

major shortcoming, price cap regulation began to be used in the 1980s by the British authorities. It works by establishing the maximum price that can be set, which is typically adjusted for inflation and an "efficiency target" factor (*X*). Since there is no cap on the profit levels, any additional efficiency gains which the regulated airport can make in excess of the required *X* will directly benefit the operator. Hence, price cap regulation has been the most popular approach adopted for privatized airports. In Australia, the individual traffic forecasts are taken into account while setting the *X* values, thus demanding a better performance from developing airports.

The three major New Zealand airports rank among the most efficient in the world, with an average TE of 89 percent. Considering also AI, they are only USD 30 million over the cost frontier, and further cost savings can be achieved by reducing the demand for "materials/OS" and increasing labor demand with respect to the capital factor. Both AKL and WLG are privatized and CHC remains publicly owned. However, none of them is subject to price regulation. AIAL (2006) considers that price control may result in decisions regarding commercial matters being imposed by a regulator, which can cause inefficiencies and stifle investment. Regarding operational matters, the territorial isolation increases mean aircraft size, thus enabling a more efficient utilization of airport capacity. This last argument also justifies the presence of Japan at the top of the classification.

Analysing just the Asia-Pacific sample, its average scale of production is the biggest of the four continents, serving almost 23 mppa and 420,000 equivalent movements. Especially significant are the values of the mix variable, whose mean is 2.33, indicating an average aircraft of 158 metric tons MTOW. This is explained by the greater importance of long-haul freighter aircraft at these airports, many of them ranking among the world's busiest airports in terms of cargo traffic. Therefore, it is clear that the successful exploitation of scale economies by the operation of larger aircraft is responsible for their having less than 7 percent technical inefficiency. Exceptional cost savings of roughly USD 200 million can be achieved at each airport, by increasing allocative efficiency. Moreover, it is worth noting that the estimations of AI are consistently higher in the Asian airports, usually reaching over 10 percent. On the one hand, the process of land reclamation generates additional capital costs that are not faced by any other airports in the world. Therefore, high AI levels resulting from the excessive use of capital are expected to appear in Asian airports. On the other hand, as seen in Table 7.7, the average input prices for the Asian sample are significantly higher than in the rest of the world. This might indicate the presence of an unidentified heterogeneity in the financial data reported by these airports. For that reason, the AI estimates obtained for the Asian airports should be treated with caution.

Table 7.7 Average input prices at the different regions (in thousands PPP USD)

	Wc	Wm	Wp
Europe	2,36	739,19	42,02
America	3,28	533,27	67,66
Asia-Pacific	21,66	2441,29	98,15
Oceania	4,37	400,74	53,92

7.3 Selected case studies

Table 7.8 features a very interesting selection of case studies, focusing on the temporal evolution of their TE levels, as measured by the *eta* parameter. The most efficient airport in the world during the years 2000 to 2006 was HKG with less than 4 percent technical inefficiency. In monetary terms, this translates into USD 30 million per year over the TE cost frontier. The airport opened for commercial operations in 1998, replacing the former Hong Kong Intl, which has remained closed since then. Despite its short history, HKG has been consistently ranked among the top performers by many surveys[19]. It is one of the busiest airports in the world, regardless of the measured variable. In 2006, HKG ranked fourteenth in terms of passenger traffic (43.8 mppa), and second in terms of cargo (3.6 million metric tons). In addition, according to the classification presented in Table 4.2, it is also the third busiest airport in the world by equivalent aircraft operations/total landed tonnage. The high level of TE is explained by the rapid adjustment of the forecast traffic level to the existing capacity. Before the most recent expansion, the declared capacity of its single passenger terminal and the two cargo facilities was 45 mppa and 3 million metric tons, respectively. As the development in air traffic has almost been equal to the increase in operating costs, the level of TE has remained constant, except for the last two years, when a significant financial effort was made concerning the recent opening of the new check-in terminal and rail link. This slight TE decrease is typical of the aforementioned scale-creating periods, where the technical inefficiency was artificially increased because of factor indivisibilities and the presence of idle capacity. By expanding its capacity, HKG is also expanding its short-run efficient scale from 45 mppa to its (land-restricted) ultimate

[19] Between 2001 and 2005, and again in 2007, HKG was ranked 1st in Skytrax's World Airport Awards.

capacity of 85 mppa. For that reason, the HKG airport is one of the finest examples of the exploitation of scale economies in the industry. Taking into account previous experience in other countries and the extreme land shortage in this very small state, it is quite surprising that a brand new airport was the chosen alternative to accommodate the increasing traffic rather than the operation of a multi-airport system and the splitting of production.

Table 7.8 Evolution of technical efficiency estimates at selected airports

	VIE	PEK	PRG	FRA	BGY	HKG	NRT	RIX	AMS	DFW	MEM	LAX
2006	0.76	0.89	0.81	0.81	0.91	0.96	0.95	0.78	0.85	0.80	0.86	0.75
2005	0.75	0.90	0.82	0.81	0.90	0.97	0.95	0.78	0.87	0.80	0.87	0.78
2004	0.74	0.91	0.81	0.80	0.90	0.97	0.96	0.77	0.88	0.80	0.87	0.80
2003	0.72	0.91	0.80	0.78	0.90	0.98	0.96	0.75	0.88	0.79	0.87	0.81
2002	0.70	0.91	0.79	-	0.89	0.98	0.96	0.73	0.89	0.78	0.87	0.83
2001	0.67	0.90	0.77	-	0.87	0.98	0.96	0.71	0.89	0.77	0.86	0.84
2000	0.64	0.89	0.75	-	-	0.98	-	-	0.89	0.75	0.85	0.84
1999	0.61	-	-	-	-	0.98	-	-	0.88	-	-	-
eta	-0.05	0.00	-0.06	-0.07	-0.06	0.17	0.12	-0.10	0.01	-0.03	-0.01	0.12

The consideration of the temporal variation of TE at individual airports allows us to introduce a new quantitative measure: the savings (losses) related to the evolution of TE. Knowledge of that information is crucial for airport managers and regulators, as it provides a financial stream on the basis of which the returns of the original investment or the effectiveness of a certain policy can be quantified, thus providing a solid background for future initiatives. The calculation of these cost savings simply results from the difference between the inefficiency losses associated with both the current and the base year. The following case studies will serve as examples.

There is a strong relationship between the evolution of the scale elasticity and the technical inefficiency. As highlighted in the previous chapter, there is a group of small regional European airports which are experiencing explosive growth up to the point when they can no longer be considered as regional airports. Their development is mainly based on very basic structures, which were designed taking into account their expandability as the main factor. This allows a rapid adjustment of infrastructure and demand, thus avoiding capacity gaps. This behavior should have a very positive impact on the airport's overall performance (Figure 7.5). The most efficient airport in the mentioned category is BGY, which scores an excellent TE of 91 percent in 2006. This translates into USD 6 million over the cost frontier. However, during the last six years, BGY has managed to reduce its inefficiency from 13 percent to the present 9 percent, saving an average of USD 1.4 million each year for an aggregated benefit slightly over

USD 8 million. This amount approximately covers the annual capital costs of a small-size airport. The same analysis could be done for RIX, though its current TE level (78 percent) is still below the international average. In spite of that, the steep increase of overall performance is one of the most notable of the whole sample. This represents an aggregated saving of almost USD 13 million in the last six years (Table 7.9). Regarding AI, the negative sign of the labor-related parameter indicates that RIX is currently operating with an excess of its own personnel. The average number of AA employees in the 1-5 mppa category is 286, while RIX has 830 on the payroll[20]. This lack of outsourcing seems to be slightly hindering the cost minimization.

Table 7.9 Cost savings related to the evolution of TE at BGY and RIX (2001-2006)

BGY			RIX		
Base Inefficiency	Current level	Savings (million PPP USD)	Base Inefficiency	Current level	Savings (million PPP USD)
13%	9%	2.62	29%	22%	7.14
13%	10%	1.74	29%	22%	3.56
13%	10%	1.48	29%	23%	2.37
13%	10%	1.37	29%	25%	1.40
13%	11%	0.61	29%	27%	0.74
13%	13%	-	29%	29%	-

Another airport showing steady growth both in passenger traffic and operational efficiency is PRG. It has benefited from accession to the EU, since when it has become the busiest airport within the new Member States. In 2006, its Terminal 2 was opened. In spite of the significant increase in costs related to this new facility, the 7.4 percent increase in passenger traffic prevented the TE level from sinking, decreasing only by 1 percent to the current 81 percent, which is USD 47 million over the frontier. In spite of that, during the last seven years, PRG has increased both its passenger and aircraft operations by 100 percent, while increasing operating costs only by 70 percent, which explains the negative sign of the *eta* parameter and the 6 percent increase in TE. The aggregated cost savings during this period amounted to USD 58 million.

Regarding the evolution of TE, no other airport has managed to increase its performance by a higher amount than VIE. Its current TE of 76 percent is still below the international average, translating to an annual over-expenditure of USD 105 million. In spite of that, VIE scored a very poor 61 percent back in 1999, and this 15 percent increase in TE has generated cost savings up to USD 245 million in these last eight years. The main reason for that increase can be found in the steady 6.2 percent annual growth of passenger traffic during that time. In addition, its terminal buildings did not undergo significant

[20] It is only outnumbered by NUE, with roughly 1,000 FTEEs.

renovation. Therefore, this indicates that the increase of TE is related to a better utilization of the provided facilities, which had too much idle capacity in the past. However, the increase in the number of equivalent aircraft operations has not been so pronounced because the average aircraft size is still too small (57.26 metric tons). For that reason, in 2006 the airport started building a new terminal which will make the airport more capable of dealing with higher passenger volumes, and it will also make the infrastructure capable of handling bigger aircraft, such as the Airbus A380. Regarding AI, VIE can clearly achieve additional cost savings (USD 6 million) by substituting some of its own costly employees by outsourced labor.

At major hubs, there is a mix of increasing and decreasing trends, but all of them are related to the same traffic and capacity development issues (Figure 7.6). FRA, for example, presents a "normal" level of TE, despite all the aforementioned limitations of the German airports. Its average aircraft size is by far the biggest in Europe with 116 metric tons MTOW per landing. Consequently, the modifications to the airport to make it compatible with the A380 have already started[21]. Even so, FRA is already operating under severe capacity constraints, which has caused the national carrier Lufthansa to divert part of its traffic to MUC. In terms of total production, the German hub is very much like HKG, ranking among the world's busiest in passenger, cargo and (equivalent) aircraft operations. However, unlike the Asian airport, FRA has not been expanded at the same speed, and thus further efficiency gains in the near future are not expected. For that reason, there are plans to expand the airport with a fourth runway and a third terminal, but they will not enter into service earlier than 2010. Exactly the same applies to AMS, but in this case, the capacity restrictions have reduced its TE from its former 88 percent to the current 85 percent. This translates into aggregate losses of USD 68 million during the last four years.

Regarding the American airports, the case of DFW is an example of the continuous struggle to improve performance in spite of the tremendous traffic shocks suffered by the airport. Appendix 7B shows the flexibility of total costs (even capital) at the time of adapting it to the traffic level. This is reflected in cost savings of up to USD 121 million between 2001 and 2006. On the other hand, the case of LAX (Figure 7B.2) is also clearly related to the parallel evolution of traffic and costs. However, in this case, the distance between the two increased year by year, as the significant reduction of aircraft

[21] This includes the building of a large A380 maintenance facility (Lufthansa, 2006).

size and passengers served after 9/11 did not have any financial counterpart, which led to a great decrease of TE. The total estimated losses for the AA related to this inefficient behavior amount to 150 million USD.

7.4 Multi-airport systems

In this last subsection, a very interesting experiment will be carried out with the purpose of validating the proposed methodology as a valid tool for policy and investment decisions[22], especially regarding the development of a multi-airport system (MAS) serving the same metropolitan area.

With the most ambitious airport expansion project still to be fully operational, Beijing AA is planning a second airport to come into service by the time PEK reaches its expanded capacity of roughly 85 mppa. Construction will take five years, and it is expected to be fully operational by 2015 (BCIA, 2006). This example illustrates that the operation of a MAS can be considered as an alternative project to the expansion of current facilities. As noted, the existence of unexhausted scale economies in the industry clearly provides economic justification for airport expansion. Under hypothetical DRS, the alternative approach to accommodate the increasing demand is the development of a MAS. This should provide lower average costs per traffic unit, provided the infrastructure of the second airport is efficiently used, i.e. it is not operating with a significant excess of capacity.

MASs are present in many world-class cities, such as London, New York, Paris or Tokyo, which are capable of attracting and generating huge amounts of traffic. The typical MAS features a major international airport (e.g. LHR, JFK, CDG) that serves as an established hub for major international (full-service) carriers and then one (or more) secondary airports which are focused on domestic, regional and commuter traffic. In Europe, it is typical that these secondary airports (e.g. BGY, ORY, HHN) serve as technical bases primarily for low-cost carriers that run point-to-point networks. In other cases, the MASs may remain as the result of a failed (i.e. rushed) transfer of traffic from the old to the new airport, as in the Montreal case (see Chapter 1).

Most of these MASs are operated under a single AA that only publishes consolidated financial statements. If the AA is managing only a single airport, the consolidation perimeter may include all kinds of related companies providing both aeronautical and

[22] For the moment, only the financial analysis for the AA is covered.

commercial service at the airport. This is basically the same information that is provided by the MAS. However, the kind of segmental information needed for cost allocation among different airports is rarely given, and hence they can not be included as cost-minimizing firms in the database used for the estimating the cost frontier. In spite of that, this consolidated data can still be very helpful in order to test the consistency of results. In this experiment, the MASs will be considered as single decision-making units. Under the presence of IRS, the observed operating costs of the MASs should be significantly higher than the predicted frontier costs for the aggregated production level, leading to an abnormally high level of economic inefficiency. In order to show that, the consolidated financial and operational data for the year 2006 of the five most important European MASs were collected. This includes London, Paris, Rome, Milan and Berlin, each of them operated under a single AA (Table 7.10). Other MASs such as Chicago, New York or Washington D.C. offer disaggregated data on airports and hence are featured directly in the estimation database. The same applies to other private airports serving large metropolitan areas such as LTN or BGY.

Table 7.10 Multi-airport systems in Europe (2006)

City	AA	Airports	ATM_{737}	PAX	CGO	TER	RUN
BERLIN	Berliner Flughäfen	TXL THF SXF	233,659	18,506,506	37,059	98,168	15,095
LONDON	BAA	LHR LGW STN	1,508,473	122,339,000	1,806,930	664,905	13,865
MILAN	Aeroporti di Milano (SEA)	MXP LIN	345,542	31,314,392	423,794	404,000	10,240
PARIS	Aéroports de Paris (AdP)	CGD ORY	1,083,926	82,349,567	2,240,724	913,800	23,185
ROME	Aeroporti di Roma (ADR)	FCO CIA	391,407	35,134,383	188,550	302,284	16,902

The estimation of the operating efficiency follows a very basic methodology. The output vector is simply aggregated. Note that this is only possible through the previous homogenization of aircraft operations. The factor quantity indexes that allow the calculation of input prices are obtained by combining the marginal productivities estimated in Chapter 3 and the aggregate quantities of fixed factors. These variables are logged and deviated from the same approximation point featured in the cost frontier. Then the efficient cost that corresponds to the MAS's scale of production, and the price vector is estimated using the cost frontier parameters. Considering the system as a single operating unit, the frontier assigns a certain level of average costs in accordance with the presence of IRS. This value is expected to be significantly lower than the actual costs achieved by the separate airports (MAS), regardless of whether they may be operating with absolute efficiency. Finally, an approximate measure of the multi-airport system's operating efficiency is obtained by dividing the optimal expenditure by the observed total costs.

Table 7.11 Economic efficiency estimates at European MASs

City	Airports	ATM_{737}	Economic Efficiency	Comparable airports	Estimated Savings (PPP USD)
BERLIN	TXL THF SXF	233,659	0.31	0.59 - 0.92	175,549,000
LONDON	LHR LGW STN	1,508,473	0.74	0.79 - 0.98	422,730,000
MILAN	MXP LIN	345,542	0.39	0.63 - 0.93	375,064,000
PARIS	CGD ORY	1,083,926	0.50	0.79 - 0.98	867,429,000
ROME	FCO CIA	391,407	0.50	0.63 - 0.93	315,469,000

The final results are shown in Table 7.11 above. As expected, all MASs show significant levels of inefficiency. The interpretation is very clear: the aggregate output level could have been produced more efficiently by a single airport, thus saving from 26 to 69 percent of the total operating costs, simply because the current technology guarantees the presence of scale economies even at these huge levels of production. A very interesting result is presented in the next column. The aggregate savings of a hypothetical traffic consolidation at these five MASs are estimated at PPP USD 2.1 billion for the year 2006. The overinvestment in redundant airfield infrastructures can be identified as the main reason. The fifth column shows the confidence interval for the efficiency estimates for a comparable set of sample airports (see Annex 4). For Milan, Rome and Berlin, a direct comparison was possible because their aggregated traffic volumes (18-35 mppa) are attained by many other individual airports in the world. The cost performance of both the Paris and London systems were compared with other leading airports such as AMS or ATL.

The results are especially relevant for the London case, where up to four commercial airports serve the metropolitan area. The MAS composed of the three BAA airports (LHR, LGW and STN) serves more than 120 mppa and 1.5 million ATM_{737}, representing the biggest scale of production subject to analysis here. This level of output was identified as the industry's MES for aeronautical activities (see Chapter 6). Hence a single airport would expect to achieve minimum average costs at this point. The split of production in three different locations makes the actual costs much higher than the optimal level. The extra annual costs that can be saved by consolidating traffic are estimated to represent 26 percent of the actual expenditure, i.e. PPP USD 422 million. In spite of that, London has the most (financially) efficient MAS in Europe, but this result can be explained by the evident underinvestment in airside infrastructures. LHR, LGW and STN are best known by their very constrained and congested runway capacity. As of 2007, LHR is the world's busiest airport in terms of number of international passengers and also in terms of equivalent aircraft operations and total landed tonnage (see Section 4.1). This huge amount of traffic is served by only two extremely congested runways and their respective overcrowded terminals. The same applies to LGW, which recently broke the barrier of 35 mppa (more than the whole MAS at Rome, Milan or Berlin) with a single runway[23]. Taking into account only the quantity of traffic served in relation to the total operating expenditures, both airports should theoretically score very high in overall operating efficiency. Unfortunately, the very relevant effect of these capacity shortages in terms of congestion, delays and overall passenger service quality has not been taken into account. This permanent data shortcoming may explain the moderate 26 percent inefficiency level.

On the contrary, the MAS at Paris [24] features the second-longest commercial runway system in the 2006 sample (after DFW) and the longest in Europe. In addition, the total floor area of all passenger terminal buildings at CDG and ORY is 37 percent greater than the aggregate surface offered in the London airports. The annual inefficiency costs related to the seeming overinvestment in redundant air- and landside infrastructures are valued at roughly PPP USD 860 millions. In the Italian MAS, the inefficiency is clearly explained by the moderate amount of passenger traffic which is very low in comparison with the other European capitals. As shown in the previous chapter, such a level of activity could be perfectly well accommodated in a single airport, thus saving from USD 315 to USD 375 million.

However, the ultimate example of inefficiency can be found in Berlin, where an incredibly high amount of idle capacity remains unused at the three airports serving the metropolitan area and its surroundings. Air transportation to/from Berlin faces great competition from rail. Output figures are very poor in comparison with the infrastructure offered, e.g. 15,000 m of runways. CPH is able to handle more than 20 mppa with only 9,700 m. The central location of THF and its considerable amount of capacity would make it ideal to serve as Berlin's first airport. In spite of that, it is almost abandoned[25]. This situation generates annual losses for the AA of PPP USD 175 million. For that reason, *Berliner Flughäfen* is currently expanding SXF under the new name of Berlin-Brandenburg International (BBI), which will remain as the only major airport serving the area. The objective is clearly the reduction of costs derived from the traffic consolidation under the presence of strong scale economies in the current level of air traffic to/from Berlin.

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[23] In fact, LGW is the world's busiest single-runway airport.
[24] LeBourget was not included as it serves primarily general and business aviation.
[25] At the time of the Nazis, THF was Berlin's primary airport serving both civilian and military traffic.

At the beginning of this section, it was implicitly stated that the efficiency of the MAS was expected to be significantly lower than that actually achieved by the separate airports. Empirical evidence for that intuition is now provided using data on two American MAS, whose airports were individually included in the estimation sample. They are the aforementioned Chicago system that includes both ORD and MDW, and the Washington D.C. system featuring IAD and DCA[26].

The results are presented in Table 7.12. As expected, the inefficiency derived from the split of traffic is added to the individual airports' operational inefficiency, but most interesting is the possibility of separating and quantifying both effects for a deeper analysis. This was not possible in the previous example, where the cost savings took into account not only the benefits of traffic consolidation but also those derived from the perfectly efficient behavior of the individual airports. In this example, however, it is assumed that the individual airports present "normal" efficiency levels, and thus the benefits of the consolidation are estimated to represent from 6 to 24 percent of the aggregated total costs at these MAS. Thus in Washington D.C. this is quantified at USD 114 million[27], and only USD 69 million in Chicago. This last value is clearly explained by the small influence of MDW with respect to ORD in the MAS, the benefits of traffic consolidation being less evident than in the case of more similar airports.

Table 7.12 Economic efficiency estimates at American MASs (2006)

City	Airports	ATM737	Economic Efficiency		Estimated Savings (thousands PPP USD)	
			Individual	MAS	Individual	MAS
WASHINGTON D.C.	IAD DCA	583,260	0.84 ; 0.79	0.60	92,850	207,110
CHICAGO	ORD MDW	1,127,393	0.77 ; 0.86	0.71	194,643	264,354

To summarize, the most relevant results linked to the presence of MAS are no surprise at all. As expected, the level of economic efficiency is significantly lower than that observed at the individual airports because of the presence of inefficiencies derived from the splitting of traffic. The total effect may amount up to 70 percent of the annual operating costs for the AA. This provides additional quantitative justification for the current expansion trend observed in the industry. Finally, it should be clear that this methodology does not account for land restrictions, because this is of little interest for the validation of results. The fact that, for example, the London, New York or Chicago airport systems may be totally justified because LHR or MDW could not be further

[26] BWI was not considered in the Washington system as it serves many other important areas.
[27] This is calculated as the difference between the two last columns in Table 7.7.

expanded, does not change the fact that, at current output levels, the atomization of aeronautical infrastructure provision is always made at some efficiency cost.

As a final note on the MAS, it is worth noting that the choice of expansion vs. new airport is currently being faced by many AAs and local authorities and, especially in the case of public operators, the final decision can be expected to be based on political rather than economic grounds. However, in some cases, the deciding agent can surprisingly decide that no such choice exists at all. The Spanish airport industry provides an excellent example of such inconsistent behavior.

The significant increase of passenger traffic at the country's primary hub MAD was solved by the national operator AENA, as advised by the technology, with the construction of a new terminal building (T4) and the expansion of the runway system. After the inauguration in early 2006, MAD has been experiencing very strong traffic growth and has consolidated its position as the main European gateway to South America (AENA, 2007). As of 2007, MAD has overtaken AMS as the fourth busiest European Airport surpassing the frontier of 50 mppa. (ACI, 2008). In spite of that, works are currently underway for the inauguration in Spring 2008 of a new private airport in Ciudad Real (200 km south of Madrid), sponsored by local institutions. The project was considered earlier when MAD capacity was congested and the aforementioned choice was being discussed. The secondary airport would provide an initial capacity of 2.5 mppa and a single 4,000 runway with the intention to serve both domestic and international flights as a low cost alternative to MAD. Inexplicably, the new airport project was approved only once the expansion of the major hub was completed and all the attractiveness of the project vanished, proving that economic grounds may not always guide airport investment decisions and a strong political component is usually behind the existence of MASs.

Appendix 7A Chapter 7 figures

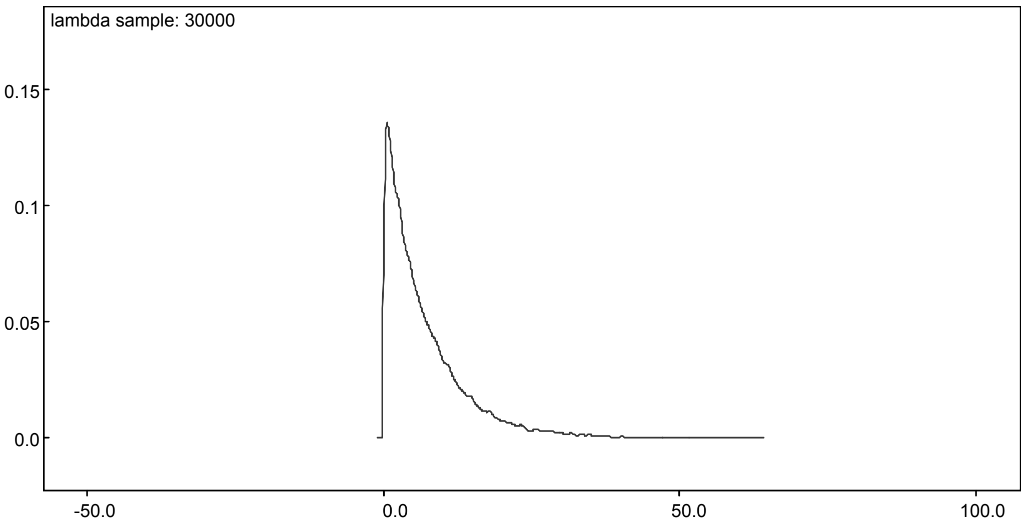


Figure 7.1 Kernel density picture of the lambda node

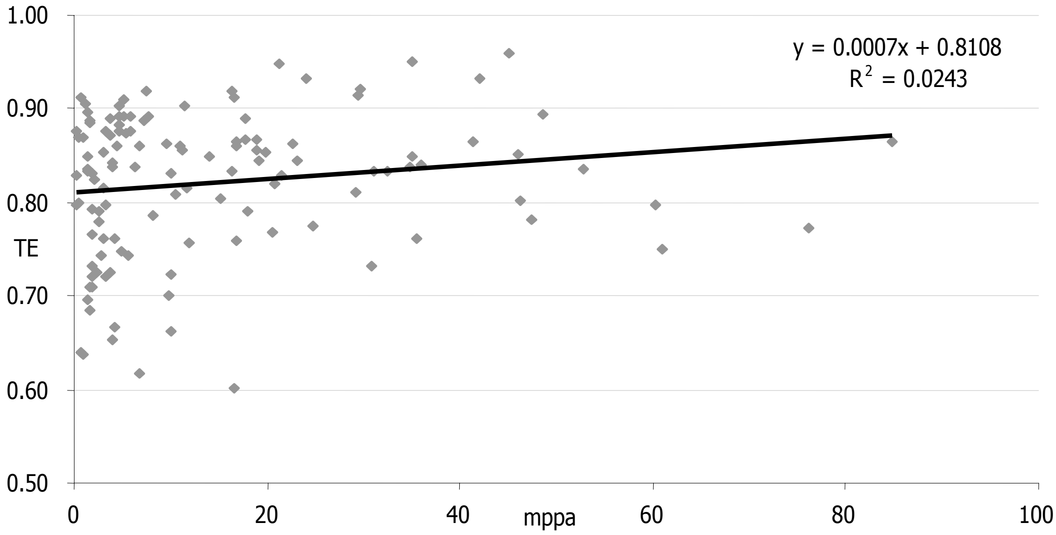


Figure 7.2 Relationship between airport size (mppa) and technical efficiency (TE)

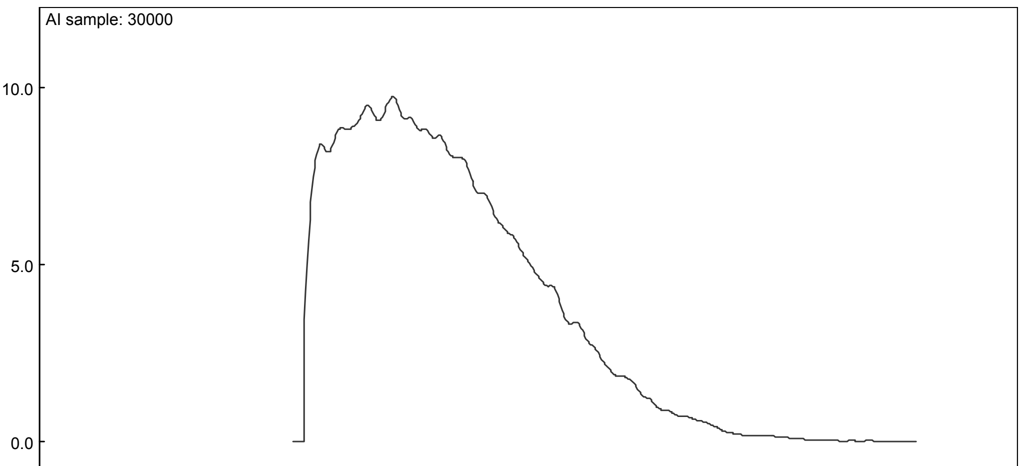


Figure 7.3 Kernel density picture of the C^{al} (Allocative Inefficiency) node under a truncated normal distribution

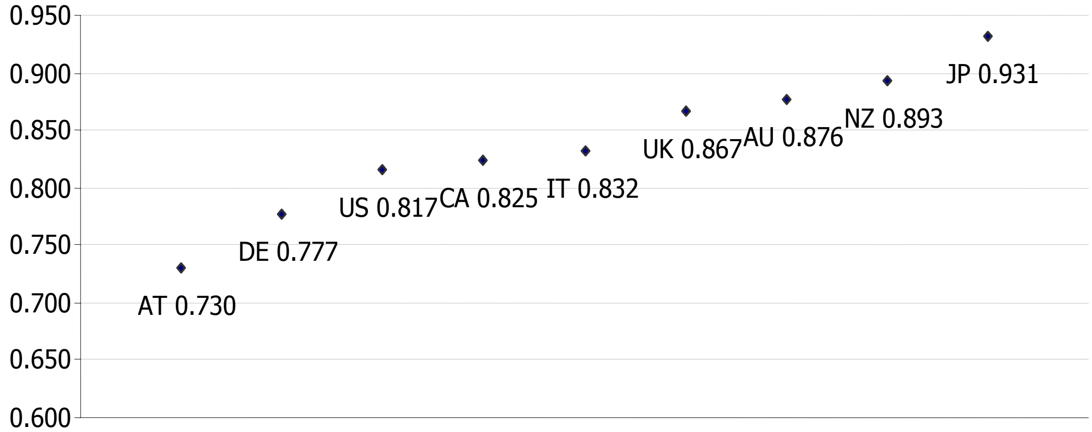


Figure 7.4 Weighted average TE at major geographical clusters (2006)

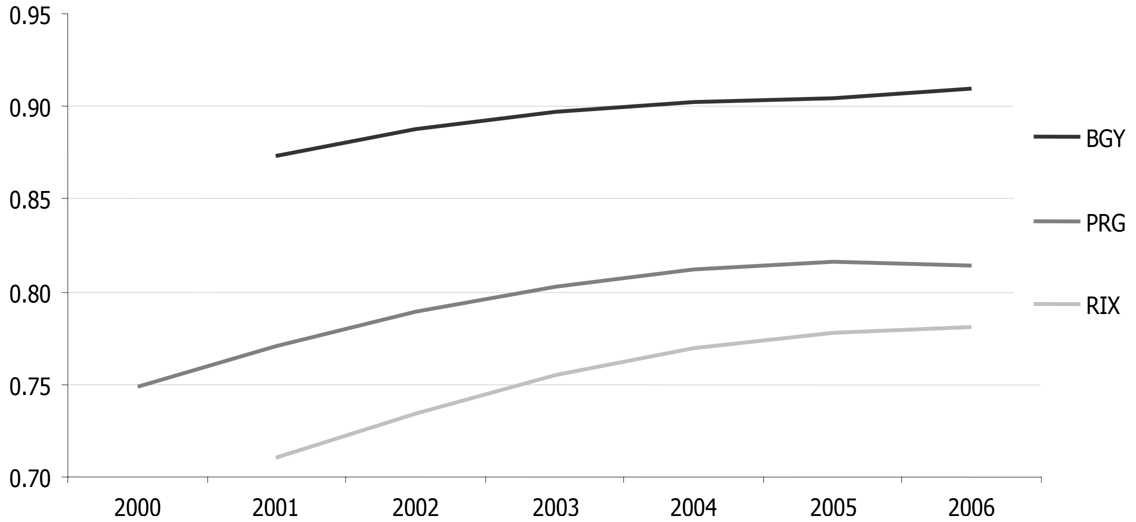


Figure 7.5 Evolution of TE estimates at rapidly growing airports

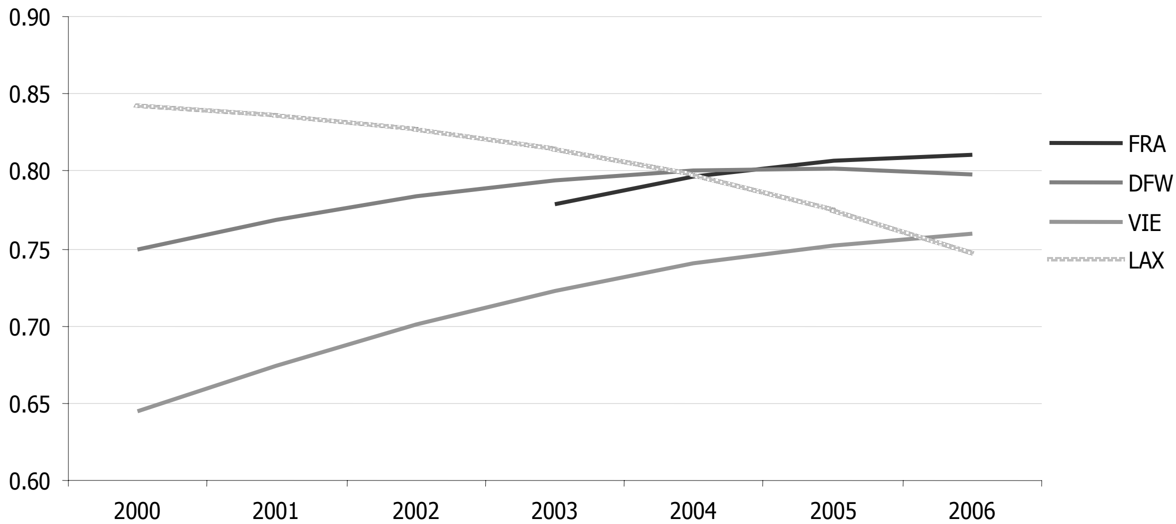


Figure 7.6 Evolution of TE estimates at several major hubs

Appendix 7B Evolution of passenger traffic and operating costs at selected airports

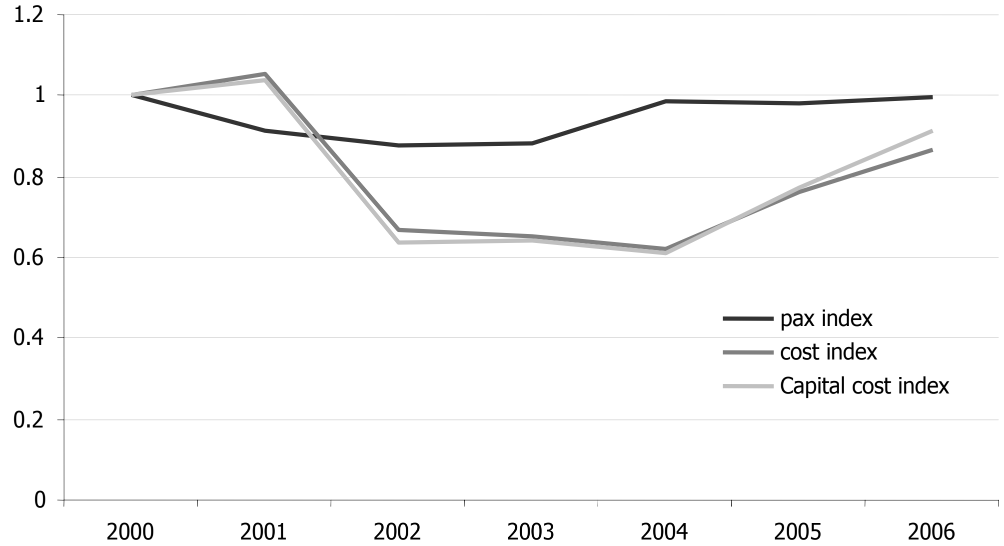


Figure 7B.1 Dallas Fort-Worth. DFW

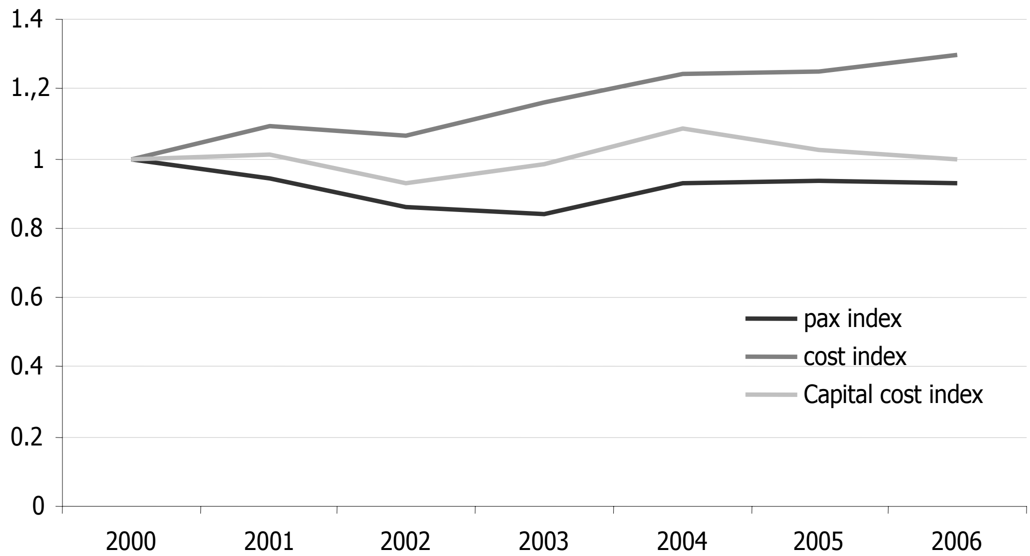


Figure 7B.2 Los Angeles. LAX

CHAPTER 8

MARGINAL COSTS AND OPTIMAL PRICING

The ultimate purpose of this chapter is to compare the actual airport charges and the estimated marginal costs (MC) as an indication of how far optimal pricing is from current practices. However, this analysis is limited because of two previously mentioned issues: first, the lack of information on externalities does not allow us to interpret the obtained MC in terms of social benefit; and second, the presence of strong IRS in the industry clearly hinders the adoption by the AA of these *first-best* prices, except, in the unlikely event that airports were to be subsidized by public authorities, or aeronautical activities were to be cross-subsidized by commercial revenues. The first of these issues is beyond the scope of this dissertation, and the second may only serve as a justification for the adoption of *second-best* policies in the best cases. However, even so, there will be significant dead losses to account for.

The first part of this chapter deals with the estimation of marginal costs (MC) for aircraft operations, passengers, cargo, and even commercial revenues, using the parameters of the cost function. The calculation of the MC from a translog specification is not as straightforward as in the quadratic case. As noted, the output partial derivatives can be directly interpreted in terms of cost elasticities. Hence:

$$\frac{\partial \ln C^o}{\partial \ln Y_i} = \frac{\partial C^o}{\partial Y_i}\frac{Y_i}{C^o} \quad ; \quad MC_i = \frac{\partial C^o}{\partial Y_i} = \frac{\partial \ln C^o}{\partial \ln Y_i}\frac{C^o}{Y_i}.$$

The second part of the MC formula is the ratio between the total costs and the i-th output. Although the concept of average cost (AC) does not exist in a multiproduct environment, in this chapter, the above-mentioned ratio will be labeled as such for the sake of exposition. In addition, it is worth noting here that only the first part of the cost frontier (lnC^o) is going to be used when predicting total costs. Otherwise, the estimated values could not be used in the analysis of optimal airport pricing.

8.1 Long-run results

Individual estimates of MC for all specified outputs in the long-run model were calculated and are presented in Annex 4. The traffic-weighted average MC values are

USD 304.80, USD 4.52, USD 40.02 and USD 160.57 for ATM_{737}, PAX, CGO and REV, respectively. In addition, the kernel density pictures for these MC estimations are provided in Appendix 8C.

Marginal costs are functions of both the output vector and the input prices, and for that reason, a great variability is observed in the estimated values when plotting them against the relevant output. This variability will be partially eliminated from the analysis in this subsection. This practice may reduce the overall significance of results, but, on the other hand, it allows us to provide a comprehensive list of MC for a wide range of production scales. This kind of information may be very interesting for airport managers or governmental bodies as a quick reference guide for pricing or regulatory purposes (see Appendix 8B.1). The methodology is fairly simple: the airport-specific MC estimates will be plotted against the corresponding output, and then moving averages (MAs) will be taken in order to smooth the graphical evolution. The choice of the MA period depends upon the roughness of the original data[1]. The graphical outcomes for the long-run model can be seen in the Figures 8.1 to 8.4[2].

The MC for the ATM_{737} variable is intended to serve as an indicator of the optimal (*first-best*) landing charge that ensures the most efficient utilization of the provided airside capacity. Note that full LTO cycles are considered rather than single landing/takeoff operations. In addition, because of the linear assumption with respect to the impact of the aircraft's weight on the landing costs, the calculation of an optimal unit rate per metric ton MTOW only requires dividing the obtained MC by 68, which is the weight in metric tons of the base aircraft[3]. The evolution of the moving average MC is as follows: in the first part, it presents an overall decreasing tendency until reaching the minimum at roughly 75,000 ATM_{737} for a marginal cost of USD 247.92. After this level, the average MC increases steadily until reaching the USD 400 level around 900,000 ATMs. Note that the lack of additional information on such large scales of production does not allow a very precise estimation of the slope of the AC over a million ATMs, and, for that reason, these results should be treated with caution especially when dealing with planning issues. This information is summarized in the first column of Table 8.1.

[1] These values represent the minimum number of MA periods required to identify some important features of the MC function, such as its minimum and the overall tendencies.

[2] All the figures in this chapter (Figures 8.1 to 8.9) are presented in Appendix 8A.

[3] This was explained in Chapter 3. Note that this also assumes that a linear unit rate per metric ton MTOW will be the system applied for the calculation of landing charges.

It can be seen that the observed evolution of the average MC agrees with the presence of scale economies in the provision of infrastructure for aeronautical activities at current levels of production. Nevertheless, it is also clear that these economies of scale are going to be exhausted as soon as the biggest hubs reach their ultimate projected capacities. At the scale of production in which the IRS associated with the aviation sector are expected to disappear (1.65 million ATM_{737}), the MC per metric ton MTOW may be up to 50 percent higher than that estimated at the current world's busiest airports. Thus the landing charges will start to increase at the level where airlines could start de-hubbing at these airports, unless the cost complementarities of commercial revenues allow airports to charge sub-optimal aeronautical charges[4].

Table 8.1 Average long-run marginal costs at different production levels

ATM737	MC		PAX	MC		CGO	MC	
(000)	mean	range	(mppa)	mean	range	(mmtc)	mean	range
0 to 5	425.0	415.9-439.2	0 to 1	4.11	4.03-4.21	0 to 0.1	221.3	81.6-360.9
5 to 15	392.3	373.9-411.4	1 to 5	3.75	3.52-4.03	0.1 to 0.5	62.4	48.6-81.6
15 to 75	285.8	247.9-370.0	5 to 25	3.47	3.17-3.68	0.5 to 1	43.1	38.8-48.6
75 to 300	278.3	249.3-288.9	25 to 50	4.04	3.68-4.33	1 to 1.5	36.3	34.1-38.8
300 to 500	301.3	289.0-314.9	50 to 60	4.42	4.33-4.51	1.5 to 2.5	31.2	28.9-34.1
500 to 900	350.3	315.0-390.9	60 to 85	4.74	4.51-4.98	2.5 to 4	26.6	24.8-28.9

Regarding passenger service, the average MC has its minimum at roughly 9 mppa with an estimated value of USD 3.23. The moving average keeps the same level until reaching 40 mppa, where a significant increase in MC estimates is appreciated. Earlier, in Chapter 6, it was stated that the presence of DRS beyond 60 mppa was the most likely reason for the overall scale economies to become exhausted. The proposed evolution fits perfectly well with that result, showing increasing MC estimates from the point that serving an additional passenger starts to require additional investments (people movers and ground access infrastructures). Related to that, and as a word of caution, the probable adoption of new operational procedures in order to deal with the forecast passenger levels up to 120 mppa will probably change the shape of the industry's MC function. For that reason, it is not advisable to use the proposed values much beyond the 85 mppa level, until new empirical evidence can be provided.

The average MC of the *cgo* variable is decreasing in the whole range of production, indicating that the provision of infrastructure for freight processing is a major contributor in the creation of scale economies. MC estimations range between USD 24 and USD 300. However, a more plausible explanation for this trend is that the increase of production also increases the presence of the freight companies which provide their

[4] Of course, these practices would not be possible if dual-till price regulation is enforced.

own facilities, and thus have less impact on the AA's total costs. In this context, the service of a single *cgo* unit may not be homogenous across all sample airports, thus having an indeterminate impact on the estimation of the degree of scale. A very interesting experiment[5] would consist of locating this hypothetical breakpoint in the MC function, in order to find the expected increasing trend in MC of any production process which makes use of fixed factors.

In addition, under the proposed approach, these results allow us to test the convenience of a separate specification of both the *pax* and the *cgo* variables instead of the usual WLUs. If only the information provided by the average values is considered, the wrong conclusions could be drawn. As the cargo variable was measured in metric tons, the average MC for an additional 100 kg of cargo is USD 4.0, which is actually very close to the average costs imposed by the additional passenger (4.52). However, the evolution of both the MC through different production levels will eventually show that the aggregation is unsatisfactory. As shown in Figure 8.5, the MC imposed by an additional passenger is equal to the MC imposed by an additional 100kg. of cargo at around 14 million WLUs. This value is very close to the average sample airport (11 mppa) and, for that reason, the average MC are very similar in value. Nevertheless, this equality does not hold for any other scale of production. At smaller airports, the production of cargo is more expensive than the service of passengers. On the other hand, at bigger airports, the new investments in passenger terminal infrastructures are usually paid by the AA, thus increasing the MC, as explained. This effect is not seen in the specialized cargo airports, where these additional infrastructures are provided by the freight companies. Therefore, passengers become more expensive than cargo at bigger scales of production. The perfect example is HKG, which produces significantly high levels of both outputs. At this airport the estimated MC for an additional passenger is USD 11.58, while handling an additional 100 kg of cargo only costs USD 3.4 to the AA.

The *rev* variable was specified in order to avoid the estimation bias derived from the impossibility of separating the costs of these retail activities in the collected data. The average MC invested in the production of an additional PPP USD 1,000 of commercial revenues is estimated at USD 160.57. The main conclusion to draw from this value is that, on average, airports are still very far from their optimal commercial development (i.e. MC*rev* = USD 1,000) indicating that they still have enough room to expand their scope of on-site services. Related to that, major changes in the provision of

[5] This is left for future research.

infrastructure for retail activities are expected in the near future, as it appears to becoming the most important source of airport revenues. The planning and construction of huge retail surfaces and the trend towards diversification[6] is nowadays overtaking the development of airside infrastructures in almost every Master Plan. In this context, the presence of strong demand complementarities between transport and retail activities may radically change the setting of airport charges in the near future. The provision of infrastructure for air transportation might become completely subsidized by the revenues generated by both passengers and visitors. These results reinforce the Beesley (1999) argument which puts emphasis on the demand complementarities in order to show that airport price regulation was not needed, because airports would not extract the monopoly rents from aeronautical activities on account of the presence of important demand complementarities from commercial activities.

8.2 Short-run results

Regarding the short-run model, only the aeronautical outputs are considered because the level of commercial revenues was assumed to be fixed given the terminal surface *(ter)*. The output-specific cost elasticities are obtained from the partial derivatives of the variable cost frontier as specified in Chapter 5. Only one second-degree interaction could be included in the final model. Thus the MC of an additional *atm* is allowed to vary with the level of airside infrastructures, measured by the *run* variable. In an optimal scenario, the specification would also have featured a second-degree interaction for the *pax* variable, preferably with the fixed terminal factor. However, the multicollinearity problems did not allow it.

$$\frac{\partial \ln VC^o}{\partial atm} = \alpha_2 + \gamma_9 wm + \gamma_{10} wp + \rho_{22} run \ ;$$
$$\frac{\partial \ln VC^o}{\partial pax} = \alpha_3 + \gamma_{11} wm + \gamma_{12} wp \ ;$$
$$\frac{\partial \ln VC^o}{\partial cgo} = \alpha_4 + \gamma_{13} wm + \gamma_{14} wp.$$

The traffic-weighted average MC values are USD 79.72, USD 1.14 and USD 5.02 for ATM_{737}, PAX and CGO, respectively. These values are considerably lower than the long-run estimations in Section 8.1, as capital costs are not taken into account. From the ratio between long- and short-run estimates, the average proportion of capital costs which should be included in the corresponding optimal charges can be estimated,

[6] The development of the SkyPlaza at HKG (golf course included) is a perfect example of that.

resulting in 74, 75 and 87 percent for ATM_{737}, PAX and CGO, respectively. This is again consistent with the consideration of freight handling as an airline activity, the airport being responsible only for providing some basic infrastructures. The individual MC estimates, along with their moving averages, are presented in Figures 8.6 to 8.8.

In spite of the second-degree interaction, no increasing trend could be identified in the upper tail for the average MC of the *atm* variable. This indicates that, in the short run, airports are interested in serving as much demand as they can. Another interesting result is obtained by comparing the evolution of both long- and short-run MC estimates. The difference between the two curves becomes more significant as production increases, showing that *atm* becomes more capital intensive at major international hubs. However, as usual, the availability of financial information on the full transport perimeter (i.e. including ground handling firms) may play an important role in the validation of this result. As in the long-run case, Appendix 8B.2 provides a list of average MC for different scales of production, and this information is summarized in Table 8.2.

Table 8.2 Average short-run marginal costs at different production levels

ATM737	MC		PAX	MC		CGO	MC	
(000)	mean	range	(mppa)	mean	range	(mmtc)	mean	range
0 to 5	258.1	212.8-333.4	0 to 1	2.79	2.31-14.8	0 to 0.1	18.60	13.32-40-38
5 to 15	174.7	155.7-201.5	1 to 5	1.80	1.52-2.03	0.1 to 0.5	8.71	6.14-12.73
15 to 75	115.8	99.0-143.6	5 to 25	1.15	1.01-1.46	0.5 to 1	5.11	4.38-6.08
75 to 300	77.4	67.1-94.1	25 to 50	1.20	0.99-1.54	1 to 1.5	3.94	3.59-4.35
300 to 500	61.5	58.0-65.5	50 to 60	1.68	1.56-1.83	1.5 to 2.5	3.15	2.81-3.58
500 to 900	52.8	57.3-49.2	60 to 85	2.31	1.93-2.70	2.5 to 4	2.49	2.24-2.81

The evolution of the average MC for the *pax* variable is much more interesting, it reaches the minimum at roughly 30 mppa (USD 0.98), showing a slight increase thereafter, and reaching an average of USD 2.5 at the biggest hubs. This indicates that the presence of DRS in the service of passengers may be related not only to the infrastructure but also to the higher requirements of labor and supplies. Regarding CGO traffic, the same pattern as the long-run approach is observed, with a negative slope over the whole range of production considered.

8.3 Optimal vs. actual charges

Assuming all the above-mentioned shortcomings with respect to the consideration of these MC as optimal charges in terms of social benefit, the airport-specific MC estimates will be now compared with the observed prices. In order to do that, seven international case studies from the estimating sample will be provided. The primary objective is to test whether airports excessively exploit their market power by setting charges with no relation to the operating costs. In this connection, it would be very interesting to find out whether infrastructures are over- or under-priced if fare levels are consistent with airport characteristics, such as excess capacity and even if some degree of cross-subsidization among aircraft categories exists. This could be a good indicator of the presence of aircraft-mix reorientation policies in the long-run view of the airport operator. In addition, the results will provide empirical evidence regarding the "real" approach used by the AA at the time of calculating infrastructure prices. This is mainly related to the nature of operating costs covered by the users, i.e. total costs (*single-till*) vs. only aeronautical (*dual-till*). In addition, the suitability of the long-run approach to describe the airport's cost function and provide optimal prices in terms of MC can be also empirically tested by taking into account the short-run estimated prices.

This analysis will be focused exclusively on landing *(atm)* and passenger charges, as defined in Chapter 1. As both production processes are inevitably related, the analysis will take into account the overall level of charges. Furthermore, in order to make a fair comparison between estimated MC and actual prices, some adjustments are necessary. The most important of these relates to the usual practice of charging only the departing passengers. In those cases, the MC of serving an additional passenger will not be directly comparable to the published price, which may be calculated taking into account the cost imposed by the arriving counterpart. A separate specification of arriving and departing passengers would not have provided any better results because both variables are extremely correlated and, in addition, most commercial airports present basically the same figures of incoming and outgoing traffic. For that reason, the estimated passenger MC will be doubled before comparing it with the actual charge. The same applies to the landing (runway) charge. It will be assumed to cover the whole aircraft turnaround. Hence an aggregate price will be calculated if the operator charges the landing and takeoff movements separately.

Additionally, and considering the empirical evidence provided in Chapter 3 about the technological relationship between infrastructure costs and aircraft weight, only those airports featuring constant or increasing unit rates per metric ton MTOW will be analyzed. The consideration of any airport with decreasing unit rates, such as MAN, in spite of being probably closer to optimal pricing, may lead to wrong interpretations if compared with the linear schedule provided by the present methodology. Finally, it is worth noting that, in the presence of noise or other environmental surcharges to the landing price, the total amounts will be calculated using the most neutral conditions.

Under the likely presence of increasing unit rates, a proper analysis of the landing price systems can only be done using fare schedules that comprise several aircraft categories. In this section, six very common airliners from the aircraft database of Annex 2 will be featured, three of them wide-bodies (see Table 8.3). They were all chosen as representatives of their weight categories, and, hence, it is not implied that all of them actually operate at the analyzed airports. Nevertheless, in order to facilitate the presentation of results, aircraft selection took into account the relative frequency of use within the US airport system, calculated using the referred data from BTS (2007).

Table 8.3 Selected airliners

	MTOW (metric tons)	Takeoff distance (m)	Wingspan (m)	Seats
ATR72	22	1,290	27	72
B737-300	57	2,109	29	128
A320-200	75	2,090	34	150
B767-300	171	2,850	48	210
B777-200	267	3,170	61	305
B747-400	377	3,600	64	416

The first case study is Brussels airport (BRU) former Brussels National, which is a recently privatized airport owned by Macquaire with a 30 percent share retained by the Belgian State. In 2005, the airport was awarded the title of Best Airport in Europe by ACI/IATA. The efficiency estimation for the year 2006 reports TE of 86 percent, about 4 percent above the world's average and 6 percent above the European average. Operational figures for the last decade (Figure 8.9) showed a steady growth trend, exceeding the 21 million passenger level in the year 2000. Nevertheless, this tendency was reversed in the year 2001 when the flag airline Sabena went bankrupt and canceled all its flights at BRU. This translated into a sharp fall in passenger traffic, losing more than 6 million in two years (almost 30 percent). Regarding airside infrastructures, BRU provides more than 9,500m of serviceable runways, which is more than HKG or VIE, serving about 250,000 aircraft operations per year with an average MTOW of 64 metric tons. During the last five years, the traffic figures have shown a slow recovery, but are still very far from the pre-2001 levels, indicating that BRU is currently operating with a significant excess capacity, aggravated by the fact that, in 2002, a new international pier was opened.

Airport charges are regulated by a license granted to the airport operator, with the declared objective to reach *dual-till* returns. Its actual landing and takeoff charge (LC) rule is linear in MTOW, but the unit rate (R) can deviate according to both noise (N) and time-of-the-day (D) considerations. Additionally, lower and upper limits for the weight factor are imposed between 25 and 175 metric tons.

$$LC = R\ x\ MTOW\ \ x\ N\ x\ D\,.$$

Taking into account only operational and maintenance/recovery costs (i.e. under neutral noise conditions), the 2006 turnaround fares obtained for the six selected airliners are presented in Table 8.4[7]. The first conclusion to draw is that, as expected, runway charges at BRU are calculated according to long-run considerations, i.e. including capital costs. The depreciation of the airside infrastructure is the most important source of costs at an average commercial airport. Therefore, it seems to be obvious that the use of the infrastructure will be the major component of the final price, as required by the *dual-till* approach. Otherwise, no aeronautical cost recovery can be expected. As a matter of fact, short-run values are presented but not used in the analysis.

The results indicate, at first sight, that BRU applies sub-optimal pricing. Narrow-body aircraft (that represent up to 90 percent of the annual movements) are priced about 14 percent below their estimated MC. Moreover, the wide-bodies segment (less than 10 percent of traffic) is also blatantly underpriced, putting in doubt the declared aeronautical cost recovery. The setting of an upper weight limit at 175 metric tons makes actual charges deviate up to 150 percent from their efficient MC. At first sight, these results deny the existence of true engagement with the *dual-till* principles clearly induced by the excess capacity. The *atm* underpricing will help to increase traffic and passenger flows through the uncongested terminal buildings and thus maintain a high level of commercial benefits in order to sustain a covert *single-till* pricing policy. On the other hand, airport managers and practitioners often criticize the simplistic view of the airport's activity that is implicit in empirical studies like the present one. Airport charges are very important strategic variables, and some other goals than cost recovery should also be considered "optimal". In this case, the cross-subsidized prices for heavier aircraft clearly indicate the existence of an underlying "mix-reorientation" policy, with the objective of consolidating BRU as a long-haul hub for transatlantic destinations, especially with the US. This development was interrupted by 9/11.

Table 8.4 Marginal costs and actual landing charges at BRU (in EUR)

unit rate	**3.63**	**0.97**	**3.12**	**3.12**
	Optimal	Short-run	Actual	No Weight limit
ATR72	79.86	21.34	78.0	68.6
B737-300	206.91	55.29	177.8	177.8
A320-200	279.51	74.69	240.2	240.2
B767-300	620.73	165.87	533.5	533.5
B777-200	969.21	258.99	546.0	833.0
B747-400	1368.51	365.69	546.0	1,176.2

[7] Note that they are expressed in euros.

However, this conclusion does not extend to the passenger charge. BRU is known to charge one of the highest prices in Europe (only to outbound pax). The comparable MC estimation is EUR 6.60, which is certainly well below the current charges (as of 2006) of EUR 14.95 for originating and EUR 7.60 for transfers. Note that these prices only account for the use of facilities (PFC) because security (PSC) is levied separately. Hence, the final interpretation is that passengers are cross-subsidizing aircraft operations. As an example, the turnaround of a full A320-200 (all departing passengers) generates EUR 2482.7 of revenue, against an MC of only EUR 1269.5. This case study shows that a separate analysis of both outputs may lead to the wrong conclusions.

Macquaire also has a significant share of the public company Copenhagen Airport A/S which operates the busiest airport in the Nordic countries (CPH). During the last 15 years it has experienced a steady annual 4 percent growth in both passenger and cargo traffic, as well as an increase of 37 percent in the average aircraft weight served. Regarding TE estimates, it scores a notable average of 89 percent. In addition, CPH has been rated the most efficient airport in Europe by the Air Transport Research Society (ATRS, 2006). The regulation of aeronautical charges follows a *dual-till* regime. Runway charges are calculated on a linear basis and are payable only at takeoff. Table 8.5 presents the optimal and actual charges, expressed in euros[8]. Even though CPH is often referred to as one of the cheapest airports in Europe (TRL, 2006), all aircraft segments seem to be significantly overpriced. The actual system of passenger fees discriminates between domestic and international flights, as they are only payable by departing passengers. An average price was calculated at EUR 13.90, which is significantly higher than the comparable MC estimation at EUR 4.7. These results clearly indicate that no significant correlation can be expected between technical and pricing efficiency because of the presence of market power derived from the natural monopoly in the provision of aeronautical infrastructure. In spite of that, fare levels at CPH are lower than those of its main competitors, e.g. OSL or ARN.

Table 8.5 Marginal costs and actual landing charges at CPH (in EUR)

unit rate	**5.73**	**2.86**	**8.75**
	Optimal	Short-run	Actual
ATR72	126.0	62.9	192.4
B737-300	326.5	163.0	498.6
A320-200	441.0	220.2	673.6
B767-300	979.4	489.1	1,495.8
B777-200	1,529.2	763.6	2,335.6
B747-400	2,159.3	1,078.2	3,297.8

[8] The currency conversion was based on historic rates (DKK/EUR).

The last European example is STR. Like most German airports, it is publicly owned and managed, scoring a very poor, though increasing, TE of 72 percent. In addition, the lack of flexibility in the labor markets (that is characteristic of these countries) generates very important allocative distortions, in the sense that too much of its own labor is demanded against the (cheaper) outsourcing alternative. In spite of that, during the last four years, STR has experienced an average 9 percent growth in passenger traffic, while showing only a moderate increase in total costs. The landing charge rule is perfectly linear in MTOW with a fixed unit rate of EUR 3.40 per landing and per takeoff. The optimal long-run turnaround price is EUR 6.57, which is only 3.5 percent lower than the actual charge, indicating a very high degree of optimal pricing, and at the same time, a very low degree of aeronautical cost recovery. As in the previous case, under a short-run specification, the turnaround fare amounts only to EUR 2.55 per metric ton MTOW, and hence the long-run price will again be the leading approach. The results are presented in Table 8.6.

Exactly the same applies to the passenger charges. The calculation of the passenger fee is a bit more complicated than in the BRU case because prices are slightly different according to the passenger's origin/destination. The intermediate price category comprises the flights within the EU. If the passenger security fee is added, the average charge is EUR 5.36 and the comparable MC is EUR 5.94. As in the *atm* case, STR airport is very close to optimal pricing, yet the presence of scale economies, technical and allocative inefficiencies will not allow financial breakeven of aeronautical assets. This result turns out to be very interesting when taking into account that most German airports are regulated under a *single-till* approach. Hence, it can be deduced that commercial revenues are expected to cover aeronautical losses, derived not from the subsidized infrastructure charges but from the airport's own operational inefficiency. In addition, these results again support the absence of a direct relationship between technical and pricing efficiency even if the airport is being severely inefficient.

Table 8.6 Marginal costs and actual landing charges at STR (in EUR)

unit rate	**6.57**	**2.55**	**6.80**
	Optimal	Short-run	Actual
ATR72	144.54	56.1	149.6
B737-300	374.49	145.35	387.6
A320-200	505.89	196.35	523.6
B767-300	1123.47	436.05	1,162.8
B777-200	1754.19	680.85	1,815.6
B747-400	2476.89	961.35	2,563.6

Both ATL and DFW airports were chosen to represent the US industry. They rank among the world busiest airports and for that reason serve as very important observations in the 50-80 mppa range of production. Regarding TE, ATL presents a TE of about 86 percent and in 2006 was rated the world's top performer by the ATRS. DFW shows a slow but steady recovery from 9/11 and the de-hubbing of Delta, with an average TE of about 80 percent . The calculation of airport charges in the US is slightly different from that in the rest of the world. The landing fee rule also follows a linear system in aircraft weight[9]. However, the unit rates are in 1,000 lbs instead of metric tons. In order to homogenize the results, the published unit rates were converted to metric tons MTOW and are shown in this unit in Tables 8.7 and 8.8. In addition, passenger charges are not directly levied because terminal use is included in the lease agreements. For that reason, there is no direct comparison between optimal and current passenger facility charges (PFC), as it would require extensive knowledge of each carrier's own contract conditions.

But the most significant difference is the price discrimination between signatory and non-signatory airlines, whose unit rates are 75 percent higher in ATL and 30 percent higher in DFW. A signatory airline should be a party to the Airport Use Agreement, thus agreeing to "pay the stipulated fees for the operation of the leased premises in an amount which, together with the charges paid by other entities, will be sufficient to satisfy the airport's financial obligations[10]". This definition fits perfectly well with the results of ATL, because signatory airlines are significantly underpriced and thus cross-subsidized by the new entrants.

Apart from these agreements, one of the major characteristics of the US industry is the significant involvement of dominant carriers in the setting of airport charges. This discrimination is clearly imposed as a barrier to entry. However, this may be a reasonable approach to the incumbent carriers such as Delta or American Airlines if they are bearing a great part of the construction and maintenance costs of the dedicated terminals and other leased infrastructures. In spite of the similarities between both airports, the level of charges is much lower in ATL than in DFW, but exactly the same policy is found in the American Airlines' hub. However, in this case, all signatory and new entrant carriers are blatantly overpriced by three to five times their marginal infrastructure costs. This overpricing may reach USD 2,500 for a signatory airline operating a B747-400 into DFW.

[9] In DFW, the maximum landing weight is used instead of the MTOW.

[10] In DFW, gross revenues should also cover 1.25 times the payment of principal and interest on the joint revenue bonds. In addition, there is an intermediate price category that is applicable to those airlines that receive a permit from the AA (DFW, 2006).

Table 8.7 Marginal costs and actual landing charges at ATL (in USD)

unit rate	2.91	0.13	1.91	3.35
	Optimal	Short-run	Signatory	Non signatory
ATR72	64.02	2.86	42.02	73.70
B737-300	165.87	7.41	108.87	190.95
A320-200	224.07	10.01	147.07	257.95
B767-300	497.61	22.23	326.61	572.85
B777-200	776.97	34.71	509.97	894.45
B747-400	1,097.07	49.01	720.07	1,262.95

Table 8.8 Marginal costs and actual landing charges at DFW (in USD)

unit rate	2.58	0.38	9.63	12.52
	Optimal	Short-run	Signatory	Non signatory
ATR72	56.76	8.36	211.86	275.44
B737-300	147.06	21.66	548.91	713.64
A320-200	198.66	29.26	741.51	964.04
B767-300	441.18	64.98	1,646.73	2,140.92
B777-200	688.86	101.46	2,571.21	3,342.84
B747-400	972.66	143.26	3,630.51	4,720.04

Because of the lack of price information for 2006, no Asian airports could be included in this brief collection of case studies. For that reason, the last two examples come from the Oceania sample. The calculation of infrastructure charges at SYD airport is much more complicated than in the previous cases because the use of landing and passenger facilities at the international terminal is merged in a lump-sum charge, which is passenger-based (both arriving and departing). Under this approach, only a joint analysis can be carried out by comparing the MC with the price for a whole turnaround of the selected airliners assuming 100 percent occupancy[11].

The results are shown in Table 8.9 and are presented in AUD. For the calculation of optimal long- and short-run prices the two estimated unit rates were considered always showing the *atm* first. The MC of the aircraft turnaround was added to the MC of every single passenger for the aggregate optimal price. Note that short-run unit rates are higher for the passenger service. It means that, given the current prices, it is more expensive for the AA to provide labor and supplies to serve a single passenger than to serve a metric ton of aircraft. However, as usual, the long-run is the leading approach for analysis, especially taking into account the overwhelming difference between optimal and actual prices. In this case, the difference between signatory and non-signatory airlines is only about 3 percent. Hence, new entrants are not expected to cross-subsidize the operation of incumbent carriers. On the other hand, the use of the international terminal is seriously overpriced for all users: lump-sum charges are, on average, 100 percent higher than the respective MC.

[11] Seat capacity is shown in Table 8.3.

Table 8.9 Marginal costs and actual landing charges at SYD (only international flights) (in AUD)

unit rate	**10.59 - 9.43**	**0.76 - 1.28**	**24.45**	**25.19**
100% load factor	Optimal	Short-run	Signatory	Non signatory
ATR72	1,590.90	201.04	3,520.80	3,627.36
B737-300	3,017.71	371.00	6,259.20	6,448.64
A320-200	3,644.43	442.52	7,335.00	7,557.00
B767-300	5,771.49	667.56	10,269.00	10,579.80
B777-200	8,579.83	983.72	14,914.50	15,365.90
B747-400	11,838.19	1,351.48	20,342.40	20,958.08

However, the analysis of these results should be done with caution, as the methodology for the estimation of passenger prices implicitly assumes all of them impose the same costs on the infrastructure. However, the existence of different terminals providing different facilities may produce biased results that inevitably lead to wrong interpretations. Thus the necessity for terminal-disaggregated financial and operational information as featured in the proposed reporting form described in Chapter 4 would help to resolve this type of problem. In spite of that, the null hypothesis of overpricing at SYD's international terminal is supported by a very wide confidence range.

The last case study is the busiest airport in New Zealand, located in the city of Auckland (AKL). It is one of the most technically-efficient airports in the present sample (90 percent), though it is not subject to any price regulation. AKL has been ranked by TRL (2006) among the most expensive airports in Oceania. The level of charges has been a source of conflict between the AA and the users since the privatization in 1998. Air New Zealand has even filed a claim against Auckland International Airport Ltd. (AIAL) requiring a judicial review of the last price schedule (CAPA, 2007). The results shown in Table 8.10 provide further empirical evidence on this delicate issue. The landing charge rule is linear in MTOW, though the unit rate increases with the weight category. As expected, AKL users are charged twice the optimal price for the use of airside facilities. These results agree with Mackenzie-Williams (2002), which recommended the adoption of price controls at AKL because of the blatant abuse of market power.

Table 8.10 Marginal costs and actual landing charges at AKL (in NZD)

unit rate	**6.50**	**0.28**	**11.85**	**12.19**
	Optimal	Short-run	Domestic	International
ATR72	143.00	6.16	161.41	161.41
B737-300	370.50	15.96	675.56	694.86
A320-200	500.50	21.56	912.60	938.67
B767-300	1,111.50	47.88	2,026.67	2,084.58
B777-200	1,735.50	74.76	3,164.46	3,254.86
B747-400	2,450.50	105.56	4,468.17	4,595.82

Appendix 8A Chapter 8 figures

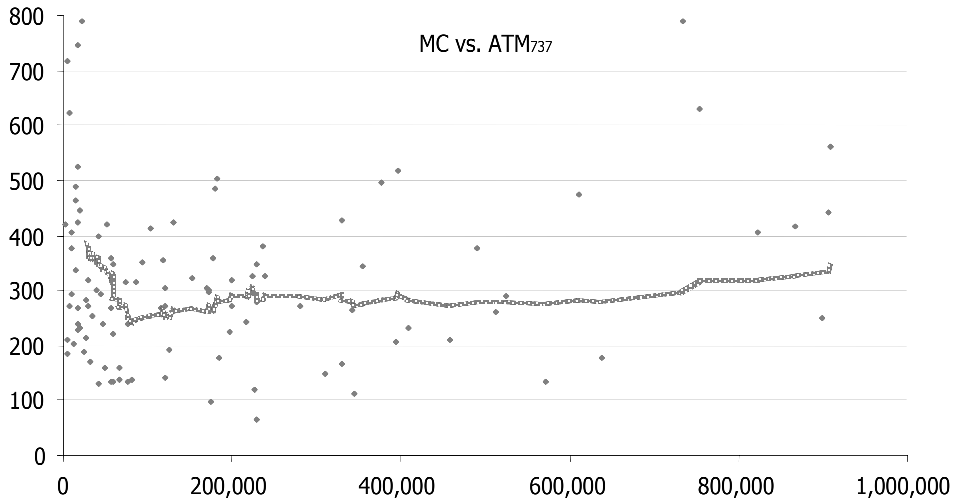


Figure 8.1 Evolution of the ATM_{737} long-run marginal cost estimates (Moving Averages, 30)

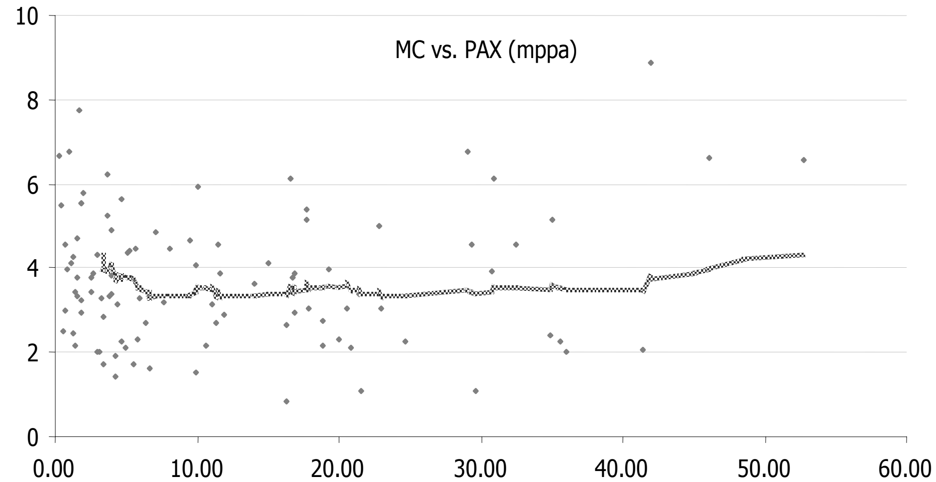


Figure 8.2 Evolution of the PAX (in mppa) long-run marginal cost estimates (Moving Averages, 30)

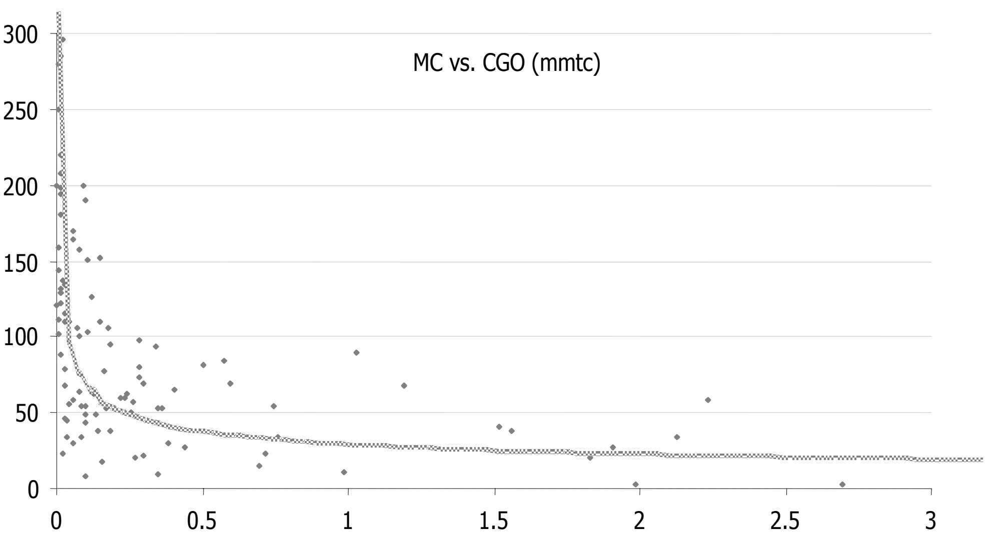


Figure 8.3 Evolution of the CGO (in million metric tons) long-run marginal cost estimates (Moving Averages, 20)

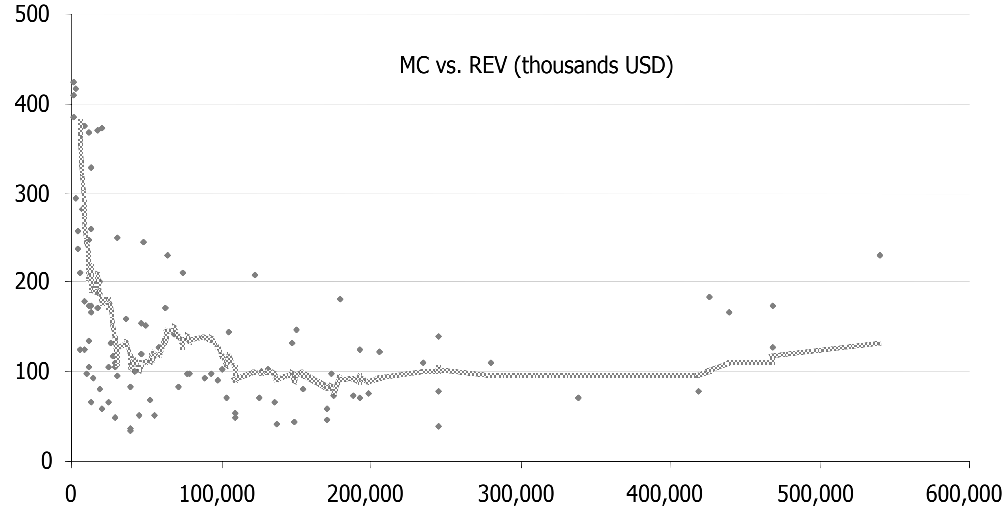


Figure 8.4 Evolution of the REV (in USD) long-run marginal cost estimates (Moving Averages, 10)

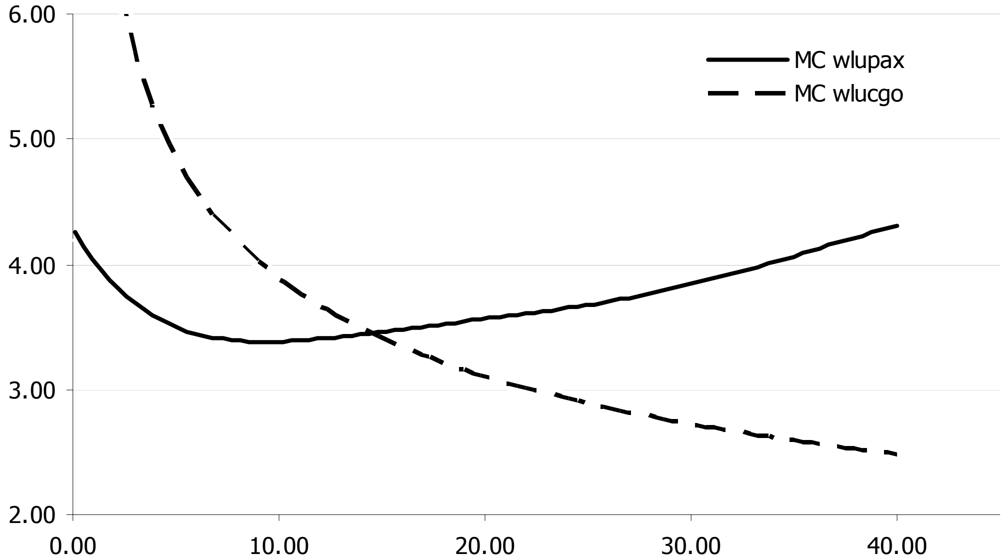


Figure 8.5 Comparison between PAX and CGO (100Kg) long-run average marginal costs (in million wlus)

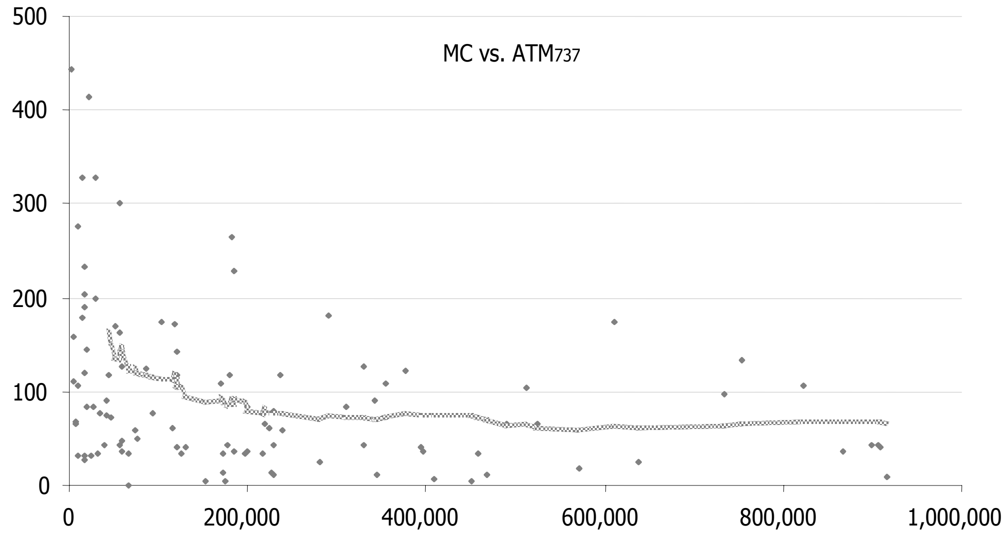


Figure 8.6 Evolution of the ATM_{737} short-run marginal cost estimates (Moving Averages, 30)

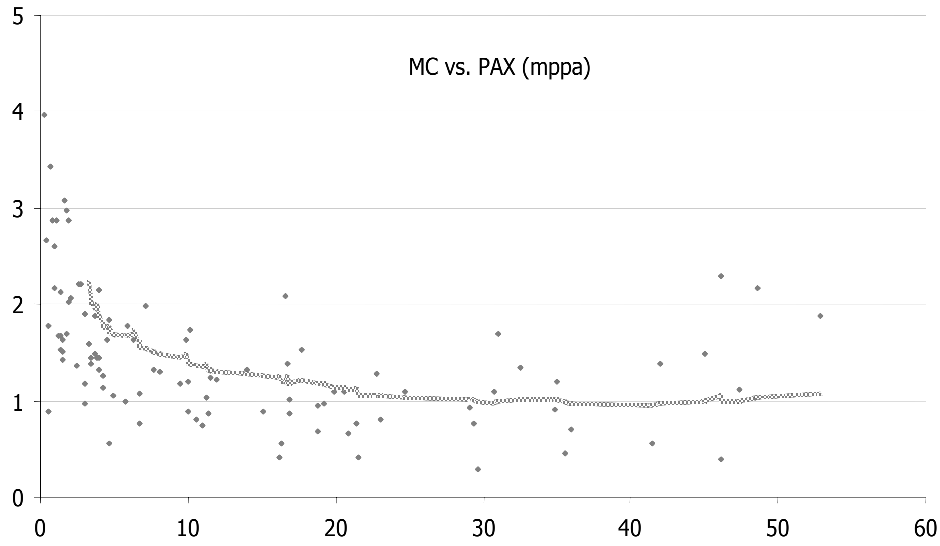


Figure 8.7 Evolution of the PAX (in mppa) short-run marginal cost estimates (Moving Averages, 30)

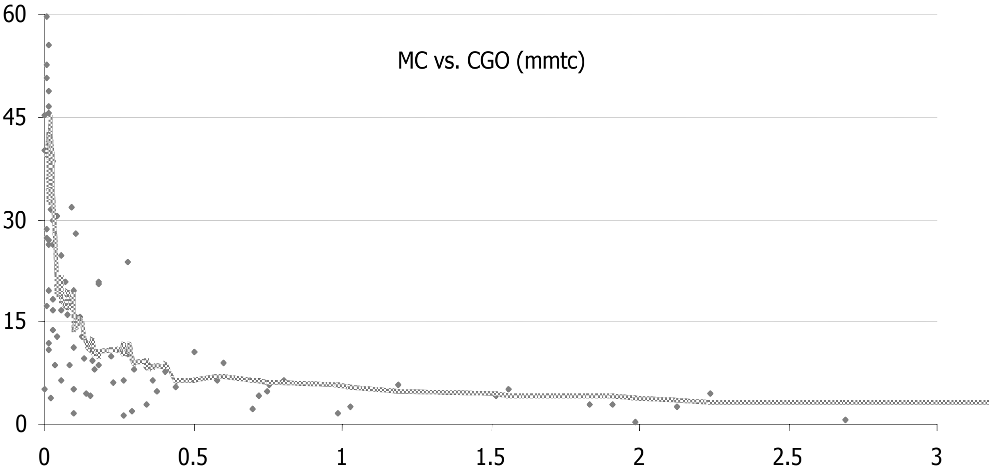


Figure 8.8 Evolution of the CGO (in million metric tons) short-run marginal cost estimates (Moving Averages, 4)

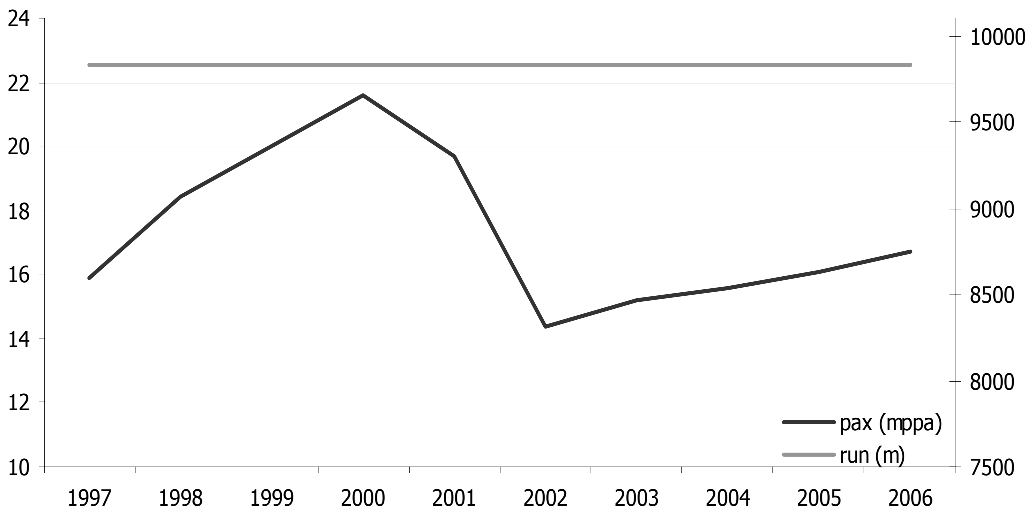


Figure 8.9 Evolution of traffic and capacity at BRU

Appendix 8B Average MC estimations at different output levels

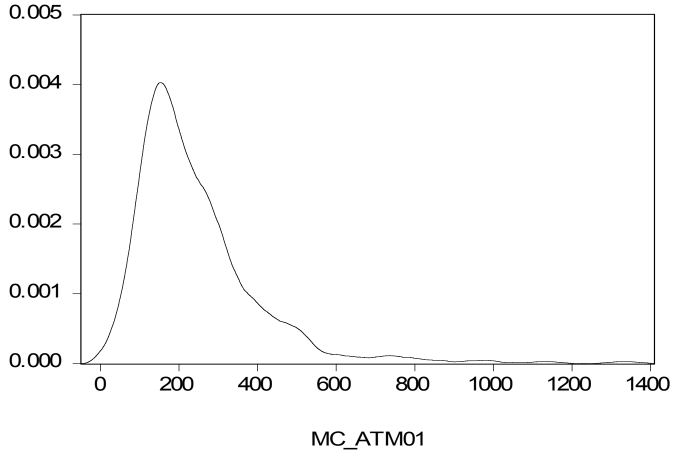
Appendix 8B.1 Reference values under a long-run approach (PPP USD 2006)

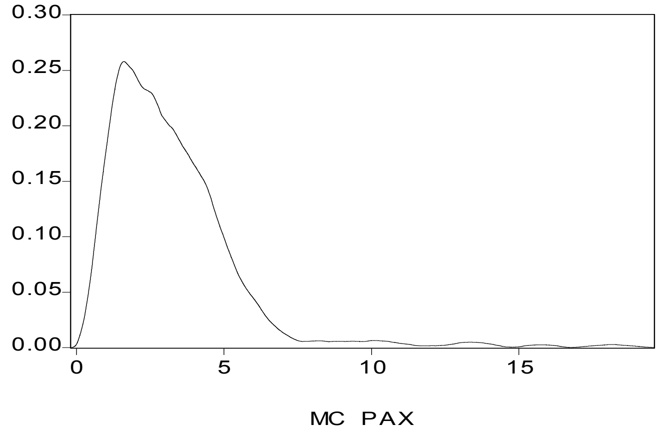
atms	MC ATM737	Unit Rate	mppa	MC pax	mmtc	MC cgo
15,000	373.92	5.50	0.5	4.11	0.05	102.14
30,000	322.17	4.74	1	4.03	0.10	81.67
45,000	283.92	4.18	1.5	3.94	0.15	71.65
60,000	259.17	3.81	2	3.87	0.20	65.30
75,000	247.92	3.65	2.5	3.80	0.25	60.76
110,000	271.63	3.99	3	3.73	0.30	57.29
145,000	274.27	4.03	6	3.43	0.40	52.21
180,000	277.16	4.08	9	3.23	0.50	48.59
215,000	280.29	4.12	12	3.44	0.60	45.81
250,000	283.67	4.17	15	3.47	0.70	43.59
285,000	287.29	4.22	18	3.51	0.80	41.75
320,000	291.16	4.28	21	3.57	0.90	40.19
355,000	295.27	4.34	24	3.85	1.00	38.85
390,000	299.63	4.41	27	3.90	1.10	37.67
425,000	304.23	4.47	30	3.96	1.20	36.63
460,000	309.08	4.55	33	4.01	1.30	35.69
495,000	314.17	4.62	36	4.07	1.40	34.85
530,000	319.51	4.70	39	4.13	1.50	34.08
565,000	325.09	4.78	42	4.18	1.60	33.38
600,000	330.92	4.87	45	4.24	1.70	32.73
635,000	336.99	4.96	48	4.29	1.80	32.14
670,000	343.31	5.05	51	4.35	1.90	31.58
705,000	349.87	5.15	54	4.40	2.00	31.06
740,000	356.68	5.25	57	4.46	2.10	30.58
775,000	363.73	5.35	60	4.51	2.20	30.12
810,000	371.03	5.46	63	4.57	2.30	29.69
845,000	378.57	5.57	66	4.62	2.40	29.29
880,000	386.36	5.68	69	4.68	2.50	28.90
915,000	394.39	5.80	72	4.74	2.60	28.54
950,000	402.67	5.92	75	4.79	2.70	28.19
985,000	411.19	6.05	78	4.85	2.80	27.87
1,020,000	419.96	6.18	81	4.90	2.90	27.55
1,055,000	428.97	6.31	84	4.96	3.00	27.25
1,090,000	438.23	6.44	87	5.01	3.10	26.97
1,125,000	447.73	6.58	90	5.07	3.20	26.69
1,160,000	457.48	6.73	93	5.12	3.30	26.43
1,195,000	467.47	6.87	96	5.18	3.40	26.17
1,230,000	477.71	7.03	99	5.24	3.50	25.93
1,265,000	488.19	7.18	102	5.29	3.60	25.70
1,300,000	498.92	7.34	105	5.35	3.70	25.47
1,335,000	509.89	7.50	108	5.40	3.80	25.25
1,370,000	521.11	7.66	111	5.46	3.90	25.04
1,405,000	532.57	7.83	114	5.51	4.00	24.84
1,440,000	544.28	8.00	117	5.57	4.10	24.64
1,475,000	556.23	8.18	120	5.62	4.20	24.45

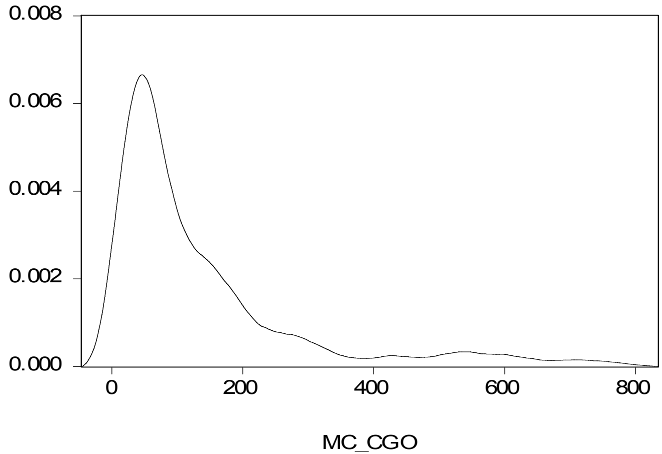
Appendix 8B.2 Reference values under a short-run approach (PPP USD 2006)

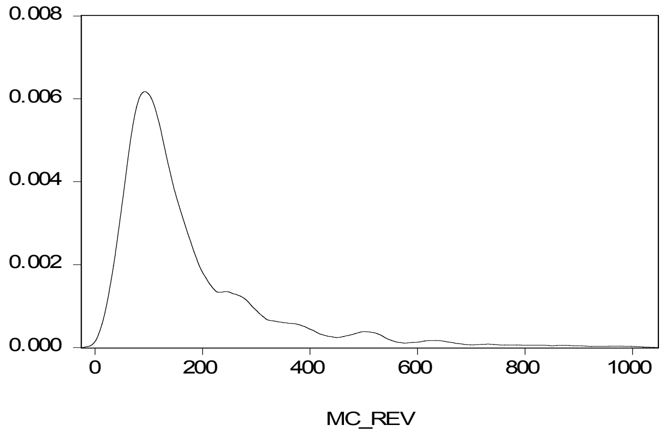
atms	MC ATM737	Unit Rate	mppa	MC pax	mmtc	MC cgo
15,000	155.71	2.29	0.5	2.79	0.05	18.60
30,000	128.14	1.88	1	2.31	0.10	13.32
45,000	114.33	1.68	1.5	2.07	0.15	10.96
60,000	105.45	1.55	2	1.92	0.20	9.54
75,000	99.03	1.46	2.5	1.81	0.25	8.57
110,000	88.92	1.31	3	1.72	0.30	7.85
145,000	82.28	1.21	6	1.43	0.40	6.83
180,000	77.42	1.14	9	1.28	0.50	6.14
215,000	73.65	1.08	12	1.19	0.60	5.62
250,000	70.59	1.04	15	1.12	0.70	5.22
285,000	68.04	1.00	18	1.06	0.80	4.90
320,000	65.86	0.97	21	1.02	0.90	4.63
355,000	63.96	0.94	24	1.01	1.00	4.40
390,000	62.29	0.92	27	0.99	1.10	4.20
425,000	60.81	0.89	30	0.98	1.20	4.03
460,000	59.47	0.87	33	0.99	1.30	3.87
495,000	58.25	0.86	36	1.09	1.40	3.74
530,000	57.15	0.84	39	1.18	1.50	3.62
565,000	56.13	0.83	42	1.28	1.60	3.51
600,000	55.19	0.81	45	1.38	1.70	3.41
635,000	54.31	0.80	48	1.47	1.80	3.31
670,000	53.50	0.79	51	1.57	1.90	3.23
705,000	52.74	0.78	54	1.67	2.00	3.15
740,000	52.03	0.77	57	1.76	2.10	3.08
775,000	51.35	0.76	60	1.86	2.20	3.01
810,000	50.72	0.75	63	1.96	2.30	2.94
845,000	50.12	0.74	66	2.06	2.40	2.88
880,000	49.55	0.73	69	2.15	2.50	2.83
915,000	49.01	0.72	72	2.25	2.60	2.78
950,000	48.50	0.71	75	2.35	2.70	2.73
985,000	48.01	0.71	78	2.44	2.80	2.68
1,020,000	47.54	0.70	81	2.54	2.90	2.63
1,055,000	47.09	0.69	84	2.64	3.00	2.59
1,090,000	46.66	0.69	87	2.73	3.10	2.55
1,125,000	46.24	0.68	90	2.83	3.20	2.51
1,160,000	45.85	0.67	93	2.93	3.30	2.47
1,195,000	45.47	0.67	96	3.02	3.40	2.44
1,230,000	45.10	0.66	99	3.12	3.50	2.41
1,265,000	44.74	0.66	102	3.22	3.60	2.37
1,300,000	44.40	0.65	105	3.32	3.70	2.34
1,335,000	44.07	0.65	108	3.41	3.80	2.31
1,370,000	43.75	0.64	111	3.51	3.90	2.28
1,405,000	43.44	0.64	114	3.61	4.00	2.26
1,440,000	43.14	0.63	117	3.70	4.10	2.23
1,475,000	42.85	0.63	120	3.80	4.20	2.20

Appendix 8C Long-run marginal costs kernel density pictures









Chapter 9

Conclusions and Future Research

This work has aimed to provide a reliable methodology to estimate scale elasticities and marginal costs (MC) in the airport industry. This is expected to shed some light on "best practices" regarding the provision of infrastructure for air transport. The econometric estimation of the industry's cost function as defined by economic theory has been chosen as a suitable tool to evaluate the airports' performance. The lack of financial data on airports may explain the relative scarcity of this kind of studies in the past literature. Furthermore, previous works are usually characterized by the use of limited databases and methodologies with respect to the definition of outputs, input prices, and model specifications. Thus, previous results do not provide general conclusions and are difficult to summarize.

This dissertation fills the existing gap by proposing the first multiproduct specification of the long-run cost function in the airport industry. There are also some specific characteristics which are worth highlighting. First, the database is much larger than other databases used in the past. It is an unbalanced panel data of 161 international airports which contains an important range of different sizes and time spans. Second, the model specification is one of the most flexible. A translog stochastic cost frontier has been used including both technical and allocative inefficiencies. And finally, a Bayesian model was compiled and estimated using WinBUGS.

As noted, one of the major shortcomings of this study concerns the input data. The database is mostly composed of financial information directly collected from the AA's published statements. Thus, the conclusions of the study can only be ascribed to the operational procedures and, as no external effects derived from airport operations have been included in the database, the results cannot be generalized and interpreted in terms of social costs. For that reason, this analysis is limited to the airports' own internal market and the estimated results of, for example, MC do not include the external costs (noise and environmental costs) which can be quite significant in the case of airports. So, the results of economies on scale should be interpreted with caution because the inclusion of external costs could change some conclusions. Nevertheless, the proposed methodology could be adapted to the analysis of these externalities, if adequate data are provided to researchers. In the final subsection of this chapter this issue will be further addressed. In any case, the results of this work are of major interest for airport operators, private or public, airlines, air transport regulators, and even policy makers.

9.1 Overview of the methodology

The key points of the methodological process are related to the definition of the output vector, the calculation of the input prices, and the estimation strategy. Because of the extreme complexity of airport operations and the aggregated nature of the collected data, only a limited number of productive processes or activities can be specified in the cost function. In this context, technological independence is the main criterion used at the time of defining the output vector. Under that approach, three productive processes can be easily identified, i.e. the provision of infrastructure for: i) aircraft operations, ii) passengers, and iii) freight handling.

(i) The specification of aircraft operations (ATM) leads to a problem of output separation, because different aircraft may impose very different costs on the infrastructure. The ideal approach is to treat different aircraft as different outputs, but the lack of information in some cases and econometric problems in others precluded us from using this approach. Thus, the homogenization of ATMs was necessary in order to avoid biased results, and this was done by converting ATMs into “equivalent” aircraft operations using the Boeing 737 as the standard (= ATM_{737}). A linear approach in the aircraft’s weight was used to establish each airport’s aircraft mix index, but other non-linear approaches could also be implemented if more information about the costs of different aircraft were available.

(ii) Passenger operations (PAX) were also specified, although it is known that there were some problems of multicollinearity with the ATM variable. However, if one of these two important variables is excluded, the results could be biased and the loss of information could be significant, because the landing and passenger fees are two basic components of the aeronautical revenues. In order to minimize the multicollinearity problem, additional variability was provided by significantly increasing the sample size with an old database of Spanish airports.

(iii) Regarding the output vector, it is worth noting here that passenger and cargo (CGO) operations were specified separately instead of aggregating them in work load units (WLUs). The empirical question concerning whether this aggregation makes economic sense is addressed in this work. In fact, in previous studies, this practice has always been challenged because it is difficult to imagine that the resources used to serve one passenger are similar to those used to serve 100 kg. There are also other concerns regarding the activities approach, as the involvement of airlines is usually higher in freight, especially in those airports that have dedicated cargo terminals in the hands of the big cargo operators such as Fedex or UPS.

The fourth specified output was the provision of infrastructure for commercial activities which was included as commercial revenues (REV) in an effort to avoid the estimation biases derived from the impossibility of separating the costs of these retail activities in the collected data. Concession revenues are becoming more important in the efficient management of airports. To generate optimal revenues from non-aviation activities in the terminals and on the airport's periphery needs an optimal allocation of space. This task is extremely complex because it can affect not only the passenger processing efficiency but also its aircraft counterpart. In some cases, commercial concessions' revenues can contribute a significant proportion (60–85 percent) of total airport revenue, and this activity is clearly gaining momentum in airport management because the chief executive officers of airports need to maximize concessions' commercial revenues without putting service quality and safety at risk.

Regarding the calculation of input prices, three major input categories were identified: namely, labor, materials/outsourced services, and capital. The best estimation of the labor price was obtained by dividing the recorded payroll costs by the number of full-time equivalent employees (FTEEs). With respect to the other prices, a theoretically consistent procedure was proposed, which was closely tied to the estimation of each factor's marginal productivity and the development of an input quantity index. The demand for capital was assumed to be related to the output level, and hence the long-run model was the leading approach when analysing the industry structure and technical efficiency issues.

Once the explanatory variables were defined, some functional form had to be postulated in the stochastic specification of the cost function. This dissertation used a translog model because it does not impose restrictions on the underlying technology. In addition, the cost frontier was estimated jointly with the input cost share equations obtained by applying Shephard's lemma. The likely presence of operational inefficiencies in airport operations was modeled using stochastic frontier analysis (SFA). Thus, a one-sided disturbance term was added to the frontier specification representing the extra costs derived from inefficient behavior. Technical inefficiency was assumed to be exponentially distributed. However, it was allowed to change over time using the Cuesta (2000) formulation which is a generalization of the one proposed by Battese and Coelli (1992). In addition, the effect of the allocative inefficiency (AI) was also included using the "shadow price" approach proposed by Kumbhakar (1997). Nonlinear complexities of the proposed model made advisable the use of numerical methods. So, in this dissertation, Bayesian Inference and Markov chain Monte Carlo (MCMC) simulation was used in order to estimate the parameters of the cost system.

9.2 Overview of the results

This paper provides empirical evidence about the existence of important economies of scale in airport operations, and, thus, it can justify the current trend of capacity expansion programs observed in major hubs. For the year 2006, the range of estimated economies of scale varies between 4.36 and 1.23, with an average value of 1.75. A basic methodology was proposed in order to analyze the likely level of output at which the economies of scales would be exhausted. The industry's minimum efficient scale (MES) was calculated to be at 2.27 million ATM_{737}. The most interesting conclusion to draw from this result is that, within the current technological frontier, the world's leading airports will continue to benefit from scale economies in the provision of infrastructure for air transportation and commercial activities until they reach between two or three times their current scales.

In order to disentangle whether economies of scale could be exhausted by the terminal activities, the degree of scale specific for passenger production was analyzed. The results indicate that decreasing returns to scale appear over 61.5 million passengers, which is the current scale of, for example, LHR or DFW. However, the future scenario of airport regulation could play an important role in order to determine the optimal size of airports. If airport activities are unbundled, and each activity is regulated and managed independently, the optimal size could be totally different than in an environment in which all the activities are under the umbrella of the Airport Authority.

Regarding the evolution of the scale elasticity estimates at individual airports, the main result indicates that traffic-expansion periods (scale-consuming) alternate with capacity-expanding periods (scale-creating). This allows the airports to exploit their scale potential in a higher output range. For this reason, even though most airports show steady increases in aircraft and passenger operations, the temporal evolution of the scale elasticity is not always downwards. In fact, optimal airport development (without capacity gaps) can only be seen in those small and middle-size airports, such as BGY or RIX, which are currently experiencing explosive traffic growth.

Economies of scale were found to be highly dependent on the cost complementarities between aviation and commercial activities. Without commercial support, the provision of aeronautical infrastructure alone exhausts all its scale potential at approximately 1.65 ATM_{737} or 126 mppa. Hence, if only operating costs are considered, the upcoming generation of major airports will be still enjoying scale economies in their aeronautical activities in the long run. Nevertheless, as offered capacities are approaching the MES, it is possible that some airports in the near future will encounter decreasing returns to scale when considering only the aviation sector. In spite of that, these airports could still enjoy scale economies if they were in charge of the development of commercial activities. In fact, as explained, airports could be considered just large “shopping malls”, where some aircraft eventually takeoff and land.

So it would seem that today the role and core activities of an airport are becoming quite blurred. Maybe there are some who still adhere to the traditional view which saw airports as transport interfaces that ensure the efficient movement of passengers between one destination and another. However, after some incredible developments, including hotels and golf courses, even the concept of ‘airport cities’ has appeared, viewing airports within a broader spectrum of economic change and commercial opportunity. So, airports are far from being only transport interfaces; they can now be considered leisure attractions and primary points of interest in their own right. This change of philosophy represents one of the most significant contemporary developments that will affect the structure of the industry in the coming years.

Regarding efficiency estimates, the results indicate that technical inefficiency ranges between 15-18 percent for the mean airport. In addition, the costs associated with allocative distortions may deviate up to 16 percent from the efficient expenditures, yet the average AI level was estimated to be 6.3 percent. Surprisingly, no significant correlation was found between airport size and operational efficiency. Individual estimations related to each airport’s potential savings can be easily calculated from their TE and AI estimates. On average, small-size airports may be losing up to USD 4.3 million each year. The typical middle-size international airport in Europe is expected to accumulate losses of between USD 45 and USD 80 million. Finally, major hubs may be spending up to USD 146 million per year over the cost frontier.

The analysis of the differences in TE among the nine major geographical clusters featured in the database allows us to test the influence of many country-specific variables in airport performance. This includes the geographical location, the type of ownership or the regulatory framework concerning, for example, the setting of charges. The results indicate that, on average: i) public airports are less efficient than private ones; ii) price cap regulation seems to be more effective than rate of return regulation regarding the cost efficiency; and iii) the operation of bigger aircraft in freight traffic leads to a better utilization of airport capacity.

In Germany and Austria, there is a significant level of AI, which is explained by the lack of flexibility in labor markets that translates into higher salaries than the rest of Europe. In addition, the level of outsourcing in ground handling operations and other non-core activities is almost non-inexistent. Consequently, the signs of the estimated allocative distortions indicate blatant overuse of the airport's own labor. Apart from that, US airports show normal efficiency levels around the sample mean. However, the temporal evolution of the TE indicates a steady downward trend, clearly explained by the tremendous traffic shock of 9/11. Asia-Pacific airports are the most efficient group in the sample, with technical inefficiency of less than 7 percent. As a matter of fact, the most efficient airport during the period 2000-2006 was HKG, with technical inefficiency of less than 4 percent.

Finally, both efficiency and scale results were validated by estimating the economic efficiency of five European multi-airport systems (MASs) using the parameters of the estimated cost frontier. Efficiency results ranged between 0.31 and 0.74 indicating that the atomization of air traffic in the presence of such significant scale economies always carries an efficiency loss. In a deeper analysis, additional data on two American MAS (whose individual airports were included in the estimating sample) were used. This allowed the separate quantification of the extra costs derived from the split of traffic from those related to the inefficient behavior of the individual airports. The results indicate that the benefits for traffic consolidation represent between 6 and 24 per cent of the aggregated total costs at these two MASs.

Individual estimates of long-run marginal costs were obtained, and the traffic-weighted average values are USD 304.80, USD 4.52 and USD 40.02 for aircraft operations, passengers and cargo, respectively. In addition, the separate specification of *pax* and *cgo* variables instead of work load units (WLUs) is also justified by results. It can be seen that the individual estimates for Miami and Memphis of MC for passengers and cargo are totally different, and the ratios between cargo and passenger MC also justify the need to disaggregate the aggregate output WLU into two components. With respect to the commercial revenues, the main conclusion that can be drawn from the estimated MC is that airports are still very far from their optimal commercial development and still have enough room to expand their scope of on-site services.

From the comparison between optimal and current charges, it was found, as expected, that most landing and passenger charge schemes are higher than the first-best prices, but, in general, fare schedules are consistent with airport characteristics, such as excess of capacity or the price regulation approach. In addition, it was shown that airport charges are always closer to the estimates of the long-run approach rather than to those of the short-run approach. The explanation for this is that, historically, the airports have proved to be financially robust firms. In fact, in many countries, airports are still in public hands but they do not usually receive any kind of financial government assistance because they are expected to operate as commercial entities with a diverse degree of autonomy.

Empirical evidence was given supporting the idea that price regulation seems to be a reasonable policy to control the monopolistic position of airports. However, the necessity to put airports under the potential threat of price cap regulation is controversial. In some countries, when the central government gives up ownership of airports that have been characterized as “potential” monopolies, price cap regulation has then been considered necessary.

No significant relationship could be found between the operational efficiency and pricing schedules. Other pricing strategies that could be observed were: i) the cross-subsidization between aircraft categories, indicating the presence in the long run of mix-reorientation policies of the airport operator; ii) high passenger charges that cross-subsidize the use of airside infrastructures; and iii) price discrimination between signatory and non-signatory airlines (US) where the new entrants cross-subsidize the incumbent airlines, thus creating an important barrier to entry.

9.3 Future research

The natural extension of this work and the subject of any further research related to the airports’ cost function would be the introduction of environmental/externality costs into the specification. Airports may be privatized, but they still offer a public service. The estimation of the social cost function would allow a better analysis of the structure of the industry in terms of social benefit. One of the most important results provided by this study is that both current and projected major international hubs will still be enjoying increasing returns to scale in aeronautical operations until they reach their ultimate capacities. This may be true in terms of financial expenditures for the Airport Authorities, but this analysis, being important, could be extended in different ways to consider major externalities that have not been included in this work. For example, congestion and scarcity costs can be really significant in airports that are operating near their capacity, or the noise for a surrounding area can be a real problem which completely constrains future expansion programs of the airport.

However, the cost function could be used without loss of generality for a number of different purposes. For example, in the case of congestion, the costs associated with delays could be included using different outputs for periods of time where congestion and scarcity is important. Thus the carriers could know the MC that incorporate this externality, and a better adjustment for obtaining first-best prices could be made in terms of peak and off-peak MC. The same idea could be applied to passengers, separating different outputs for passengers who have experienced delays or any other problem associated with, for example, the reliability and punctuality of baggage-handling systems. This approach could also be used to study the service quality of the airport. And finally, the inhabitants of surrounding regions would really expect night flights to be charged according to the annoyance caused, or, in an extreme case, no night flights at all should be allowed because of the elevated social MC. Finally, these people would also want to know whether the proposed airport expansion which could eventually destroy their homes, is justified by the technology and social benefit. The basic economic intuition that motivates any further research on this subject is that the present study is only the first step and the values of the output cost elasticities are clearly underestimated, thus artificially increasing the optimal potential size of airports. So marginal costs and technical efficiency should be further studied, taking into account all the important externalities.

However, this task is not without difficulties because many of the aforementioned variables are very difficult to value using objective measures. The past literature provides abundant examples of the valuation of external effects applied to airport operations. Future research will not be focused on the improvement of the existing methodologies, but on the incorporation of published results, especially those related to the estimation of the value of travel time, into the econometric estimation of the airport industry's social cost function. This is not the first approach to this issue: Yu (2004) and, more recently, Yu et al. (2008) used DEA and Malmqvist productivity indexes to analyze the efficiency of Taiwan airports, taking into account externalities. Thus the total amount of noise charges paid by the carriers was used as a proxy for the production of aircraft noise. In addition, the neighboring population was also specified as an environmental variable into the estimated output distance function. The results indicate that the consideration of these kind of variables substantially affects the analysis of operational performance. Taking these works as examples, this last subsection will focus on the possible incorporation of noise, delays, and organizational complexities into the present stochastic cost frontier methodology.

There is a large literature on the effects of airport noise on property values, public annoyance, and land use planning around the airport (Uyeno et al., 1993; Levesque, 1994; Feitelson et al., 1996; McMillen, 2004). Economic efficiency suggests that the carrier should pay the full cost of environmental damage caused by its activity, thus creating an incentive for the reduction of such damage to the level where the MC of the abatement solution is equal to the MC of the damage. Empirically, the desired and simplest approach implies the availability of a proper monetary quantification of total noise costs, which could be simply aggregated with the financial component covered in this research. This quantification could be obtained, as in the above-mentioned studies, from the total noise charges paid by the users. However, there is no empirical evidence that guarantees that airports are setting optimal noise charges (related to noise costs), so this procedure is only a rough approximation. Taking into account the results obtained in this dissertation, the most likely scenario is a certain abuse of market power reflected in not very high overcharging because of the strong complementarities with the commercial activities. Another approach, perhaps more objective, is to equate the noise costs with the annual investment in noise abatement programs. In fact, this is exactly the same treatment given to the capital input in the present methodology, because the economic depreciation theoretically represents the (historic or current) cost of recovery. In addition, this also allows an easier definition of input prices, e.g. average expenditure per affected house or unit of population. However, this would also be another approximation because these programs depend on the regulation policy with respect to these externalities, and they may be far from being optimal.

Even in the best scenario, where the policies are implemented at their optimal level, there are still some other problems. The first one is that airports are not comparable in terms of geographical location[1]. An implicit demand of "silence" is defined at the time of considering noise production, yet this silence only has any value if it is enjoyed by the individuals. For that reason, even if the noise production is the same at both downtown airports and those on reclaimed land, the lack of noise abatement costs will always result in a higher efficiency for the latter. This is explained by the significant allocative distortion (overuse of the silence input) that the model will assign to the downtown airport with respect to the non-silence-demanding cost frontier. In order to correct that, Coelli et al. (1998) suggested that, when environmental variables are positively correlated with efficiency, they may then be included as non-discretionary inputs. The incorporation of that solution into the present SFA methodology will be a major research objective.

Additionally, it is clear that noise costs are only related to the aircraft operations, but the joint specification of ATMs and passengers in the model could also have an impact on the specific scale elasticities and hence on the estimates of social marginal costs[2]. For that reason, a comparison of the total and partial models, using only the ATM variable, should be made in order to analyze the impact of the joint specification. At the end, the financial MC for an additional ATM (obtained in this dissertation) can be deducted from the social MC in order to obtain the optimal noise charge.

Apart from that, the increase of production and the expansion of capacity will invariably lead to further organizational complexities and traffic delays. Runway congestion and inefficient baggage management generate additional costs in terms of time losses for the passengers and the carriers. Both optimal runway pricing and the quantification of delay costs have been extensively treated in the past literature. As in the previous case, the desired scenario implies the availability of a proper monetary quantification of delay costs which can be aggregated with the financial component. Accurate data on airport delays for the US industry can be obtained from the Bureau of Transportation Statistics, and the transformation of delay minutes into delay costs can be done using average values of travel reported in previous studies.

Additional inefficiency costs associated with other operational components, such as time spent at check-in counters, boarding gates or luggage-claiming areas or even some costs associated with possible disruption of services, such as those for locating lost

[1] This is also a major problem for the use of housing values as a proxy for noise costs: major distortions may appear when comparing housing values in the environs of downtown and outskirts airports.
[2] As noted, it does not have a major impact in the calculation of global scale elasticities because of the aggregation of the individual effects.

baggage, could also be estimated, provided that enough information on these subjects is available for researchers. The calculation of optimal charges would follow the same procedure described above for the noise charges, but no environmental restrictions are to be considered in this case. All airports should be comparable in terms of congestion, unless the performance is capped by an inefficient terminal or runway design. Taking into account the current architectural trends, the effect of airport design on operational efficiency is also likely to be a major issue in the near future.

ANNEXES

Annex 1 IATA airport codes

Airport	*Code*	*Airport*	*Code*	*Airport*	*Code*
Amsterdam	AMS	Hannover	HAJ	Perth	PER
Aarhus	AAR	Haikou	HAK	Phoenix	PHX
Lanzarote	ACE	Hamburg	HAM	Pittsburgh	PIT
Adelaide	ADL	Hat Yai	HDY	Palma de Mallorca	PMI
Malaga	AGP	Frankfurt Hahn	HHN	Palermo	PMO
Auckland	AKL	Hong Kong	HKG	Pamplona	PNA
Alicante	ALC	Phuket	HKT	Prague	PRG
Anchorage	ANC	Tokio Haneda	HND	Pisa	PSA
Alice Springs	ASP	Honolulu	HNL	Panama City	PTY
Athens	ATH	Humberside	HUY	Shanghai Pudong	PVG
Atlanta	ATL	Washington Dulles	IAD	Reus	REU
Barcelona	BCN	Ibiza	IBZ	Riga	RIX
Orio al Serio	BGY	Incheon	ICN	Rostock	RLG
Birmingham	BHX	Indianapolis	IND	Reno	RNO
Bilbao	BIO	Jacksonville	JAX	South Florida	RSW
Badajoz	BJZ	New York Kennedy	JFK	Santiago	SCQ
Bangkok	BKK	Kansas City	KCI	Louisville	SDF
Billund	BLL	Osaka	KIX	Santander	SDR
Bologna	BLQ	Kuala Lumpur	KLU	Seattle	SEA
Brisbane	BNE	Klagenfurt	KLU	San Francisco	SFO
Bournemouth	BOH	Las Vegas	LAS	Singapore Changi	SIN
Boston	BOS	Los Angeles	LAX	Salt Lake City	SLC
Bremen	BRE	La Coruña	LCG	La Palma	SPC
Bristol	BRS	Almeria	LEI	Lambert - St. Louis	STL
Brussels	BRU	New York LaGuardia	LGA	London Stansted	STN
Baltimore/Washington	BWI	Liege	LGG	Stuttgart	STR
París Charles de Gaulle	CDG	London Gatwick	LGW	Sevilla	SVQ
Chiang Rai	CEI	London Heathrow	LHR	Sydney	SYD
Cologne	CGN	Ljubljana	LJU	Salzburg	SZG
Christchurch	CHC	Linz	LNZ	Tenerife norte	TFN
Charlotte	CLT	Gran Canaria	LPA	Tenerife sur	TFS
Columbus	CMH	London Luton	LTN	Tallin	TLL
Chiang Mai	CNX	Madrid	MAD	Tampa	TPA
Copenhagen	CPH	Menorca	MAH	Turin	TRN
Cincinnati - N.Kentucky	CVG	Manchester	MAN	Tucson	TUS
Cardiff	CWL	Orlando	MCO	Knoxville	TYS
Dayton	DAY	Chicago Midway	MDW	Brescia	VBS
Washington Reagan	DCA	Memphis	MEM	Venice	VCE
Denver	DEN	Mexico City	MEX	Hierro	VDE
Dallas - Fort Worth	DFW	Miami	MIA	Vigo	VGO
King Fahd Intl.	DMM	Murcia / San Javier	MJV	Vienna	VIE
Dresden	DRS	La Valetta	MLA	Vitoria	VIT
Darwin	DRW	Basel/Mulhouse/Freiburg	MLH	Valencia	VLC
Dortmund	DTM	Melilla	MLN	Valladolid	VLL
Detroit	DTW	Minneapolis / Sant Paul	MSP	Verona	VRN
Düsseldorf	DUS	Munich	MUC	Wellington	WLG
San Sebastian	EAS	Newcastle	NCL	Jerez	XRY
Eindhoven	EIN	Tokio Narita	NRT	Halifax	YHZ
East Midlands	EMA	Nantes	NTE	Montreal Mirabel	YMX
New Ark	EWR	Nuremberg	NUE	Ottawa	YOW
Fort Lauderdale	FLL	Cordoba	ODB	Montreal Dorval	YUL
Florence	FLR	Chicago O'Hare	ORD	Vancouver	YVR
Munster	FMO	Paris Orly	ORY	Winnipeg	YWG
Frankfurt	FRA	Oslo	OSL	Calgary	YYC
Fuerteventura	FUE	Ostend	OST	Victoria	YYJ
Girona	GRO	Asturias	OVD	Toronto Pearson	YYZ
Granada	GRX	Paderborn	PAD	Zagreb	ZAG
Graz	GRZ	Portland	PDX	Zaragoza	ZAZ
Geneva	GVA	Beijing	PEK	Zurich	ZRH

Annex 2 Aircraft technical specifications

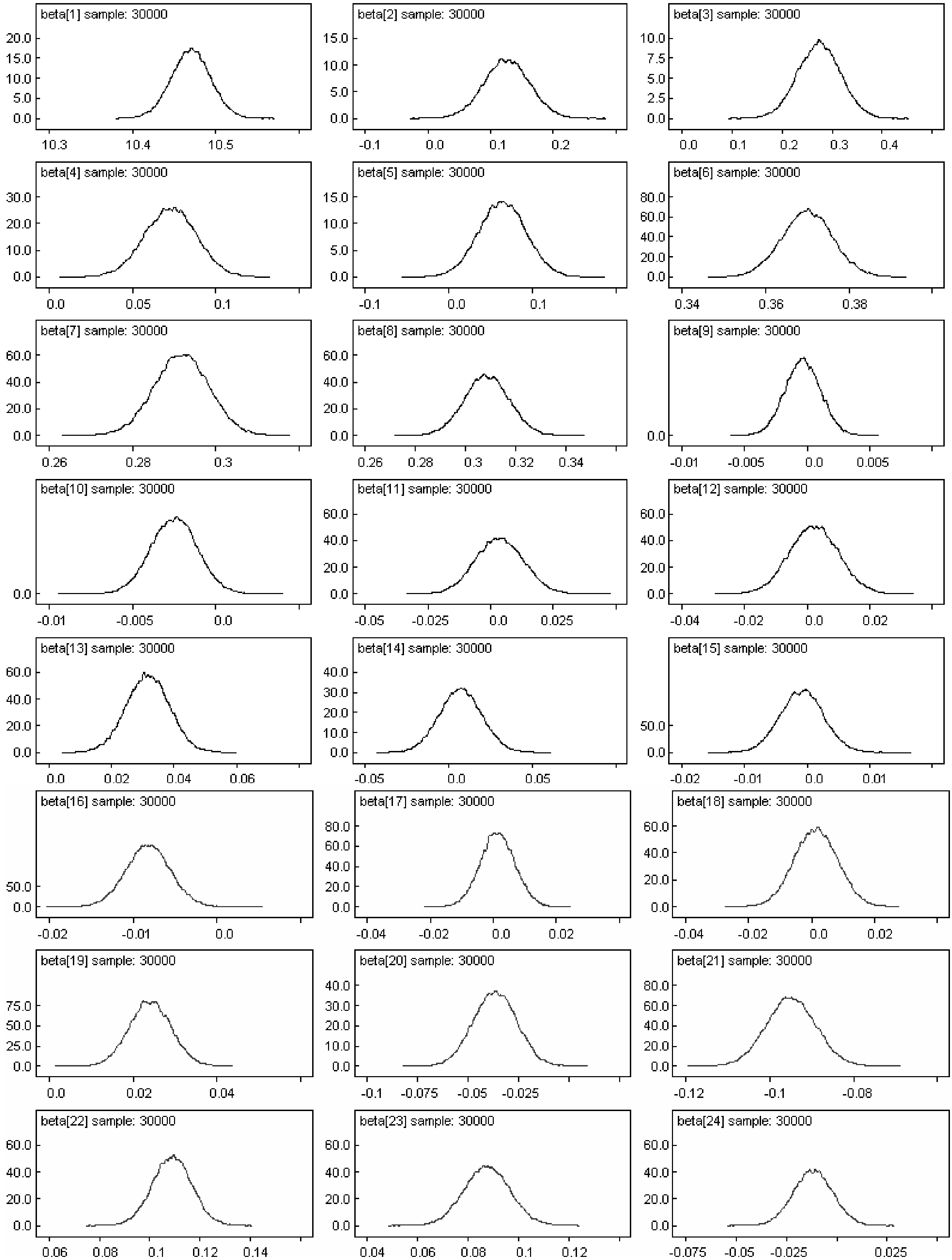
FAA Code	Description	tod	mtow	seats	wingspan	weight factor
133	Beech 65/65a-80/65b-80 (Queen Air)	-	4.0	9.0	15.0	0.059
125	Cessna C-402/402a	-	3.0	9.0	13.0	0.044
479	Pilatus Pc-12	-	5.0	9.0	16.0	0.074
406	Beech 200 Super Kingair	-	6.0	13.0	17.0	0.088
111	Beech King Air 90	-	5.0	13.0	14.0	0.074
457	Beech King Air C-90	-	5.0	13.0	14.0	0.074
416	Cessna 208 Caravan	-	4.0	14.0	16.0	0.059
417	Cessna 406 Caravan Ii	-	4.0	14.0	16.0	0.059
403	Beech 99 Airliner	-	5.0	15.0	14.0	0.074
404	Beech C99	-	5.0	15.0	14.0	0.074
405	Beech 1900 A/B/C/D	-	8.0	19.0	18.0	0.118
469	British Aerospace Jetstream 31	-	7.0	19.0	16.0	0.103
486	Shorts Harland Sc-7 Skyvan	-	6.0	19.0	20.0	0.088
412	Casa/Nurtanio C212 Aviocar	-	8.0	20.0	20.0	0.118
485	Dehavilland Twin Otter Dhc-6	-	6.0	20.0	20.0	0.088
471	British Aerospace Jetstream 41	-	11.0	29.0	18.0	0.162
449	Dornier 328	-	14.0	30.0	21.0	0.206
632	Dornier 328 Jet	-	14.0	30.0	21.0	0.206
461	Embraer Emb-120 Brasilia	-	12.0	30.0	20.0	0.176
487	Shorts 330	-	10.0	30.0	23.0	0.147
459	Saab-Fairchild 340/A	-	13.0	34.0	21.0	0.191
456	Saab-Fairchild 340/B	-	13.0	34.0	21.0	0.191
430	Convair Cv-580	-	19.0	40.0	28.0	0.279
441	Aerospatiale/Aeritalia Atr-42	1165	18.0	42.0	25.0	0.265
674	Embraer-135	-	21.0	44.0	20.0	0.309
676	Embraer-140	-	21.0	44.0	20.0	0.309
675	Embraer-145	-	21.0	44.0	20.0	0.309
CAT1	**1-49 seats**		**9.9**	**24.1**	**18.6**	**Average**
444	Antonov 24/26/32	-	21.0	50.0	29.0	0.309
407	British Aerospace (Hawker-Siddeley) Bae-748	-	21.0	50.0	31.0	0.309
628	Canadair Rj-100/Rj-100er	-	24.0	50.0	21.0	0.353
629	Canadair Rj-200er /Rj-440	-	24.0	50.0	21.0	0.353
150	Curtiss C46/20t/A/D/F/R Commando	-	22.0	50.0	33.0	0.324
450	Fokker Friendship F-27/Fairchild F-27/A/B/F/J	-	20.0	55.0	29.0	0.294
408	British Aerospace Bae-Atp	-	26.0	64.0	31.0	0.382
631	Canadair Rj-700	-	32.0	70.0	23.0	0.471
483	Dehavilland Dhc8-100 Dash-8	-	29.0	70.0	28.0	0.426
484	Dehavilland Dhc8-300 Dash 8	-	29.0	70.0	28.0	0.426
482	Dehavilland Dhc8-400 Dash-8	-	29.0	70.0	28.0	0.426
442	Aerospatiale/Aeritalia Atr-72	1290	22.0	72.0	27.0	0.324
657	Bombardier Crj 705	-	34.0	75.0	25.0	0.500
677	Embraer 170	-	36.0	78.0	26.0	0.529
673	Embraer Erj-175	-	37.0	84.0	26.0	0.544
835	Avroliner Rj85	-	44.0	85.0	29.0	0.647
867	British Aerospace Bae-146-200	-	44.0	85.0	24.0	0.647
602	Fokker F28-4000/6000 Fellowship	-	33.0	85.0	25.0	0.485
638	Canadair Crj 900	-	44.0	86.0	25.0	0.647
216	Mcdonnell Douglas Dc-6	-	49.0	89.0	36.0	0.721
630	Mcdonnell Douglas Dc-9-10	-	41.0	90.0	27.0	0.603
635	Mcdonnell Douglas Dc-9-15f	-	43.0	90.0	27.0	0.632
710	Boeing 727-100	2000	73.0	94.0	33.0	1.074
711	Boeing 727-100c/Qc	2000	73.0	94.0	33.0	1.074
620	Boeing 737-100/200	1900	50.0	100.0	28.0	0.735
608	Boeing 717-200	1950	50.0	106.0	28.0	0.735
644	Airbus Industrie A-318	1375	68.0	107.0	34.0	1.000
603	Fokker 100	-	44.0	107.0	28.0	0.647
616	Boeing 737-500	2470	53.0	108.0	29.0	0.779
678	Embraer 190	-	48.0	108.0	29.0	0.706
633	Boeing 737-600	1950	56.0	110.0	34.0	0.824
621	Boeing 737-200c	1990	53.0	115.0	28.0	0.779
640	Mcdonnell Douglas Dc-9-30	1777	50.0	115.0	28.0	0.735
550	Lockheed L-188a/C Electra	-	53.0	117.0	30.0	0.779
868	British Aerospace Bae-146-300	-	44.0	118.0	24.0	0.647
698	Airbus Industrie A319	1950	75.0	124.0	34.0	1.103
CAT2	**50-124 seats**		**41.4**	**85.5**	**28.5**	**Average**

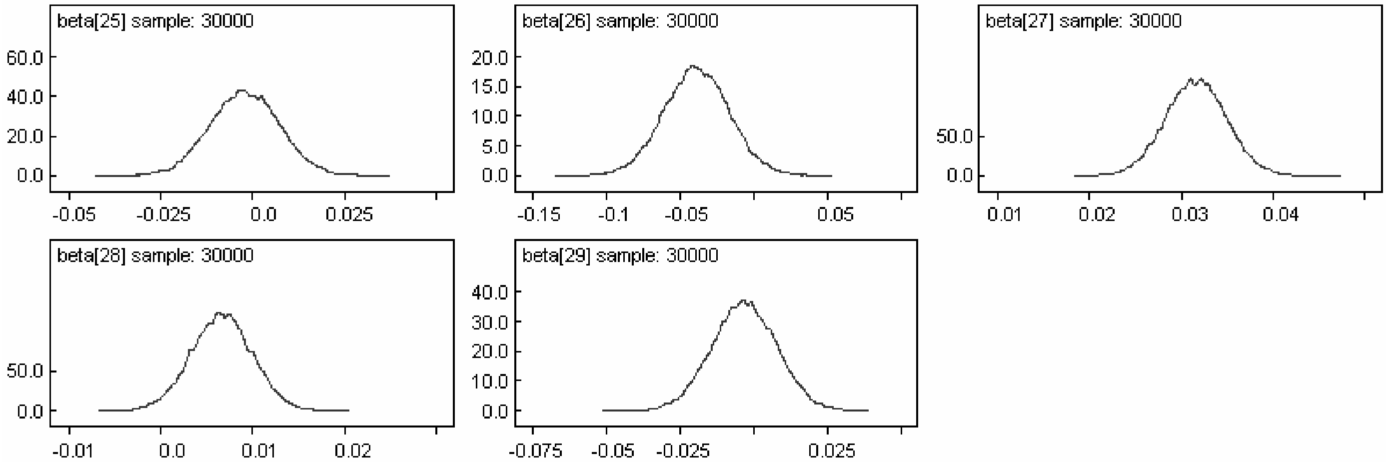
FAA Code	Description	tod	mtow	seats	wingspan	weight factor
645	Mcdonnell Douglas Dc-9-40	-	52.0	125.0	28.0	0.765
612	Boeing 737-700/700lr	2042	60.0	126.0	34.0	0.882
619	Boeing 737-300	2109	57.0	128.0	29.0	0.838
654	Mcdonnell Douglas Dc9 Super 87	-	67.0	130.0	33.0	0.985
650	Mcdonnell Douglas Dc-9-50	2362	55.0	135.0	28.0	0.809
655	Mcdonnell Douglas Dc9 Super 80/Md81/2/3/7/8	2271	68.0	142.0	33.0	1.000
715	Boeing 727-200/231a	3033	95.0	145.0	33.0	1.397
617	Boeing 737-400	2475	68.0	146.0	29.0	1.000
694	Airbus Industrie A320-100/200	2090	77.0	150.0	34.0	1.132
656	Mcdonnell Douglas Md-90	-	70.0	153.0	33.0	1.029
614	Boeing 737-800	2316	71.0	162.0	34.0	1.044
634	Boeing 737-900	2425	75.0	177.0	34.0	1.103
CAT3	**125-179 seats**		**67.8**	**143.3**	**31.8**	**Average**
851	Mcdonnell Douglas Dc-8-61	-	161.0	180.0	45.0	2.368
854	Mcdonnell Douglas Dc-8-62	-	161.0	180.0	45.0	2.368
856	Mcdonnell Douglas Dc-8-63	-	161.0	180.0	45.0	2.368
852	Mcdonnell Douglas Dc-8-63f	-	161.0	180.0	45.0	2.368
860	Mcdonnell Douglas Dc-8-71	-	161.0	180.0	45.0	2.368
864	Mcdonnell Douglas Dc-8-73	-	161.0	180.0	45.0	2.368
865	Mcdonnell Douglas Dc-8-73f	-	161.0	180.0	45.0	2.368
699	Airbus Industrie A321	2180	93.5	185.0	34.0	1.375
622	Boeing 757-200	2377	108.0	202.0	38.0	1.588
626	Boeing 767-300/300er	2850	171.0	210.0	48.0	2.515
692	Airbus Industrie A310-200c/F	1860	165.0	212.0	44.0	2.426
693	Airbus Industrie A310-300	2290	150.0	212.0	44.0	2.206
625	Boeing 767-200/Er/Em	2620	156.0	216.0	48.0	2.294
765	Lockheed L-1011-500 Tristar	-	225.0	234.0	50.0	3.309
873	Airbus Industrie A340-200	2990	275.0	239.0	60.0	4.044
623	Boeing 757-300	2550	122.0	240.0	38.0	1.794
624	Boeing 767-400	2930	204.0	245.0	52.0	3.000
CAT4	**180-249 seats**		**164.5**	**203.2**	**45.4**	**Average**
760	Lockheed L-1011-1/100/200	-	195.0	253.0	47.0	2.868
691	Airbus Industrie A300-600/R/Cf/Rcf	2280	171.0	258.0	45.0	2.515
690	Airbus Industrie A300b/C/F-100/200	2394	170.0	269.0	45.0	2.500
730	Mcdonnell Douglas Dc-10-10	2625	195.0	270.0	47.0	2.868
732	Mcdonnell Douglas Dc-10-30	2847	260.0	270.0	50.0	3.824
735	Mcdonnell Douglas Dc-10-30cf	2847	260.0	270.0	50.0	3.824
733	Mcdonnell Douglas Dc-10-40	2817	260.0	270.0	50.0	3.824
696	Airbus Industrie A330-200	2220	233.0	295.0	60.0	3.426
871	Airbus Industrie A340-300	3000	277.0	295.0	60.0	4.074
627	Boeing 777-200/200lr/233lr	3170	267.0	305.0	61.0	3.926
872	Airbus Industrie A340-500	3050	380.0	313.0	64.0	5.588
740	Mcdonnell Douglas Md-11	2207	273.0	323.0	52.0	4.015
CAT5	**250-350 seats**		**245.1**	**282.6**	**52.6**	**Average**
874	Airbus Industrie A340-600	3100	380.0	380.0	64.0	5.588
816	Boeing 747-100	3050	340.0	397.0	60.0	5.000
817	Boeing 747-200/300	3190	378.0	400.0	60.0	5.559
819	Boeing 747-400	3600	377.0	416.0	64.0	5.544
818	Boeing 747c	3600	377.0	416.0	64.0	5.544
820	Boeing 747f	3600	377.0	416.0	64.0	5.544
CAT6	**+ 350 seats**		**371.5**	**404.2**	**62.7**	**Average**

Source: Ashford and Wright (2002), BTS(2007), boeing.com, airbus.com, airliners.net and Wikipedia.

Annex 3 Posterior kernel density pictures of the cost frontier parameters

Annex 3.1 Posterior kernel density pictures of the long-run cost frontier parameters




beta[25] sample: 30000
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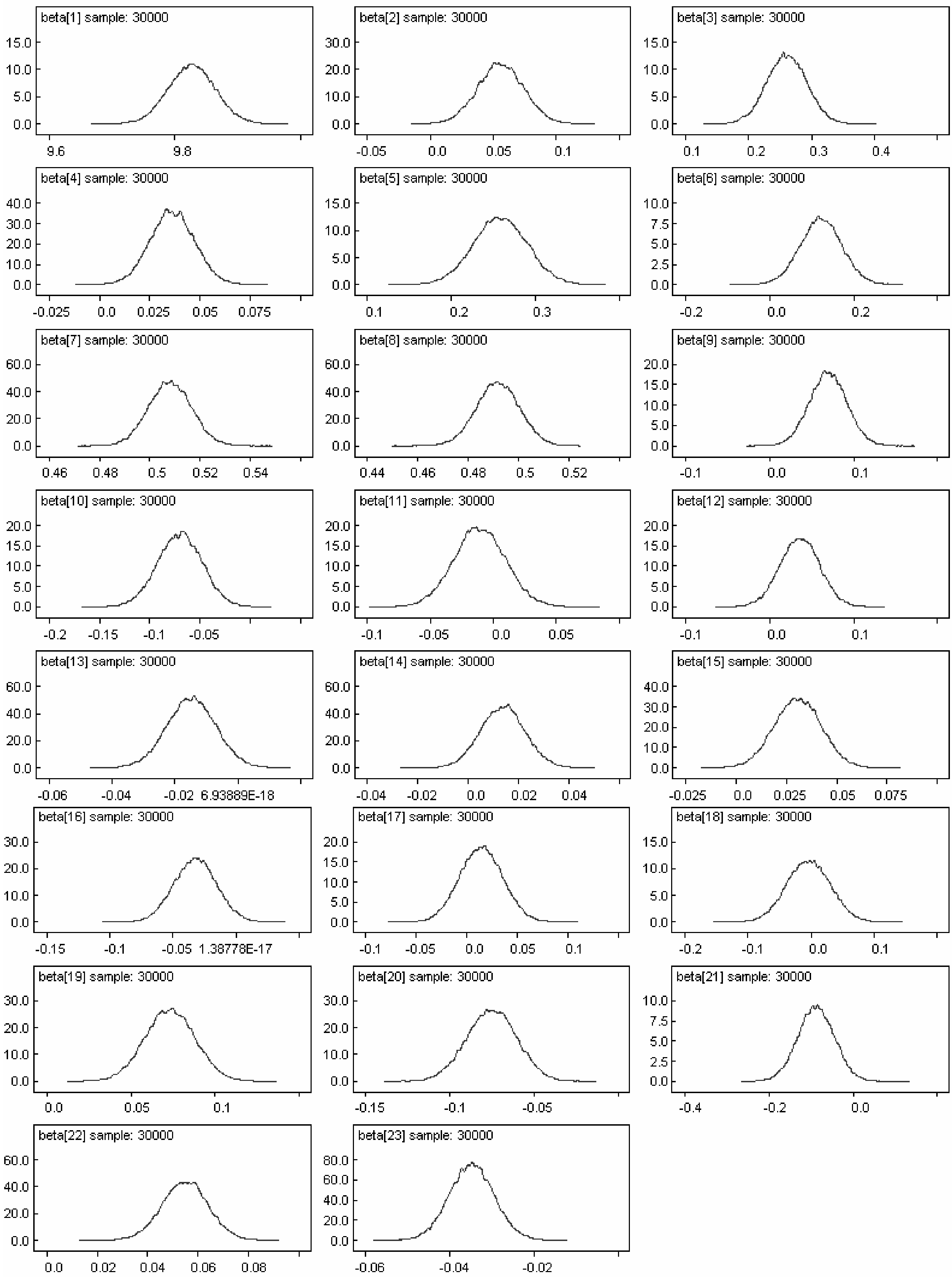
40.0
20.0
0.0
-0.05
-0.025
0.0
0.025
beta[26] sample: 30000
20.0
15.0
10.0
5.0
0.0
-0.15
-0.1
-0.05
0.05
beta[27] sample: 30000
50.0
0.0
0.01
0.02
0.03
0.04
beta[28] sample: 30000
50.0
0.0
-0.01
0.0
0.01
0.02
beta[29] sample: 30000
40.0
30.0
20.0
10.0
0.0
-0.075
-0.05
-0.025
0.025

Annex 3.2 Posterior kernel density pictures of the short-run cost frontier parameters



Annex 4 Long-run estimation results

id	airport	Scale	Scale R	MC ATM	MC PAX	MC CGO	MC REV	TE	C^{al}	eta	allm	allp
AU	ADELAIDE	1.84	1.99	221.58	2.32	198.73	96.76	0.89	1.04	0.19	-0.10	0.25
	ALICE SPRINGS	3.12	4.10	184.57	2.51	-	409.07	0.91	1.01	0.06	-0.16	0.32
	BRISBANE	1.71	1.68	323.17	2.66	76.71	49.82	0.92	1.07	0.10	-0.13	0.27
	DARWIN	2.46	3.17	622.64	3.44	398.25	415.98	0.83	1.07	0.04	-0.17	0.25
	PERTH	1.66	1.72	354.40	4.87	105.50	150.79	0.89	1.07	0.01	-0.12	0.27
	SYDNEY	1.47	1.38	517.92	6.78	83.65	109.63	0.81	1.09	0.11	-0.06	0.16
AT	GRAZ	2.35	3.00	293.63	3.99	111.37	236.82	0.64	1.07	0.08	-0.11	0.05
	LINZ	2.30	2.84	273.00	4.56	33.93	124.88	0.64	1.08	-0.01	-0.09	-0.08
	SALZBURG	1.96	2.39	424.60	5.52	279.77	247.84	0.72	1.05	-0.03	0.02	-0.13
	VIENNA	1.50	1.43	317.66	3.88	56.51	103.93	0.76	1.03	-0.05	0.27	-0.47
BE	BRUSSELS	1.55	1.49	288.08	3.77	23.06	65.34	0.86	1.07	0.00	-0.11	-0.06
	LIEGE	1.67	2.44	74.75	37.38	6.20	809.73	0.83	-	0.05	-0.21	0.09
	OSTEND	2.40	3.12	44.02	12.80	8.68	384.27	0.80	1.13	-0.02	0.00	-0.12
CA	CALGARY	1.68	1.74	269.10	2.68	62.51	119.20	0.86	1.05	0.04	-0.24	0.30
	HALIFAX	2.15	2.35	212.58	1.69	67.44	66.17	0.72	1.05	-0.06	-0.05	-0.07
	OTAWA	1.84	2.09	239.15	3.32	137.74	171.50	0.73	1.05	0.33	-0.06	0.13
	TORONTO	1.41	1.31	496.75	6.11	80.95	181.91	0.83	1.07	0.09	-0.05	0.11
	VANCOUVER	1.59	1.57	242.14	2.96	59.27	71.50	0.86	1.06	0.05	-0.11	0.11
	VICTORIA	2.40	2.92	203.59	2.17	-	124.53	0.90	1.04	0.19	-0.09	0.11
	WINNIPEG	1.77	2.03	133.39	2.84	17.94	167.06	0.88	1.04	0.20	0.02	-0.07
CN	BEIJING	1.23	0.96	628.83	10.64	90.19	231.61	0.89	1.04	0.00	-0.03	0.06
	HAINAN MEILAN	1.65	1.73	348.29	3.35	54.92	127.05	0.86	1.01	0.08	0.00	-0.02
HR	ZAGREB	1.98	2.72	168.72	3.11	122.95	312.76	0.70	-	-0.03	0.06	-0.12
CZ	PRAHA	1.55	1.48	354.75	3.86	170.23	100.35	0.81	1.01	-0.06	0.04	-0.04
DK	AARHUS	4.37	3.75	37.81	0.17	121.42	-	0.80	1.07	-0.07	0.17	-0.12
	BILLUND	1.88	3.05	231.13	3.25	29.72	-	0.79	1.00	-0.04	0.14	-0.10
	COPENHAGEN	1.56	1.48	346.63	2.10	29.60	59.87	0.89	1.01	0.02	0.21	-0.23
EE	TALLIN	1.94	2.49	335.42	4.70	158.76	212.62	0.71	1.03	-0.14	-0.05	0.04
FR	BSL/MLH/FRE	1.81	1.98	294.48	3.81	43.28	116.83	0.84	1.07	-0.08	-0.12	0.04
	NANTES	2.13	2.69	443.59	2.44	54.85	159.55	0.83	-	0.03	-0.06	0.04
DE	BREMEN	1.91	2.37	525.35	7.76	109.96	368.03	0.89	1.08	0.08	-0.04	-0.01
	DORTMUND	1.97	2.37	445.69	5.80	319.40	217.78	0.82	1.06	-0.06	-0.03	-0.02
	DRESDEN	1.94	2.52	486.93	5.55	249.75	375.97	0.73	1.05	-0.02	-0.11	0.08
	DÜSSELDORF	1.45	1.37	504.01	6.15	190.16	207.20	0.60	1.04	0.02	0.16	-0.25
	FRANKFURT	1.25	0.85	407.11	6.56	33.69	165.47	0.81	1.03	-0.07	0.11	-0.31
	HAHN	1.72	2.05	790.86	6.24	21.03	372.69	0.89	1.06	0.01	-0.06	0.05
	HAMBURG	1.59	1.60	273.17	2.89	100.08	98.58	0.76	1.06	-0.04	0.13	-0.28
	HANNOVER	1.66	1.77	356.80	4.47	285.22	154.41	0.74	1.01	-0.01	0.10	-0.18
	KÖLN/BONN	1.56	1.56	305.38	4.04	14.72	133.72	0.70	1.07	-0.09	0.04	-0.20
	MÜNCHEN	1.41	1.23	345.13	3.93	65.80	72.11	0.73	1.05	0.00	0.00	-0.18
	MÜNSTER	2.08	2.60	229.66	3.34	132.35	180.03	0.68	1.03	-0.01	-0.03	-0.05
	NÜRNBERG	1.75	1.92	398.93	4.92	49.35	159.41	0.65	1.03	-0.01	0.02	-0.20
	PAD/LIPPSTADT	1.97	2.65	344.25	5.43	308.96	350.68	0.85	-	0.04	0.00	-0.03
	STUTTGART	1.55	1.55	510.93	5.94	157.13	210.44	0.72	1.04	-0.01	-0.11	-0.02
GR	ATHENS	1.61	1.58	359.35	4.11	126.74	102.16	0.80	1.06	-0.08	-0.05	0.06
HK	HONG KONG	1.33	1.18	559.92	11.58	33.91	65.12	0.96	1.12	0.17	-0.03	-0.05
IT	BOLOGNA	1.87	2.06	299.21	3.37	115.51	131.89	0.84	1.05	0.01	-0.04	-0.02
	BRESCIA	2.79	4.83	418.92	6.66	23.54	721.46	0.88	1.09	0.04	-0.08	0.06
	FIRENZA	2.10	2.66	268.11	3.78	513.11	281.14	0.88	1.03	0.08	0.05	-0.12
	ORIO AL SERIO	1.62	1.89	309.83	4.40	37.73	370.07	0.91	1.03	-0.06	-0.07	-0.03
	PALERMO	1.88	2.23	131.91	1.43	309.38	135.22	0.76	1.01	-0.11	0.03	-0.03
	PISA	1.96	2.26	171.07	2.02	122.17	92.17	0.76	1.01	-0.09	0.08	-0.19
	TORINO	1.87	2.10	253.03	3.27	193.84	105.95	0.80	1.03	-0.04	0.02	-0.14
	VENEZIA	1.73	1.92	267.48	2.70	133.77	177.03	0.84	1.03	-0.05	-0.04	0.02
	VERONA	1.77	2.19	318.98	4.29	219.85	328.06	0.82	1.02	0.00	0.00	-0.02
JP	OSAKA KANSAI	1.38	1.20	1,408.74	30.32	117.21	173.51	0.91	1.16	0.21	-0.13	0.07
	TOKIO NARITA	1.31	1.17	787.50	18.39	57.99	184.94	0.95	1.14	0.12	-0.17	0.05
LV	RIGA	1.89	2.26	281.07	3.75	180.84	188.93	0.78	1.02	-0.10	0.03	-0.12
MT	MALTA	1.76	2.12	271.81	3.86	129.13	200.48	0.74	1.01	-0.04	0.00	0.01
MX	MEXICO CITY	1.39	1.39	165.01	2.28	102.62	230.80	0.78	1.02	-0.09	-0.10	0.17

NL	AMSTERDAM	1.29	1.07	474.65	6.61	40.84	127.29	0.85	1.04	0.01	-0.06	-0.06
	EINDHOVEN	2.23	2.78	378.22	4.14	46.70	211.35	0.91	1.09	0.12	-0.18	0.17
NZ	AUCKLAND	1.61	1.59	300.91	4.56	59.95	91.57	0.90	1.08	0.22	-0.12	0.14
	CHRISTCHURCH	1.77	2.20	135.94	1.73	33.71	524.14	0.87	1.01	0.08	-0.16	0.19
	WELLINGTON	1.91	2.09	133.13	2.26	1,117.18	81.37	0.90	1.03	0.24	-0.03	0.19
NO	OSLO	1.54	1.45	484.53	5.15	199.70	98.05	0.89	1.07	-0.01	-0.06	0.10
PA	PANAMA CITY	1.74	2.08	114.49	2.01	16.25	97.98	0.73	-	-0.05	0.00	0.04
SI	LJUBLJANA	1.95	5.40	237.80	4.27	87.82	173.48	0.83	1.04	-0.05	-0.11	0.15
ZA	JOHANNESBURG	1.47	1.33	381.08	5.37	69.09	79.04	0.87	1.06	0.01	0.00	-0.03
KR	INCHEON	1.37	1.14	229.60	4.67	16.11	64.16	0.93	-	0.08	0.01	0.14
CH	GENEVA	1.62	1.62	423.17	3.46	163.90	98.96	0.83	1.05	0.05	0.01	-0.16
	ZURICH	1.53	1.44	325.82	3.99	52.77	74.49	0.84	1.05	0.11	-0.01	-0.09
TH	BANGKOK	1.34	1.22	416.57	8.88	68.40	79.18	0.93	1.11	0.03	-0.03	-0.07
	CHIANG MAI	2.26	2.59	463.88	1.99	78.47	97.87	0.85	1.06	0.03	-0.03	0.00
	PHUKET	1.99	2.23	747.50	3.15	207.53	118.21	0.86	1.05	0.03	0.01	0.01
UK	BIRMINGHAM	1.64	1.66	433.97	4.67	678.88	142.20	0.86	1.03	0.08	-0.07	-0.07
	BOURNEMOUTH	2.01	2.60	406.64	6.78	129.30	174.23	0.87	1.05	0.05	0.00	-0.04
	BRISTOL	1.79	1.98	444.59	4.02	315.65	157.17	0.88	-	0.16	-0.01	0.01
	CARDIFF	2.05	2.57	268.10	2.72	395.47	136.44	0.77	-	-0.05	-0.16	0.19
	EAST MIDLANDS	1.64	1.81	420.25	5.62	22.16	250.12	0.89	1.06	0.08	-0.10	0.10
	HUMBERSIDE	2.31	3.33	208.92	5.49	199.16	295.31	0.87	1.03	0.06	0.12	-0.20
	LONDON LUTON	1.60	1.63	445.85	4.59	328.03	170.84	0.92	-	0.03	-0.13	0.04
	MANCHESTER	1.45	1.27	703.66	5.02	151.80	138.96	0.86	1.01	0.03	0.03	-0.16
	NEWCASTLE	1.90	2.14	515.94	3.61	222.82	152.31	0.88	-	0.07	-0.02	-0.02
US	ANCHORAGE	1.45	1.59	36.84	4.34	2.53	259.08	0.89	1.06	0.18	-0.01	-0.07
	ATLANTA	1.44	1.37	198.15	1.69	53.66	71.97	0.86	1.01	0.16	-0.01	0.03
	BWI	1.51	1.53	279.84	3.05	62.54	170.37	0.77	1.03	0.13	-0.13	0.07
	CHARLOTTE	1.54	1.59	110.57	1.07	52.62	119.12	0.92	1.02	0.18	-0.07	0.21
	CINCINNATI	1.79	1.83	98.50	0.85	109.29	36.26	0.83	1.01	0.24	-0.04	-0.01
	DALLAS-FW	1.48	1.40	175.67	1.52	33.67	38.22	0.80	1.03	-0.03	0.04	0.00
	DAYTON	1.94	2.06	159.79	3.41	9.03	58.31	0.79	1.09	0.02	-0.11	-0.13
	DENVER	1.43	1.35	260.50	2.60	98.21	76.83	0.78	1.04	0.04	0.05	0.04
	DETROIT	1.52	1.48	205.24	1.99	94.84	70.20	0.84	1.04	0.24	0.04	-0.01
	DULLES	1.58	1.53	270.23	3.04	53.06	43.90	0.84	1.07	0.02	-0.10	-0.01
	FT LAUDERDALE	1.49	1.45	327.57	3.40	109.70	145.36	0.95	1.02	0.18	-0.13	0.12
	HONOLULU	1.46	1.42	148.02	2.30	26.59	98.23	0.85	1.02	0.04	-0.04	0.11
	INDIANNAPOLIS	1.57	1.60	178.28	4.47	10.77	119.50	0.79	1.08	-0.09	-0.08	0.13
	JACKSONVILLE	1.77	1.85	237.77	3.27	64.31	83.50	0.88	1.07	0.11	-0.06	0.00
	KANSAS CITY	1.70	1.74	190.96	2.17	49.00	68.42	0.81	1.04	0.06	-0.06	0.05
	KNOXVILLE	2.08	2.38	186.60	2.94	44.62	104.34	0.71	1.08	0.03	-0.11	0.12
	LAS VEGAS	1.49	1.42	134.59	1.41	151.09	45.43	0.80	1.01	-0.05	0.01	0.04
	LOS ANGELES	1.34	1.21	248.74	3.37	26.65	111.14	0.75	1.03	0.12	0.01	-0.12
	LOUISVILLE	1.55	1.64	65.70	5.26	3.19	111.33	0.87	1.10	0.03	-0.12	0.19
	MEMPHIS	1.53	1.57	76.63	3.12	3.30	105.06	0.86	1.08	-0.01	-0.12	0.19
	MIAMI	1.40	1.34	288.92	4.58	20.51	132.40	0.83	1.05	0.08	-0.02	-0.19
	MIDWAY	1.55	1.61	303.55	2.74	621.42	246.12	0.86	1.00	0.18	-0.05	0.13
	MINN/ST PAUL	1.57	1.54	232.94	2.25	80.16	42.07	0.76	1.05	0.18	-0.05	0.02
	O'HARE	1.37	1.29	296.94	3.12	37.41	122.41	0.77	1.04	0.00	-0.02	-0.03
	ORLANDO	1.47	1.37	264.55	2.42	106.27	74.74	0.84	1.03	0.00	-0.04	0.09
	PHOENIX	1.46	1.38	210.26	2.08	73.87	80.99	0.87	1.02	0.10	-0.08	0.04
	PITTSBURGH	1.77	1.82	139.66	1.53	53.65	50.36	0.66	1.04	0.08	-0.08	0.17
	PORTLAND	1.63	1.64	295.63	3.61	50.72	82.90	0.85	1.09	0.12	-0.08	0.03
	PT. COLUMBUS	1.92	1.99	138.84	1.61	541.99	33.50	0.62	1.03	0.10	-0.01	-0.07
	REAGAN	1.63	1.62	273.03	3.06	-	93.62	0.79	1.02	0.07	-0.03	-0.02
	RENO	1.92	2.01	159.59	2.12	57.88	48.15	0.75	1.06	0.03	0.01	-0.10
	SALT LAKE CITY	1.65	1.67	119.07	1.06	37.82	51.08	0.83	1.01	0.05	-0.01	-0.02
	SAN FRANCISCO	1.42	1.34	378.22	5.14	69.27	124.92	0.85	1.06	0.08	0.01	-0.09
	SEATTLE	1.48	1.40	428.67	4.55	93.28	146.96	0.91	1.04	0.19	-0.02	-0.05
	SW FLORIDA	1.75	1.85	316.31	3.17	296.07	101.12	0.89	1.03	0.14	0.00	-0.09
	TAMPA INTL	1.64	1.60	222.93	2.14	484.53	55.06	0.87	1.03	0.13	-0.03	0.06
	TUCSON	1.87	2.03	132.98	1.89	56.26	67.34	0.67	1.03	-0.01	0.12	-0.16
	Average values	**1.75**	**-**	**304.80**	**4.52**	**40.02**	**160.57**	**0.82**	**1.04**	**0.05**	**-0.03**	**0.00**

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RESUMEN

El objetivo de este trabajo es proponer una metodología fiable para la estimación de las tasas aeroportuarias óptimas a través de un acercamiento a la frontera tecnológica de la industria. La tarificación de este tipo de infraestructuras siempre ha sido tema central en las políticas de transporte, tanto dentro de la Comunidad Europea como en el resto del mundo. El enfoque más comúnmente aceptado es la tarificación de acuerdo a los costes marginales generados por el usuario. Así mismo, también se busca dar justificación económica a los proyectos de expansión de capacidad con el objetivo de ayudar a una mejor y más eficiente provisión de infraestructuras aeroportuarias. Para ello, un análisis apropiado de la tecnología, especialmente referido a la existencia de rendimientos de escala, es muy importante debido al explosivo crecimiento en la demanda de transporte aéreo. La literatura existente señala que, si el investigador dispone de suficiente información acerca de los precios de los factores productivos, la metodología más apropiada para la obtención de los costes marginales de operación y economías de escala es la estimación econométrica de la función de costes.

La ausencia de suficiente información financiera sobre aeropuertos es el principal problema al que se enfrenta el investigador. Esto explica la relativa escasez de estudios previos sobre este tema, los cuales no ofrecen resultados concluyentes debido al uso de muy distintas y limitadas bases de datos. Esta tesis se basa en un importante esfuerzo de recopilación de información con el objetivo de superar las mencionadas limitaciones. La base datos es un *pool* (no equilibrado) de 161 aeropuertos de todos el mundo entre 1990 y 2006, cubriendo todas las escalas de producción existentes en la actualidad. Las fuentes de información más importantes son los propios estados financieros de las autoridades aeroportuarias así como las estadísticas de tráfico aéreo publicadas por la Organización de Aviación Civil Internacional (ICAO) y consultadas en el centro de documentación de AENA.

La falta de una metodología específica para la industria aeroportuaria es otro de los problemas que este trabajo intenta solucionar. Primero, la naturaleza multiproductiva de la actividad aeroportuaria se respeta en la especificación de la función de costes, lo cual permite obtener estimaciones de costes marginales específicos para cada uno de los

procesos observados, i.e. operaciones de tráfico aéreo (*atm*), pasajeros y mercancías. La consideración de la variable *atm* de forma agregada genera un sesgo importante en las estimaciones debido a que distintas aeronaves imponen distintos costes. De esta forma, si el tráfico de distintas aeronaves es agregado como homogéneo, esto conducirá a una subestimación del grado de economías de escala en la industria. Esto es debido a que el tamaño de aeronave siempre incrementa con la escala de producción (e.g. con el tamaño del aeropuerto), imponiendo de esta forma una estructura creciente en los costes medios. La solución a este problema es muy simple y se basa en homogeneizar las observaciones en términos de un modelo de aeronave que sirva de referencia. Respecto a los otros dos procesos, pasajeros y carga son especificados de forma separada en lugar de utilizar unidades agregadas de tráfico (*wlu*). Los resultados demuestran que el uso de la mencionada variable no es recomendable debido a que los procesos no generan los mismos costes sobre la infraestructura.

El cuarto output especificado son los ingresos comerciales *(rev)* recaudados por el aeropuerto mediante explotación directa o a través de las concesiones que tenga otorgadas. Esto es necesario debido a que las cifras de costes incluidas en la base de datos incluyen los costes no sólo de los factores necesarios para las actividades aeronáuticas sino también los de las actividades comerciales (e.g. el uso de superficie de los edificios terminales). Las prácticas contables no permiten separar ambos tipos de costes y por tanto la inclusión del output mencionado tiene como objetivo minimizar el sesgo de estimación. De no hacerlo existiría un importante riesgo de sobretarificación basada en las estimaciones de costes marginales.

Otra novedad importante esta relacionada con el cálculo de los precios de los factores como input fundamental en la estimación de una frontera de costes. Este ha sido siempre un tema conflictivo en la literatura previa, debido a que los enfoques utilizados eran demasiado simples o carecían de fundamento teórico. En esta tesis, se propone un procedimiento que es consistente desde el punto de vista teórico, aunque también presente ciertas limitaciones relacionadas con los supuestos de competencia de los que parte. De esta forma los precios de los tres factores considerados (trabajo, materiales y capital) se obtienen dividiendo los costes respectivos por índices de cantidad que se asumen correlacionados con las demandas agregadas del factor en cuestión.

Sin embargo, la novedad más importante que este trabajo propone desde el punto de vista metodológico es la estimación de forma separada de las ineficiencias técnicas y asignativas siguiendo el modelo propuesto por Kumbhakar (1997). Dicho modelo utiliza un enfoque de precios sombra para obtener la estimación de las demandas de factor técnicamente eficientes (que son no observadas). Bajo la existencia de dichos precios sombra, las proporciones de factor serían también eficientes de forma asignativa y por lo tanto pueden derivarse mediante la apliación del lema de Shephard sobre la nueva función de costes.

La especificación translogarítmica utilizada para describir la frontera de costes es complementada por las ecuaciones de participación que se obtienen mediante la aplicación del lema de Shephard. El modelo es estimado como un sistema de ecuaciones aparentemente no relacionadas (Zellner, 1962). No obstante, la consideración de la ineficiencia asignativa impone cierto nivel de no linealidad en la especificación. Por ello se hace necesario recurrir a métodos numéricos (MCMC) e inferencia bayesiana para llevar a cabo la estimación de los parámetros de la función de costes así como de aquellos relativos a las distribuciones de ineficiencia técnica y asignativa. El software utilizado para la estimación es el WinBUGS (Lunn et al., 2003), utilizando un código basado en Griffin and Steel (2007), donde se describen las bases para la estimación de fronteras de costes utilizando el mencionado software.

Los resultados inciden en la presencia de importantes economías de escala en todos los niveles de producción considerados, no obstante, las mismas de agotan en niveles de producción superiores debido a la presencia de rendimientos decrecientes en la provisión de infrastructuras en el lado tierra (i.e. el tráfico de pasajeros). Este resultado se explica claramente por la necesidad de fuertes inversiones en infraestructuras para el tránsito de pasajeros que no son necesarias en aeropuertos más pequeños. A pesar de ello, la próxima generación de aeropuertos todavía seguirá disfrutando de economías de escala con o sin el apoyo de las actividades comerciales, hasta casi duplicar su capacidad actual.

Respecto a la eficiencia técnica, que sigue una distribución exponencial, los resultados varían (en promedio) entre el 82 y 85%. La comparación entre los distintos clústeres geográficos revela resultados muy interesantes sobre la influencia de ciertas variables de entorno sobre la eficiencia operativa. Por ejemplo, los aeropuertos públicos (e.g. Austria o Alemania) presentan niveles de eficiencia significativamente menores que el resto del mundo, especialmente en comparación con aquellos países donde la mayoría de los aeropuertos ya se hallan privatizados. De la misma forma, y de acuerdo con lo establecido en la teoría de la regulación, la imposición de una tasa de retorno máxima (e.g. Estados Unidos) no proporciona los incentivos necesarios para minimizar costes en comparación con el sistema de precios máximos (e.g. Reino Unido y Australia). El uso de mayores aeronaves, especialmente en el tráfico de mercancías también incrementa la eficiencia técnica mediante un más eficiente uso de la capacidad del aeropuerto. Dichos resultados, conjuntamente con los obtenidos en el análisis de la estructura industrial son contrastados utilizando datos de los 5 sistemas aeroportuarios (MAS) más importantes de Europa. Los resultados indican que la eficiencia conjunta de los mismos ronda entre el 31% y el 73% como consecuencia de la redundancia de infraestructuras.

Respecto a la ineficiencia asignativa, la distribución ajustada a los resultados indica un sobrecoste en torno a un 6% sobre la frontera eficiente. En aquellos países donde la regulación laboral es muy poco flexible, se observan distorsiones asignativas muy importantes en los factores trabajo y materiales. Los costes marginales estimados (en promedio) son 304.08, 4.52 y 40.02 PPP USD para *atm*s, pasajeros y carga en toneladas. De la comparación con los precios actuales se concluye que la mayoría de los aeropuertos ejercen su poder de mercado de forma excesiva, apareciendo la necesidad de regulación de precios por parte de las autoridades públicas. De la misma forma se detecta un patrón de subsidios cruzados entre diferentes aerolíneas con el objetivo de crear barreras de entrada.

Finalmente, el coste marginal de producir una unidad adicional de ingresos comerciales (1,000 PPP USD) es aproximadamente 160 PPP USD. El resultado indica claramente que los aeropuertos están todavía muy lejos de su nivel óptimo de desarrollo comercial, existiendo por tanto justificación económica para la fuerte tendencia observada hacia la diversificación de este tipo de actividades en las terminales de pasajeros.

RESUMEN EXTENDIDO

En cumplimiento del Artículo 2º del REGLAMENTO PARA LA ELABORACIÓN, TRIBUNAL, DEFENSA Y EVALUACIÓN DE TESIS DOCTORALES de la Universidad de Las Palmas de Gran Canaria.

a. Objetivos de la investigación y aportaciones originales

Esta disertación tiene como objetivo proporcionar una metodología fiable para la estimación de las tasas aeroportuarias óptimas, así como proveer de justificación económica a los proyectos de expansión aeroportuarios con el fin de mejorar la prestación de servicios de infraestructura para el transporte aéreo. El cobro por la utilización de las infraestructuras aeroportuarias es una cuestión central en las políticas de transporte internacionales, que apoyan los sistemas de fijación de precios basados en los costes marginales de operación. Además, un análisis adecuado de la estructura de la industria, especialmente en cuanto a la presencia de economías de escala, parece ser fundamental en este momento, donde la demanda y las previsiones de los agentes están ejerciendo demasiada presión sobre las expansiones de capacidad. La estimación econométrica de la elasticidad de escala y costos marginales en la industria aeroportuaria enfrenta una serie de problemas, tales como la heterogeneidad de datos, que explican la escasez relativa de estos estudios en la literatura anterior. En este trabajo se hace hincapié tanto en el proceso metodológico como en la estrategia de estimación con el fin de dotar a los resultados de mayor fiabilidad y exhaustividad así como facilitar significativamente la divulgación de los mismos.

En primer lugar, esta tesis intenta superar las limitaciones de una especificación monoproducto, que proporcionan estimaciones sesgadas. Cuatro variables de producto fueron incluidas en el modelo final, proporcionando estimaciones de costes marginales para cada una de ellas. Dos de ellas, como los pasajeros y las mercancías no habían sido tratadas de forma apropiada en la literatura anterior, donde se definía una variable agregada, las unidades de carga (work load units, wlu). Las estimaciones de costes marginales obtenidas en esta tesis indican que el uso de la mencionada variable en este tipo de estudios empíricos no es recomendable debido a que ambos tipos de tráfico no imponen los mismos costes a la infraestructura.

No obstante la novedad más importante en cuanto a la metodología concierne al tratamiento de las operaciones de tráfico aéreo (atm) como output en la frontera de costes. La consideración de dicha variable genera un problema de agregación ya que las distintas aeronaves hacen un uso distinto de las infraestructuras y por lo tanto tienen un impacto diferente en los costes de capital del aeropuerto. De esta forma, si el tráfico de distintas aeronaves es agregado como homogéneo, esto conducirá a una subestimación del grado de escala en la industria debido a que el tamaño de aeronave siempre incrementa con al escala de producción (e.g. con el tamaño del aropuerto), imponiendo de esta forma, una estructura creciente en los costes medios. La solución a este problema es muy simple y se basa en homogeneizar las observaciones manteniendo una aeronave de referencia.

Finalmente, el cuarto output especificado son los ingresos comerciales recaudados por el aeropuerto mediante explotación directa o las concesiones que tenga otorgadas. Esto es necesario debido a que las cifras de costes incluidas en la base de datos incluyen los costes no sólo de los factores necesarios para las actividades aeronáuticas sino también los de las actividades comerciales. Las prácticas contables no permiten una consideración separada de los mismos y la no inclusión del output mencionado proporcionaría estimaciones sesgadas, existiendo un importante riesgo de sobretarificación basada en las estimaciones de costes marginales.

Otra aportación importante esta relacionada con el cálculo de los precios de los factores como input fundamental en la estimación de una frontera de costes. Este ha sido siempre un tema conflictivo en la literatura previa, debido a que los enfoques utilizados eran demasiado simples o carecían de ninguna clase de fundamento teórico. En esta tesis, se propone un procedimiento que es consistente desde el punto de vista teórico, aunque también presente ciertas limitaciones relacionadas con los supuestos de competencia de los que parte. De esta forma los precios de los tres factores considerados (trabajo, materiales y capital) se hallan dividiendo los costes respectivos por índices de cantidad que se asumen correlacionados con las demandas agregadas del factor en cuestión.

Sin embargo, la novedad más importante que este trabajo propone es la estimación de forma separada de las ineficiencias técnicas y asignativas siguiendo el modelo propuesto por Kumbhakar (1997). Dicho modelo utiliza un enfoque de precios sombra para obtener la estimación de las demandas de factor técnicamente eficientes (que son no observadas). Bajo la existencia de dichos precios sombra, las proporciones de factor serían también eficientes de forma asignativa y por lo tanto pueden derivarse mediante la apliación del lema de Shephard sobre la nueva función de costes.

Aparte de estas aportaciones metodológicas, esta tesis también propone otras novedades relacionadas con el proceso de estimación en sí. La consideración de la ineficiencia asignativa impone cierto nivel de no linealidad en el sistema de ecuaciones a estimar. Por ello se hace necesario recurrir a métodos numéricos (MCMC) e inferencia bayesiana para llevar a cabo la estimación de los parámetros de la función de costes así como de aquellos relativos a las distribuciones de ineficiencia técnica. El software utilizado para la estimación es el WinBUGS (Lunn et al., 2003), utilizando un código basado en Griffin and Steel (2007), donde se describen las bases para la estimación de fronteras de producción y costes utilizando el mencionado software.

No obstante, nada de ello sería de algún valor si la estimación no estuviera respaldada por una base de datos representativa de la industria que se quiere analizar. Por definición, una estimación apropiada del grado de economías de escala requiere observaciones de una gran variedad de aeropuertos de distintos tamaños. La disponibilidad de información financiera sobre aeropuertos es muy limitada, lo cual explica la relativa escasez de dichos estudios en la literatura. No obstante, el presente proyecto de investigación está sustentado en un importante esfuerzo de recopilación de información hasta completar un panel (no equilibrado) de 161 aeropuertos de todo el mundo entre 1991 y 2006 para un total de 1069 observaciones.

b. Estructura de la tesis

Esta tesis se organiza de la siguiente manera: el capítulo 1 presenta una breve introducción a las operaciones aeroportuarias, describiendo las infraestructuras aeroportuarias y los diferentes procesos que sirven y la presentación de las características más importantes sobre la planificación y la gestión del mismo. De la misma forma también se hace una pequeña *survey* sobre tarificación aeroportuaria, describiendo los sistemas de precios más comúnmente utilizados para cobrar por el uso tanto de las infraestructuras del lado aire (operaciones aeronáuticas) como por el uso de las terminales y demás superficies destinadas exclusivamente al tráfico de pasajeros y sus equipajes.

La estrecha relación entre la demanda de transporte aéreo y los aeropuertos se traduce en términos de inversiones en capacidad. Por lo tanto, este primer capítulo trata de establecer un nexo de unión entre ambas variables con el objetivo de establecer el escenario de la industria en los próximos 20 años basado en las previsiones de tráfico. Dichas previsiones auguran un crecimiento explosivo de la demanda del tráfico aéreo y la evolución hacia mayores y más pesadas aeronaves. Por tanto, un correcto análisis de la estructura industrial parece ser clave en este momento, definiendo una motivación muy clara para este trabajo.

En el capítulo 2 se ofrece un amplio resumen sobre los más importantes conceptos microeconómicos en los que se basa el estudio de las funciones de costes. Aquí se presta especial atención a la estimación de las economías de escala multiproducto y la estimación de los cambios tecnológicos en la industria. Esto se complementa con los desarrollos más recientes en la eficiencia y la medición de la productividad, prestando especial atención a la decomposicion de la eficiencia técnica y asignativa dentro del marco de las fronteras estocásticas. Por supuesto, toda la literatura previa sobre tarificación aeroportuaria y la estimación de funciones de costes será repasada adecuadamente, ayudando a establecer más claramente la contribución de este trabajo dentro del ámbito de la investigación.

El capítulo 3 se refiere a las cuestiones metodológicas, tales como el ámbito de la actividad del aeropuerto que será sujeto de estudio, especialmente en relación con la subcontratación de actividades aeronáuticas y comerciales. A continuación, la definición del vector de productos se examina en profundidad, sin olvidar las posibles consecuencias derivadas de la aparición de multicolinealidad. La nueva metodología para el cálculo de los precios de los inputs es también explicada en profundidad. Por último, todas las cuestiones relativas a la estimación del modelo, como la estructura bayesiana o la elección de las distribuciones a priori, son presentadas.

En capítulo 4 se describe la base de datos, que comprende más de 160 aeropuertos de todo tipo y tamaño. Las prácticas contables y la calidad de los datos difieren considerablemente entre los países, debido a ello un nuevo estándar de recogida de datos (a semejanza del formulario J de ICAO) es diseñado y presentado en el Anexo 5. Dentro de las novedades propuestas está la desagregación de las cifras de tráfico por terminales con el objetivo de obtener estimaciones de pasajeros diferenciadas según el tipo y la calidad de las infraestructuras utilizadas. La proliferación de terminales Low-Cost en los aeropuertos europeos y asiáticos justifica estos nuevos requerimientos de información por parte del investigador. Así mismo, con el objetivo de minimizar la heterogeneidad en la valoración de los bienes de capital impuesta por las distintas prácticas contables, también se exigen los precios de adquisición de los edificios terminales e infraestructuras del lado aire con el objetivo de aplicar criterios homogéneos de valoración y de vida útil sobre los mismos.

En el siguiente capítulo se explica todo el proceso de estimación de los modelos de largo y corto plazo, aunque será siempre el primero el que prevalezca debido a las características de la base de datos utilizada. La presencia de un elevado grado de multicollinealidad entre las variables operaciones aeronáuticas y pasajeros requiere descartar un elevado número de parámetros de segundo order con el fin de lograr identificar los parámetros de forma apropiada mediante una especificación lo más parsimoniosa posible. El uso de variables de control para tal procedimiento así como su significado es también ampliamente cubierto. Los valores específicos de las distribuciones a priori son justificados de acuerdo a la información proveniente de estudios anteriores. El código completo de estimación para el software WinBUGS puede consultarse en los anexos 3a y 3b. Finalmente, en el anexo 7 se presentan las funciones de densidad a posteriori de cada uno de los parámetros de ambos modelos, lo cual permite un análisis casi inmediato de la significatividad de los mismos.

Como ya se ha mencionado, una de las utilidades principales de la estimación de fronteras estocásticas es la determinación del grado de escala de la industria. Este análisis es cubierto en el capítulo 6. El cálculo de la elasticidad de escala es presentado de forma teórica como la inversa de la elasticidad coste para el vector de outputs. Las estimaciones para los aeropuertos individuales son calculadas para cada aeropuerto y son luego utilizadas para determinar la escala mínima eficiente (MES) de la industria. El procedimiento es bastante sencillo, las estimaciones individuales son regresadas contra una variable representativa del tamaño del aeropuerto utilizando un ajuste logarítmico. Dada la disponibilidad de series temporales, la MES puede ser calculada para cada uno de los años de la muestra, lo cual tiene importantes implicaciones sobre los cambios tecnológicos experimentados por la industria así como sobre la necesidad de actualizar las estimaciones en el futuro. El análisis de escala se repite de nuevo pero únicamente considerando los *outputs* aeronáuticos, con el objetivo de contrastar la influencia de los mismos sobre el rango de expansión de los aeropuertos (e.g. el rango en el que disfrutan de rendimientos de escala). Adicionalmente, en este capítulo se presenta evidencia empírica de la subestimación del grado de escala derivada del uso de la variable agregada *atm* sin ningún tipo de homogenización.

El capítulo 7 trata de la estimaciones de eficiencia, tanto técnica como asignativa. No obstante, antes de presentar los resultados la conveniencia de la distribución exponencial seleccionada será discutido y contrastada utilizando procedimientos estadísticos. El criterio de información utilizado es el *Deviance Information Criterion* (DIC). La primera subsección da una visión general de los resultados, proporcionando los intervalos de confianza para los parámetros de ineficiencia así como estimaciones monetarias de las pérdidas anuales derivados de la ineficiencia. Luego se calcula el nivel medio de eficiencia técnica en las nueve principales regiones geográficas que aparecen en la base de datos. Dicho experimento resulta en una muy interesante clasificación de países que permite extraer algunas conclusiones sobre la influencia de ciertas variables externas sobre la eficiencia en costes, como puedan ser la propiedad pública o privada del aeropuerto, su enfoque regulatorio (tasa de retorno vs. precios máximos) o el efecto de la mera localización geográfica sobre el tipo de aeronaves que operan en las instalaciones.

Por último, los resultados de escala y eficiencia se pondrán a prueba utilizando datos de los cinco sistemas aeroportuarios (MAS) más importantes de Europa (MAS). La presencia de infraestructuras redundantes debe generar importantes ineficiencias bajo la presencia de rendimientos crecientes de escala. Adicionalmente, el uso de información de otros 2 MAS americanos, cuyos aeropuertos individuales fueron incluidos en la base de datos (Washington y Chicago) permite hacer un análisis más profundo y separar los componentes de ineficiencia propios de cada aeropuerto de aquellos derivados exclusivamente de la atomización del tráfico.

El capítulo 8 se ocupa de la obtención de los costes marginales de operación tanto de corto como de largo plazo, los cuales serán, con las debidas reservas, considerados como las tasas óptimas de uso de las instalaciones aeroportuarias. En este capítulo se presenta evidencia empírica sobre la conveniencia de una estimación separada de pasajeros y carga en la función de costes debidos a que ambos procesos no imponen los mismos costes a la infraestructura. En la última sección se comparan éstas tarifas óptimas con los precios efectivamente cobrados por los aeropuertos en Europa, los Estados Unidos y Oceanía. El objetivo es comprobar si los aeropuertos, en efecto, abusan de su poder de mercado tarificando muy por encima de los costes marginales de operación. No obstante, otras interesantes resultados pueden obtenerse, como por ejemplo la existencia de subsidios cruzados entre distintos tipos de aeronave o incluso entre distintos tipos de usuarios (aerolíneas entrantes vs. incumbentes) con el objetivo de generar barreras de entrada.

El último capítulo de esta tesis sirve como un resumen de la metodología y los resultados. Sin embargo, la estimación de los costes marginales sociales debe incluir todos los efectos externos derivados de las operaciones aeroportuarias. La presencia de importantes economías de escala incluso en los más grandes niveles de producción indica claramente la necesidad de incluir en la especificación los costes medioambientales como el ruido o la congestión generada por el tráfico de aeronaves. El desarrollo de una metodología para la valoración del impacto medioambiental de un aeropuerto esta fuera del alcance del presente proyecto de investigación y se presenta como una extensión natural al mismo siempre que la información puramente financiera de la base de datos pueda ser expandida con mediciones monetarias de esos efectos externos.

c. Revisión de literatura

Las gran mayoría de las decisiones normativas sobre la estructura de la industria aeroportuaria están relacionadas con la identificación del grado de economías de escala. Como se observa en Jeong (2005), sólo unos pocos estudios se han ocupado de la estimación de los costes derivados de los servicios de provisión de infraestructuras y además, el uso de diferentes metodologías y muy limitadas bases de datos proporciona resultados incoherentes, principalmente relacionados con 1) las limitaciones para obtener buenas mediciones de los costes de capital y los precios de los factoras, 2) una visión parcial de la actividad de los aeropuertos, expresada mediante especificaciones monoproducto y 3) La dificultad en la recogida de datos comparables entre aeropuertos de distintos países y escalas de producción.

Como una primera aproximación, Keeler (1970) utiliza Mínimos Cuadrados Ordinarios (OLS) para estimar dos especificaciones Cobb-Douglas de costes parciales para los costes de capital y de mantenimiento, utilizando las operaciones aeronáuticas (ATM) como variables de producto. Encontró retornos constantes a escala usando una mezcla de series temporales y los datos de corte transversal de 13 aeropuertos de EE.UU. entre 1965 y 1966. Sin embargo, estos resultados se ven limitados por una insuficiente base de datos, y, como se mencionó, por su enfoque parcial de la actividad.

Doganis y Thompson (1973, 1974) estimaron dos funciones de coste Cobb-Douglas, y también consideraron de forma separada los costes de capital y de mantenimiento. Como variable de producto utilizaron las unidades de carga (WLU), que se definen como un pasajero o 100 kg de mercancías. Encontraron importantes economías de escala hasta tres millones de WLU utilizando datos de corte transversal de 18 aeropuertos británicos para el año 1969. Sin embargo, sus resultados sufren de las mismas limitaciones metodológicas que los obtenidos por Keeler.

Tolofari et al. (1990) combina datos de corte transversal con series temporales sobre los siete aeropuertos controlados por British Airport Autority (BAA) entre 1979 y 1987 para modelizar una función de coste variable (corto plazo) incluyendo una variable de capital fijo. Para cada aeropuerto se calcula el nivel de capital que minimizar el valor los costes variables y de esa forma se derivan los costes de largo plazo. Por primera vez se utiliza una forma funcional flexible como la translogarítmica utilizando WLU como único output y los precios del trabajo y equipamiento. Otras variables incluidas hacen referencia al capital social del aeropuerto, al *load factor*, el porcentaje de pasajeros internacionales y de superficie de terminal utilizada más una tendencia temporal. La función de costes fue estimada dentro de un sistema de ecuaciones aparentemente no relacionadas Zellner's (1962). Los resultados indican la existencia de economías de escala hasta 20,3 millones de WLU. Un importante hallazgo, sin embargo, que no puede generalizarse fácilmente porque sólo un aeropuerto en la muestra (London Heathrow) opera con más de 20 millones de WLU al año.

Main et al (2003) construyeron cuatro funciones Cobb-Douglas usando WLU o el tráfico de pasajeros como medida de la producción, e incluyendo amortizaciones o no. Aparte de las mencionadas, las otras variables explicativas fueron el precio del personal, el precio de "otros costes", *load factor*, el porcentaje de los pasajeros clasificados como de tránsito internacional y los activos totales del aeropuerto. El precio del factor trabajo se calcula dividiendo los gastos de personal por número de empleados. Los precios de los "otros costes" se calcula como el gasto respectivo dividido por el valor de los activos tangibles. Encontraron economías de escala hasta cinco millones de WLU o cuatro millones de pasajeros, utilizando una base de datos de corte transversal 27 aeropuertos en el Reino Unido para 1988 y un panel de 44 aeropuertos de todo el mundo entre 1998 y 2000.

Rendeiro (2002) estimó una función de coste total bajo una especificación translogarítmica, utilizando WLU como medida de la producción y teniendo en cuenta el capital y los costes laborales. Utilizó una base de datos de 40 aeropuertos españoles durante los años 1996-1997. Los resultados indican que los aeropuertos cuyo volumen de tráfico está entre uno y tres millones de WLU, mostraron un mayor nivel medio de eficiencia relativa de los aeropuertos considerados pequeños o grandes.

Con el fin de examinar las economías de escala en virtud de los distintos niveles de infraestructuras y demás bienes de capital Jeong (2005), estimó una especificación translogarítmica (sus expansiones de primer y segundo orden) para el total de costes operativos, con tres definiciones diferentes de outpu: Pasajeros, WLU o un índice multilateral de producción. Para calcular los precios de los factores variables se utilizaron índices similares de inputs. Los costes de capital se aproximaron mediante índices de costes de la vida. Otras variables adicionales son el porcentaje de pasajeros internacionales, el porcentaje de retrasos, el porcentaje de volumen de carga en WLU, y la parte de los gastos contractuales en función del costo total de producción. Este estudio encontró que las economías de escala en la industria se agotan en 2,5 millones de pasajeros y 3 millones de WLU, utilizando un corte transversal de 94 aeropuertos de EE.UU. para el año 2003.

Low y Tang (2006) analizó la complementariedad/sustituibilidad de los factores de producción utilizando una base de datos de los principales aeropuertos internacionales en la región Asia Pacífico. Utilizando WLU como variable de output, la especificación de la función de costes translogarítmica impone retornos constantes a escala y cambio técnico neutral. Los resultados indican un alto grado de substituibilidad entre la subcontratación y la mano de obra, así como una muy importante complementariedad entre el capital y la subcontratación.

Por último, Martin y Voltes-Dorta (2008) proporcionan una primera aproximación a una función de costes multiproductiva, aportando evidencia empírica del sesgo en la estimación producido por el enfoque monoproducto, sobre todo en la determinación del grado de economías de escala. Los resultados indican que las mismas no se agotan para ningún nivel de producción incluido en la base de datos. Este resultado encaja perfectamente con la tendencia observada en la industria donde las expansiones de capacidad continúan muy por encima de las escalas previstas por estudios anteriores. La base de datos es un panel no equilibrado de 41 aeropuertos internacionales de todo tipo y tamaño entre los años 1991 y 2005.

El estudio de ineficiencias en la industria aeroportuaria utilizando un enfoque de fronteras estocásticas es también muy limitado en la literatura. Pels et al (2003) estimó dos fronteras estocásticas de producción utilizando *atm* y pasajeros como variables de producción pero con una singularidad: las predicciones del primer modelo fueron utilizados como inputs en el segundo. De esta forma las operaciones aeronáuticas son consideradas como un intermedio de explotación para el aeropuerto cuyo objetivo es maximizar el tráfico de pasajeros. Los resultados indican que los aeropuertos europeos son relativamente ineficientes, y que la mayoría de los aeropuertos muestran rendimientos constantes a escala en la ATM, pero rendimientos crecientes en la producción de pasajeros. La base de datos utilizada es un panel de 34 aeropuertos europeos entre 1995 y 1997.

La Tabla 2.1 resume la literatura anteriormente expuesta, haciendo especial hincapié a la definición del vector de outputs y a la forma funcional elegida para la función de costes. La tabla ayuda a localizar la contribución del presente trabajo dentro de la literatura de las funciones de costes para la industria aeroportuaria. La presente tesis ofrece la primera frontera estocástica de costes con una especificación multiproducto (incluyendo los ingresos comerciales, que nunca antes habían sido incluidos), lo cual permite una visión más amplia de las operaciones aeroportuarias, con el fin de obtener estimaciones más fiables de las economías de escala. Además, el uso de una base de datos mucho más grande que comprende aeropuertos de todo tipo y tamaño permite la obtención de resultados más creíbles y generalizables.

Tabla 2.1. Estudios previos sobre la función de costes aeroportuarios

Artículo	Forma funcional	Productos
Keeler (1970)	Cobb-Douglas	ATM
Doganis and Thompson (1973, 1974)	Cobb-Douglas	WLU
Tolofari et al (1990)	Translog	WLU
Main et al (2003)	Cobb-Douglas	Passengers or WLU
Pels et al. (2003)	Translog	ATM or Passengers
- Production Frontier		
Jeong (2005)	Translog	Passengers or WLU or Output index
Low and Tang (2006)	Translog	WLU
Martin and Voltes-Dorta (2008)	Translog	WLU and ATM
Voltes-Dorta (2008)	Translog	Passengers, Cargo, ATM index and Commercial rev.

En relación con la determinación de las tarifas óptimas por el uso de la infraestructura la literatura es mucho más rica que en el caso anterior. Merece la pena citar los trabajos de Vasigh y Hamzaee (1998); Stanmeyer y Cote (1995) así como Lim (1980). A pesar de la abundancia de estudios que han tratado este tema, sólo unos pocos se han centrado en obtener estimaciones monetarias de los precios óptimos utilizando bases de datos de aeropuertos reales. La mayor parte de la investigación académica sobre este tema se centra en la tarificación pico-valle por el uso de las pistas de aterrizaje así como de los mecanismos de asignación de las franjas de uso (*slots*) por medio, por ejemplo, de subastas. Esto incluye por ejemplo, Morrison (1987), Morrison y Winston (1989), Gillen et al. (1989), Zhang y Zhang (1997), Oum et al. (2004) y Pels y Verhoef (2004). Más recientemente, Johnson y Savage (2006) ofrecen un análisis de la fijación de precios en el severamente congestionado aeropuerto de Chicago O'Hare. Véase también Van Dender (2007). Morrison y Winston (1989) determinó que una fijación de precios óptima, incluso sin ningún tipo de inversión en infraestructura, generaría 3,82 millones de dólares en beneficios (1988 dólares). En combinación con una inversión eficiente en infraestructura, podrían generarse $ 11,01 millones de beneficios.

En lo que respecta más concretamente a estimaciones directas de los costes marginales de operación, referencias útiles incluyen Levine (1969), Carlin y Park (1970), Morrison (1983) o Oum y Zhang (1990). Morrison (1983) demostró que si la capacidad es divisible y los costes son homogéneos en la relación entre volumen y capacidad, entonces la tarificación del coste marginal social conduce a la recuperación de los costes de los aeropuertos. El coste social de la operación de una aeronave es la suma de los costes promedio de retraso del mismo, los retrasos impuestos a otros aviones y el coste adicional impuesta a la autoridad aeroportuaria. Los costes fueron estimados de forma parcial incluyendo distintas como por ejemplo el mantenimiento, operación y administración, la construcción de pistas, adquisición de terrenos y los retrasos a fin de calcular las tarifas óptimas de largo plazo. Según sus estimaciones, el coste marginal de mantenimiento, gastos administrativos y demás operaciones ronda los $ 12,34 (1976 dólares) por *atm*.

Carlin y Park (1970) calculó los costes sociales marginales por el uso de las pistas de aterrizaje para el aeropuerto de La Guardia en Nueva Cork, centrándose en los costes de retrasos durante los períodos pico. Sus estimaciones oscilan entre 3 dólares para una operación que tenga lugar a medianoche (período valle) y $ 1,090 por un aterrizaje durante las 15:00 y 16:00 (período pico). No obstante, la fijación de este tipo de precios reconduciría a un nuevo desequilibrio ya que las aerolíneas cambiarían sus horarios generando nuevos períodos pico donde antes eran valle. La clave, según el autor, está en la posibilidad de convergencia, cuya existencia no se garantiza de forma teórica.

Link et al. (2006) hacen uso de un enfoque alternativo al análisis tradicional de la función de costes. Centrándose en los gastos de personal, hace uso de series temporales en lugar utilizar datos de corte transversal. Dicho trabajo especifica un modelo SARMA para identificar una relación entre el número de horas-persona previsto en el área de servicio y el volumen de tráfico medido como ATM. Variables adicionales son las horas de trabajo nocturno, y dos variables *dummy* de temporada tanto para verano e invierno y fines de semana. Este estudio ofrece algunos resultados interesantes, por ejemplo, una estimación del coste marginal promedio de un *atm* extra de € 22,60. Para las salidas internacionales de este MC oscila entre € 25 y € 72.

No obstante, con respecto a las estimaciones numéricas, todos los trabajos anteriores se centran en estudios de casos individuales, y sus conclusiones no pueden ser generalizadas con facilidad a la totalidad de los aeropuertos en la industria.

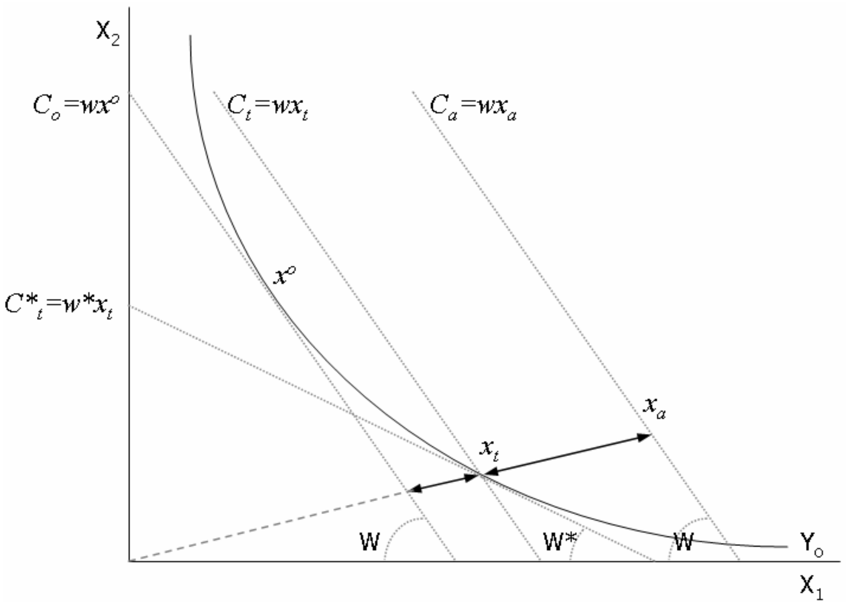
d. Planteamiento y metodología utilizada

La elección del modelo de frontera a estimar depende del objetivo que persiga el investigador, del tipo de supuestos sobre el comportamiento del productor que se esté dispuesto a asumir y de la disponibilidad de datos a la que se esté restringido. En la presente investigación se opta por el enfoque de fronteras de costes justificando esta decisión en su idoneidad para caracterizar la tecnología y las decisiones económicas de empresas que operan en entornos regulados, como por ejemplo los aeropuertos. Con la intención de medir la contribución de la producción conjunta de varios outputs sobre los cambios en la productividad, la frontera de costes es un instrumento adecuado por su sencilla adaptación a contextos multiproductivos. Se evitan así los sesgos de agregación inherentes a enfoques como el de las fronteras de producción, a la vez que se abre la posibilidad de dar un tratamiento diferenciado entre inputs variables y quasifijos simplemente estimando una frontera de costes variables.

Asumiremos que bajo las decisiones de los productores subyace el fin de minimizar sus costes. Este parece ser el objetivo apropiado cuando el entorno en que participan los agentes es competitivo y cuando el nivel de output viene determinado por la demanda. La descomposición de los costes de la ineficiencia plantea importantes requerimientos de información. Además de los precios de los inputs utilizados, niveles de outputs producidos y de los gastos totales asociados, se necesita información sobre las participaciones en los costes totales asociadas a cada uno de los inputs, o bien sobre las demandas de inputs realizadas dependiendo de la especificación adoptada por la frontera de costes.

La metodología empleada para la estimación del grado de economías de escala en la industria, así como los costes marginales de operación es la estimación econométrica de la función de costes, incluyendo la especificación de ambos tipos de ineficiencia. En la literatura especializada en la descomposición de la ineficiencia en costes, Kumbhakar (1997) incorporó una relación exacta entre la medida de la ineficiencia asignativa y su efecto en los costes. En este trabajo se utiliza la metodología propuesta por Kumbhakar adaptándola a un modelo con una función de costes multiproducto con una especificación translogarítmica. Se plantea la relación exacta entre las ineficiencias técnica y asignativa y los costes en función de los niveles de los outputs y de los precios de los inputs. Figura 2.1. De esta forma, se consigue una importante simplificación en el tratamiento econométrico de la ineficiencia.

Figura 2.1 Descomposición de la ineficiencia.



Díaz-Hernández et al. (2001)

El procedimiento trata de descomponer los costes observados (C_a) en cuatro componentes (i) la frontera de mínimo coste *(C^o),* la cual es tangente a la isocuanta objetivo (Y_o) en el nivel óptimo de demandas de factores *(x^o)* dado el vector de precios observados (*w*); (ii) La eficiencia técnica se mide mediante la distancia radial entre el coste observado y el técnicamente eficiente (C_t), dicho efecto se expresa habitualmente como e^u. El problema radica en que las demandas técnicamente eficientes (x^t) no son observadas y no pueden derivarse de forma directa mediante la aplicación del lema de Shephard sobre (C_t) porque la empresa no minimiza costes en ese punto. Para superar dicha limitación, Kumbhakar (1997) definió un vector de precios sombra (w*) bajo el cual las mencionadas demandas fuesen también asignativamente eficientes definiendo así una nueva función de costes (C*) sobre la cual el lema de Shephard sí puede ser aplicado. (iii) la ineficiencia asignativa se representa como la distancia radial entre (C_t) y (C^o), explicada por la diferencia entre (x^t) y (x^o); (iv) Aunque no está especificado en el gráfico, los shocks exógenos también están incluidos como ruido blanco (v).

Kumbhakar (1997) estableció la relación entre el vector de precios sombra y la presencia de distorisiones asignativas a partir de las condiciones de primer orden para la minimización de costes, considerando (w*) como el vector de precios i.e.

$$\underset{X}{Min}\, C^* = w^*x \quad \text{s.t. } F(X,Y) \geq 0 \qquad w^*=[w1, w_2\exp(\xi_2),\ldots,w_j\exp(\xi_j)] \qquad \frac{f_j(x)}{f_1(x)}=\frac{w_j\exp(\xi_j)}{w_1}$$

Donde $\xi_j \neq 0$ mide la ineficiencia asignativa en la proporción de los inputs *(j,1)*. La reducción ficticia del precio impuesta por $\xi_j < 0$ indica que el input j está siendo sobreutilizado con respecto al input 1 que se usa como referencia. Por el contrario, los valores positivos, $\xi_j > 0$ indican que la demanda observada del input j esta por debajo de la óptima. Tomando todo ello en consideración, los costes observados pueden modelizarse como sigue:

$$C^a = e^u \sum w_i x_t(w^*),$$

Donde u mide la eficiencia técnica del aeropuerto y

$$C^* = \sum w_i^* x_t(w^*)$$

Aplicando el lema de Shephard:

$$x_i(w^*) = \partial C^* \big/ \partial w_i^* = (\partial \ln C^* \big/ \partial \ln w_i^*)(C^* \big/ w_i^*)$$

$$C^a = e^u \sum w_i \,(\partial \ln C^* \big/ \partial \ln w_i^*)(C^* \big/ w_i^*) = e^u \sum C^* S_i^* [w_i \big/ w_i \exp(\xi_i)]$$

$$C^a = e^u C^* \cdot G \qquad donde\ G = \sum S_i^* \exp(-\xi_i)$$

donde S_i^* representa la proporción de participación en costes del input *i* dados los precios sombra *w**. Usando una especificación translogarítmica, la relación antes mencionada puede expresarse de la siguiente forma:

$$\ln C^a = \ln C^* + \ln G + u + v$$

La especificación de las distorsiones asignativas de forma exponencial permite una separación sencilla en los términos que pertenecen a la frontera C^o, de aquellos que miden exclusivamente el porcentaje de sobrecoste derivado de la ineficiencia asignativa, representado por $\ln C^{al}$.

$$\ln C^* = \ln C^o(w,y) + \ln C^{al}(\xi, w, y)$$

$$\ln C^{al}(\xi, w, y) = \ln G + \sum_i \beta_i \xi_i + \sum_i \sum_j \gamma_{ij} \xi_j \ln y_i + (1/2) \sum_j \sum_h \delta_{jh} \xi_j \xi_h$$

$$\ln C^a(w,y) = \ln C^o(w,y) + \ln C^{al}(\xi, w, y) + u + v$$

Ésta es la especificación finalmente estimada.

e. Base de datos

La naturaleza de los datos determina la utilidad de los resultados y, en este caso, el análisis está claramente limitado por los mismos. La base de datos está principalmente compuesta por datos financieros recogidos directamente de los balances y cuentas de resultados publicados por las autoridades aeroportuarias. Desafortunadamente, los mencionados estados financieros no incluyen información alguna sobre efectos externos, e.g. ruido, retrasos, ni mucho menos proveen estimaciones monetarias de los mismos. De esta forma, los resultados obtenidos en este trabajo no pueden ser interpretados de conveniencia social. Antes de proseguir, debe quedar claro que este análisis se limita al componente financiero y por esa razón es de interés sólo para las autoridades aeroportuarias como empresas privadas que supuestamente deben maximizar sus propios beneficios.

Según Oum y Waters (1996), la calidad de los datos puede ser más importante que la aplicación de las más sofisticadas metodologías. En cuanto a la industria, la recopilación de datos representa un grave obstáculo para el investigador, lo que explica la relativa escasez de este tipo de estudios sobre la función de costes y los resultados inconsistentes. La base de datos utilizada en esta tesis es un panel no equilibrado de 161 aeropuertos internacionales. El desglose geográfico de los 161 aeropuertos de la muestra es la siguiente, 94 de Europa, 45 de América del Norte, 11 de la región Asia-Pacífico y 9 de Australia y Nueva Zelanda. El único aeropuerto africano es JNB y América Central está representada por PTY. (Ver anexo 4). En América del Sur la mayoría de los aeropuertos son operados por organismos nacionales que no proporcionan información financiera desglosada por aeropuertos. Por lo tanto, ningún aeropuerto de este continente pudo incluirse en la muesta. Además, la muestra europea contiene 36 aeropuertos españoles de una antigua base de datos (1991-1997) proporcionada por el operador nacional AENA, que se incluyó para aumentar observaciones y, por tanto, mejorar la significatividad de los parámetros estimados ante la presencia de multicolinealidad entre algunas de las variables explicativas.

La recolección de datos fue completada para las siguientes variables: a) los costes totales: mano de obra, materiales y gastos de capital (amortización e intereses), b) Outputs (cifras anuales): Tráfico total de pasajeros (PAX), Operaciones aeronáuticas (ATM), toneladas métricas de carga (CGO) e ingresos comerciales (REV). C) factores fijos: Superficie total de los edificios terminales (TER-m2), metros totales de pistas de aterrizaje (RUN-m), el número de puertas de embarque (GAT), cintas de equipaje (BEL) y mostradores de facturación (CHK). D) Otros: tiempo (t), empleados a tiempo completo (FTEE) y el tonelaje total de las aeronaves procesadas (mix). Todas las variables relativas a los gastos y los ingresos comerciales fueron homogenizadas en USD manteniendo la paridad de poder adquisitivo (PPP) mediante el uso de los indicadores publicados por la OCDE.

En la Tabla 4.1 se proporcionan el rango, promedio y desviación típica de cada variable. El tamaño del aeropuerto oscila entre los 1000 pasajeros en ODB (España) en el año 1993 y los 85 millones procesados durante 2005 en ATL. El aeropuerto promedio sirve alrededor de 155.000 operaciones, el 11,3 millones de pasajeros al año y 253.000 toneladas métricas de carga. Sin embargo, debido a la transformación logarítmica, los valores pertinentes para una adecuada interpretación de las estimaciones son las medias geométricas de las variables (Gm), que están situadas en niveles muchos más bajos que las medias aritméticas.

En cuanto a los precios de los factores, la extrema diversidad de los aeropuertos y de los países que figuran en la muestra explica la gran variabilidad de los mismos, especialmente con los aeropuertos asiáticos. Con respecto al precio de los materiales, una gran parte de esta variabilidad se debe al nivel de la contratación externa (outsourcing), que es específico de cada aeropuerto.

Tabla 4.1 Base de datos

	Total Cost	PAX	ATM_{737}	CGO	REV	FTEE	TER	RUN	Wc	Wm	Wp
Max.	1,739,326	85,907,423	1,190,887	3,692,081	690,051	13,979	761,300	24,505	65.7	8,947	191.6
Min.	692	1,000	66	0	0	8	918	1,127	0.02	3.9	15.6
Mean	151,036	11,339,733	155,299	253,847	66,005	651	112,391	5,847	3.59	727.3	52.99
Gm	-	4,703,044	48,764	28,496	15,543	-	-	-	-	-	-
Sd	219,379	14,417,880	207,709	534,132	97,777	1,069	140,278	4,017	6.33	776.3	23.32

En cuanto a las fuentes de datos en general, excepto para los aeropuertos Americanos, los datos fueron recolectados directamente de los estados financieros publicados por las autoridades aeroportuarias en sus páginas web, o mediante petición directa de los ejemplares impresos. En la mayoría de los casos, los informes anuales de actividad incluyen los estados financieros como parte integrante de los mismos. En esta clase de informes puede encontrarse además todo tipo de información relacionada con las cifras de tráfico así como de factores fijos e inversiones en infraestructuras. En cuanto a la variable de tráfico de mercancías (CGO), algunas estadísticas gubernamentales también fueron consultadas, especialmente los registros de comercio exterior de países como Austria o Nueva Zelanda.

En cuanto a los datos referentes a los aeropuertos americanos, la tarea de recopilación de información fue considerablemente más sencilla ya que la Federal Aviation Authority (FAA) pone esos datos financieros a disposición del público en su página web. Las cifras de tráfico fueron consultadas en la base de datos de ICAO/ATI sobre estadísticas operacionales y financieras, que proporcionan datos para los aeropuertos de todo el mundo entre 1992 y 2004. Los datos operativos para el 2005 y 2006 se obtuvieron de los *Airport Master Records*. Otros detalles, como por ejemplo la superficie de los edificios terminales o la longitud de pistas estaban disponibles en la última edición (hasta la fecha) de 2003 de la IATA / ACI / ATAG *Airport Capacity and Demand Profiles*. Otras fuentes consultadas son la wikipedia o el *Google Earth*.

f. Modelo estimado

La estimación de la frontera de costes de largo plazo tal como se describe en secciones anteriores implica una cantidad de modelización estadística que no es soportada por los *software* de estimación de uso habitual si tener que invertir una considerable cantidad de tiempo en tareas de programación. La considerable complejidad del modelo propuesto contrasta con la extrema sencillez del software WinBUGS. Así, el procedimiento de estimación consta de dos etapas. La primera fase se centra en elegir una especificación lo más parsimoniosa posible que permita la identificación de la mayoría de parámetros importantes del modelo ante la presencia de multicolinearidad entre varias de las variables explicativas del modelo. Para ello, utilizaremos el procedimiento clásico de estimación con el software Eviews obviando, de momento, la parte del sistema relacionada con la medición de la eficiencia. Este modelo básico incluye la frontera de costes y (n-1) ecuaciones de participación. En cuanto a las restricciones paramétricas, sólo pueden especificarse los relacionados con los parámetros de primer orden de los precios de los factores (i.e. han de sumar 1), sin sin inducir problemas de singularidad.

Aparte de la necesidad de identificar correctamente los parámetros, esta primera fase es muy necesaria debido a que el software WinBUGS no permite cambiar fácilmente la especificación una vez que el código está escrito y compilado el modelo, y los tiempos de ejecución aumentan considerablemente con el número de parámetros. Además, los valores estimados de los parámetros de la frontera obtenidos en esta primera estimación se reutilizarán como valores iniciales para el proceso de muestreo en WinBUGS. Por lo tanto, al principio, la frontera incluye 45 parámetros, con todas las interacciones de segundo orden entre las variables explicativas. Se logró un excelente R^2 = 0,968, sin embargo, hubo un gran número de parámetros no significativos y muchos otros de signo equivocado. Esto indica claramente la forma en que la frontera debe ser re-especificada.

Las variables de control son están en su mayoría relacionadas con los productos, tal como se muestra en la Tabla 5.1. Se observa claramente que el parámetro de primer orden de los *atm* no es significativamente distinto de cero. Esto es claramente producido tanto por la multicolinearidad como por la sobreespecificación del modelo. Evidencia adicional puede encontrarse observando las interacciones de segundo orden. A sabiendas de que los *atm*s y los pasajeros están muy correlacionados y, por tanto, tienen la misma capacidad explicativa, los dos signos negativos de los parámetros al cuadrado y el signo positivo de la interacción no tienen ningún sentido en absoluto. A pesar de que no afectan a la bondad del ajuste, la necesidad de hacer el análisis estructural sobre los coeficientes en el análisis de escala y costes marginales requiere eliminar algunos de los parámetros.

Tabla 5.1 Variables de control en la estimación del modelo de largo plazo.

	Coefficient	Std. error	t-Statistic	Prob
atm	0.012191	0.021993	0.554305	0.5794
pax	0.302167	0.021814	13.85221	0.0000
cgo	0.080699	0.006147	13.12850	0.0000
rev	0.140641	0.011012	12.77208	0.0000
0.5*atm^2	-0.254608	0.042756	-5.954961	0.0000
0.5*pax^2	-0.275698	0.034434	-8.006606	0.0000
0.5*cgo^2	0.019469	0.003332	5.842135	0.0000
0.5*rev^2	0.082867	0.006907	11.99795	0.0000
atm*pax	0.341914	0.034776	9.831897	0.0000
atm*cgo	0.061547	0.011216	5.487427	0.0000
atm*rev	-0.137347	0.025658	-5.353060	0.0000
pax*cgo	-0.047148	0.011221	-4.201598	0.0000
pax*rev	0.073453	0.025658	3.559165	0.0000
cgo*rev	-0.042312	0.007496	-5.644881	0.0000
atm*time	-0.001673	0.004440	-0.376911	0.7063
pax*time	0.014014	0.004271	3.281550	0.0010
cgo*time	0.002889	0.001149	2.515392	0.0119
rev*time	-0.009903	0.002172	-4.560087	0.0000

Por lo tanto, sólo uno entre estos tres parámetros debe permanecer en la función de costo con el fin de minimizar el efecto de la multicolinearidad lo que permite una simplificación de la especificación y también un ahorro de grados de libertad y la reducción de los tiempos de ejecución.

El parámetro elegido para permanecer es la interacción entre las dos variables, el motivo es claro, a la hora de estimar economías de escala para cada uno de los outputs será necesario utilizar la derivadas parciales de la frontera de costes que representan las elasticidades-coste individuales. El hecho de dejar a una de las dos variables sin parámetros de segundo orden produciría un sesgo muy significativo en los resultados, que también afectarán a las estimaciones de costes marginales. Un efecto muy claro de esta situación es la aparición de elasticidades-coste y costes marginales negativos para una de las variables mientras que la otra presenta valores anormalmente altos.

En esta segunda estimación, muchos otros parámetros pasaron a ser no significativos y también fueron eliminados. Esto incluye todas las interacciones con la variable tiempo (t), que fue incluida como proxy de los posibles cambios técnicos en la industria. Por esa razón, su poder explicativo se utilizará exclusivamente en la estimación del parámetro de la ineficiencia técnica, que se permite que varíe con el tiempo mediante la generalización de Cuesta (2000) sobre el modelo de Battese y Coelli (1992).

La reducción en el número de parámetros ha afectado negativamente a la coeficiente de bondad de ajuste del modelo. Sin embargo, como muchos de ellos eran redundantes, el R^2 se redujo sólo en menos del 1% (0,961). La especificación definitiva incluye 29 variables con los valores que se muestran en la Tabla 5.2. El modelo presenta muy buen rendimiento y la mayoría de los parámetros son significativamente distintos de cero. La inversa de la suma de los parámetros de primer orden de los outputs nos proporciona una estimación del grado de economías de escala en el aeropuerto promedio. Este valor es de 1.86, que parece ser un valor muy razonable debido a la pequeñez de el aeropuerto en la media geométrica (4.7 mppa; 48,000 ATM737). No obstante, el signo positivo de la interacción antes mencionada garantiza que las economías de escala se agotarán en un, aún desconocido, nivel de producción.

Tabla 5.2 Valores iniciales para la estimación bayesiana.

	Coefficient	Std. error	t-Statistic	Prob
constant	10,70048	0,01450	738,117	0.0000
atm	0,10614	0,03018	3,51720	0.0004
pax	0,30430	0,02756	11,0402	0.0000
cgo	0,07477	0,00938	7,96782	0.0000
rev	0,05290	0,01564	3,38309	0.0007
wc	0,37379	0,00346	108,001	0.0000
wm	0,30498	0,00314	97,0965	0.0000
wp	0,32117	0,00312	103,005	0.0000
atm*wc	0,03227	0,00889	3,62985	0.0003
atm*wm	0,01235	0,02678	0,46106	0.6448
atm*wp	-0,04404	0,00848	-5,19203	0.0000
pax*wc	-0,03907	0,00777	-5,02819	0.0000
pax*wm	0,04737	0,02143	2,21030	0.0271
pax*wp	0,02863	0,00731	3,91843	0.0001
cgo*wc	-0,00175	0,00268	-0,65286	0.5139
cgo*wm	-0,02679	0,01046	-2,56109	0.0105
cgo*wp	0,00755	0,00248	3,04843	0.0023
rev*wc	0,00621	0,00417	1,48921	0.1365
rev*wm	0,00950	0,00947	1,00359	0.3157
rev*wp	-0,02364	0,00373	-6,34461	0.0000
wm*wc	-0,10656	0,00493	-21,6228	0.0000
0.5*wm*wm	0,11806	0,02912	4,05429	0.0001
0.5*wc*wc	0,10042	0,00535	18,7592	0.0000
wm*wp	-0,01318	0,00443	-2,97406	0.0030
wc*wp	-0,01789	0,00456	-3,92259	0.0001
0.5*wp*wp	-0,02607	0,00958	-2,72254	0.0065
atm*pax	0,02656	0,00375	7,07701	0.0000
0.5*cgo*cgo	0,00651	0,00265	2,45270	0.0142
0.5*rev*rev	0,02067	0,00473	4,36863	0.0000

El siguiente paso, una vez que la especificación ha sido elegida, es formular todo el sistema teniendo en cuenta principalmente los efectos asignativos definidos a través de el vector de precios sombra propuesto por Kumbhakar (1997). Adicionalmente, se considera que el sistema se beneficiará de cualquier información adicional que los datos y la teoría económica puedan proporcionar. Por lo tanto, como ningún problema de singularidad puede aparecer en la estimación Bayesiana, las tres ecuaciones de participación en costes correspondientes a cada uno de los inputs especificados y obtenidas mediante la aplicación del lema de Shephard serán incluidas en el modelo. Por último, hasta ocho restricciones paramétricas es necesario imponer para garantizar la homogeneidad lineal en el vector de precios. La especificación final es la siguiente:

$$
\begin{aligned}
\ln TC_{it}^{a} = {} & \alpha_1 + \alpha_2 atm + \alpha_3 pax + \alpha_4 cgo + \alpha_5 rev + \beta_6 wc + \beta_7 wm + \beta_8 wp + \gamma_9 atm*wc + \\
& + \gamma_{10} atm*wm + \gamma_{11} atm*wp + \gamma_{12} pax*wc + \gamma_{13} pax*wm + \gamma_{14} pax*wp + \\
& + \gamma_{15} cgo*wc + \gamma_{16} cgo*wm + \gamma_{17} cgo*wp + \gamma_{18} rev*wc + \gamma_{19} rev*wm + \gamma_{20} rev*wp + \\
& + \delta_{21} wm*wc + \delta_{22} 0.5*wm*wm + \delta_{23} 0.5*wc*wc + \delta_{24} wm*wp + \delta_{25} wc*wp + \\
& + \delta_{26} 0.5*wp*wp + \rho_{27} atm*pax + \rho_{28} 0.5*cgo*cgo + \rho_{29} 0.5*rev*rev + \\
+ & \beta_7 \xi_m + \beta_8 \xi_p + \gamma_{10} atm*\xi_m + \gamma_{11} atm*\xi_p + \gamma_{13} pax*\xi_m + \gamma_{14} pax*\xi_p + \gamma_{16} cgo*\xi_m + \\
& + \gamma_{17} cgo*\xi_p + \gamma_{19} rev*\xi_m + \gamma_{20} rev*\xi_p + \delta_{21} \xi_m*wc + \delta_{22} wm*\xi_m + \delta_{22} 0.5*\xi_m*\xi_m + \\
& + \delta_{24} \xi_m*wp + \delta_{24} wm*\xi_p + \delta_{24} \xi_m*\xi_p + \delta_{25} wc*\xi_p + \delta_{26} wp*\xi_p + \delta_{26} 0.5*\xi_p*\xi_p + \\
& + \ln(G_{it}) + u_{it} + v_{it}
\end{aligned}
$$

$$
S_C^a = \frac{\beta_6 + \gamma_9 atm + \gamma_{12} pax + \gamma_{15} cgo + \gamma_{18} rev + \delta_{21} wm + \delta_{23} wc + \delta_{25} wp + \delta_{21} \xi_m + \delta_{25} \xi_p}{G_{it}}
$$

$$
S_M^a = \frac{\beta_7 + \gamma_{10} atm + \gamma_{13} pax + \gamma_{16} cgo + \gamma_{19} rev + \delta_{22} wm + \delta_{21} wc + \delta_{24} wp + \delta_{22} \xi_m + \delta_{24} \xi_p}{G_{it} * e^{\xi m}}
$$

$$
S_P^a = \frac{\beta_8 + \gamma_{11} atm + \gamma_{14} pax + \gamma_{17} cgo + \gamma_{20} rev + \delta_{24} wm + \delta_{25} wc + \delta_{26} wp + \delta_{24} \xi_m + \delta_{26} \xi_p}{G_{it} * e^{\xi p}}
$$

$$
\begin{aligned}
G_{it} = {} & [\beta_6 + \gamma_9 atm + \gamma_{12} pax + \gamma_{15} cgo + \gamma_{18} rev + \delta_{21} wm + \delta_{23} wc + \delta_{25} wp + \delta_{21} \xi_m + \delta_{25} \xi_p] + \\
+ & [\beta_7 + \gamma_{10} atm + \gamma_{13} pax + \gamma_{16} cgo + \gamma_{19} rev + \delta_{22} wm + \delta_{21} wc + \delta_{24} wp + \delta_{22} \xi_m + \delta_{24} \xi_p] / e^{\xi m} + \\
+ & [\beta_8 + \gamma_{11} atm + \gamma_{14} pax + \gamma_{17} cgo + \gamma_{20} rev + \delta_{24} wm + \delta_{25} wc + \delta_{26} wp + \delta_{24} \xi_m + \delta_{26} \xi_p] / e^{\xi p}
\end{aligned}
$$

$$\beta_6 + \beta_7 + \beta_8 = 1$$

$$
\begin{aligned}
& \gamma_9 + \gamma_{10} + \gamma_{11} = 0 \\
& \gamma_{12} + \gamma_{13} + \gamma_{14} = 0 \\
& \gamma_{15} + \gamma_{16} + \gamma_{17} = 0 \\
& \gamma_{18} + \gamma_{19} + \gamma_{20} = 0
\end{aligned}
$$

$$
\begin{aligned}
& \delta_{21} + \delta_{23} + \delta_{25} = 0 \\
& \delta_{21} + \delta_{22} + \delta_{24} = 0 \\
& \delta_{24} + \delta_{25} + \delta_{26} = 0
\end{aligned}
$$

Respecto al código a utilizar para la estimación WinBUGS:

```
model
{for (k in 1:K){
	u[k] ~ dexp(lambda)
	eta[k] ~ dnorm(0,etasigma)
	allm[k] ~ dnorm(0.0, allmsigma)
	allp[k] ~ dnorm(0.0, allpsigma)}

for ( i in 1:N ) {
	tc[i] ~ dnorm(mu[i], prec)
	scale[i]<-1/(beta[2]+beta[3]+beta[4]+beta[5])
	eff[i] <- exp(-u[id[i]]*exp(- eta[id[i]]*(t[i]-T)))
	mu[i] <- u[id[i]]*exp(-eta[id[i]]*(data[i,30]-T)) + inprod(beta[], data[i, 1:p]) + beta[7]*allm[id[i]] +
beta[8]*allp[id[i]] + beta[10]*data[i,2]*allm[id[i]] +  beta[11]*data[i,2]*allp[id[i]] + beta[13]*data[i,3]*allm[id[i]] +
beta[14]*data[i,3]*allp[id[i]] + beta[16]*data[i,4]*allm[id[i]] +  beta[17]*data[i,4]*allp[id[i]] +
beta[19]*data[i,5]*allm[id[i]] + beta[20]*data[i,5]*allp[id[i]] + beta[21]*data[i,6]*allm[id[i]] +
beta[22]*data[i,7]*allm[id[i]] + beta[22]*0.5*allm[id[i]]*allm[id[i]] + beta[24]*data[i,7]*allp[id[i]] +
beta[24]*data[i,8]*allm[id[i]] + beta[24]*allm[id[i]]*allp[id[i]] + beta[25]*data[i,6]*allp[id[i]] +
beta[26]*data[i,8]*allp[id[i]] + beta[26]*0.5*allp[id[i]]*allp[id[i]] + log(g[i])

g[i] <- g1[i] + g2[i] + g3[i]
g1[i]<- beta[6] + beta[9]*data[i,2] + beta[12]*data[i,3] + beta[15]*data[i,4] + beta[18]*data[i,5] +
  beta[21]*data[i,7] + beta[23]*data[i,6] + beta[25]*data[i,8] + beta[21]*allm[id[i]] + beta[25]*allp[id[i]]
g2[i] <- (beta[7] + beta[10]*data[i,2] + beta[13]*data[i,3] + beta[16]*data[i,4] + beta[19]*data[i,5] +
  beta[21]*data[i,6] + beta[22]*data[i,7] + beta[24]*data[i,8] + beta[22]*allm[id[i]] +
  beta[24]*allp[id[i]])/exp(allm[id[i]])
g3[i] <- (beta[8] + beta[11]*data[i,2] + beta[14]*data[i,3] + beta[17]*data[i,4] + beta[20]*data[i,5] +
  beta[24]*data[i,7] + beta[25]*data[i,6] + beta[26]*data[i,8] + beta[33]*data[i,30] + beta[24]*allm[id[i]] +
  beta[26]*allp[id[i]])/exp(allp[id[i]])

sc[i] ~ dnorm(nu[i], prec)
sm[i] ~ dnorm(pi[i], prec)
sp[i] ~ dnorm(phi[i], prec)

nu[i]<- g1[i]/g[i]
pi[i]<- g2[i]/g[i]
phi[i]<- g3[i]/g[i]

lin[i]<-beta[6] + beta[7] + beta[8]
a[i]<-beta[9] + beta[10] + beta[11]
b[i]<-beta[12] + beta[13] + beta[14]
c[i]<-beta[15] + beta[16] + beta[17]
d[i]<-beta[18] + beta[19] + beta[20]
e[i]<-beta[21] + beta[23] + beta[25]
f[i]<-beta[21] + beta[22] + beta[24]
h[i]<-beta[24] + beta[25] + beta[26]
data[i,1] ~ dnorm(lin[i], 1000000)
zero[i] ~ dnorm(a[i], 1000000)
zero[i] ~ dnorm(b[i], 1000000)
zero[i] ~ dnorm(c[i], 1000000)
zero[i] ~ dnorm(d[i], 1000000)
zero[i] ~ dnorm(e[i], 1000000)
zero[i] ~ dnorm(f[i], 1000000)
zero[i] ~ dnorm(h[i], 1000000)
					}
lambda ~ dexp(lambda0)
lambda0 <- -log(rstar)

for (i in 1:p) {beta[i] ~ dnorm(0.0, betasigma)}
	prec ~ dgamma(a0, a1)}}
```

La primera parte se refiere a los k = 161 diferentes aeropuertos y la estimación de los efectos específicos de cada uno de ellos (ineficiencias). La segunda parte representa a las n = 1069 observaciones. Los costes totales -*tc[i]*- se distribuyen de acuerdo a una distribución normal - *dnorm -,* con toda la frontera como expresión de la media -*mu[i]*-. La codificación de la misma puede acortarse de forma conveniente utilizando la expresión vectorial - *inprod* -. El vector beta incluye todos los 29 parámetros de la frontera y incluyendo la constante (definida como un vector de unos) y todas las interacciones (calculados expresamente en el vector *data*). Un segundo conjunto de datos debe incluir el logaritmo natural de los costes totales como variable dependiente, la variable tiempo, las proporciones de participación en costes, un vector de ceros para la imposición de restricciones a la homogeneidad lineal y un nuevo vector - *id [i]* - que identifica a cada aeropuerto (1-161) para ayudar en la estimación de las ineficiencias.

Los resultados finales se muestran en la Tabla 5.3, donde se indica la media de cada uno de los parámetros así como sus intervalos de confianza al 95%, que permiten evaluar la significatividad de los mismos.

Tabla 5.3 Parámetros de la function de costes de largo plazo.

	mean	*sd*	*MC error*	*2.5%*	*median*	*97.5%*	*start*	*sample*
constant	10.4700	0.0234	1.37E-04	10.4200	10.4700	10.5200	4001	30000
atm	0.1261	0.0364	2.22E-04	0.0544	0.1261	0.1970	4001	30000
pax	0.2742	0.0425	2.42E-04	0.1904	0.2744	0.3572	4001	30000
cgo	0.0730	0.0155	8.82E-05	0.0427	0.0731	0.1031	4001	30000
rev	0.0644	0.0282	1.62E-04	0.0091	0.0644	0.1197	4001	30000
wc	0.3701	0.0061	3.50E-05	0.3581	0.3701	0.3821	4001	30000
wm	0.2918	0.0065	3.97E-05	0.2789	0.2918	0.3045	4001	30000
wp	0.3085	0.0088	5.02E-05	0.2912	0.3084	0.3257	4001	30000
atm*wc	-0.0003	0.0014	7.95E-06	-0.0031	-0.0003	0.0024	4001	30000
atm*wm	-0.0025	0.0014	8.66E-06	-0.0052	-0.0025	0.0003	4001	30000
atm*wp	0.0036	0.0095	5.23E-05	-0.0148	0.0036	0.0223	4001	30000
pax*wc	0.0022	0.0078	4.43E-05	-0.0132	0.0022	0.0177	4001	30000
pax*wm	0.0317	0.0069	3.93E-05	0.0183	0.0317	0.0451	4001	30000
pax*wp	0.0071	0.0126	7.66E-05	-0.0176	0.0071	0.0316	4001	30000
cgo*wc	-0.0008	0.0034	1.79E-05	-0.0074	-0.0008	0.0060	4001	30000
cgo*wm	-0.0082	0.0026	1.36E-05	-0.0133	-0.0082	-0.0031	4001	30000

cgo*wp	0.0014	0.0054	2.77E-05	-0.0092	0.0014	0.0121	4001	30000
rev*wc	0.0014	0.0068	3.68E-05	-0.0120	0.0014	0.0149	4001	30000
rev*wm	0.0241	0.0049	2.52E-05	0.0145	0.0241	0.0338	4001	30000
rev*wp	-0.0366	0.0107	5.77E-05	-0.0575	-0.0365	-0.0158	4001	30000
wm*wc	-0.0949	0.0059	3.46E-05	-0.1064	-0.0949	-0.0833	4001	30000
0.5*wm*wm	0.1089	0.0078	3.95E-05	0.0936	0.1089	0.1241	4001	30000
0.5*wc*wc	0.0876	0.0090	5.30E-05	0.0701	0.0875	0.1054	4001	30000
wm*wp	-0.0117	0.0097	5.91E-05	-0.0308	-0.0117	0.0073	4001	30000
wc*wp	-0.0021	0.0093	5.15E-05	-0.0203	-0.0021	0.0162	4001	30000
0.5*wp*wp	-0.0388	0.0222	1.24E-04	-0.0822	-0.0388	0.0049	4001	30000
atm*pax	0.0316	0.0033	1.88E-05	0.0252	0.0316	0.0381	4001	30000
0.5*cgo*cgo	0.0066	0.0033	1.89E-05	0.0002	0.0066	0.0131	4001	30000
0.5*rev*rev	-0.0032	0.0110	6.40E-05	-0.0247	-0.0032	0.0182	4001	30000

La estimación muestra un buen comportamiento, casi todos los parámetros son significativamente distintos de cero y presentan los signos correctos. Como era de esperar, algunos parámetros relacionados con los precios de los factores pasan a ser no significativas debido a la presencia de la distorsiones asignativas.

La homogeneidad lineal de la función de costes puede comprobarse mediante un test de Wald sobre las restricciones impuestas en el modelo. La hipótesis nula es claramente aceptada como se ve en la siguiente tabla.

Null Hypothesis: Homogeneity	$\gamma(9)+\gamma(10)+\gamma(11)=0$		
	$\gamma(12)+\gamma(13)+\gamma(14)=0$		
	$\gamma(15)+\gamma(16)+\gamma(17)=0$		
	$\gamma(18)+\gamma(19)+\gamma(20)=0$		
Chi-square	0.317671	Probability	0.9886

Por último, la robustez de los parámetros de primer orden de los *atm* y *pax* requiere de una última comprobación debido al gran impacto futuro que tendrán esos valores sobre la estimación del grado de escala y costes marginales. Para ello, el modelo fue reestimado utilizando submuestas de la base de datos a partir de 800 observaciones, pero siempre manteniendo el mismo punto de aproximación al no verse alterada la distribución de tamaños.

no. Obs	800	825	850	875	900	925	950	975	1000	1025	1050	1069
atm	0,0977	0,1022	0,1015	0,0949	0,0999	0,1045	0,1180	0,1277	0,1267	0,1303	0,1319	0.1261
pax	0,2905	0,2880	0,2865	0,2904	0,2825	0,2771	0,2695	0,2678	0,2629	0,2615	0,2615	0.2742

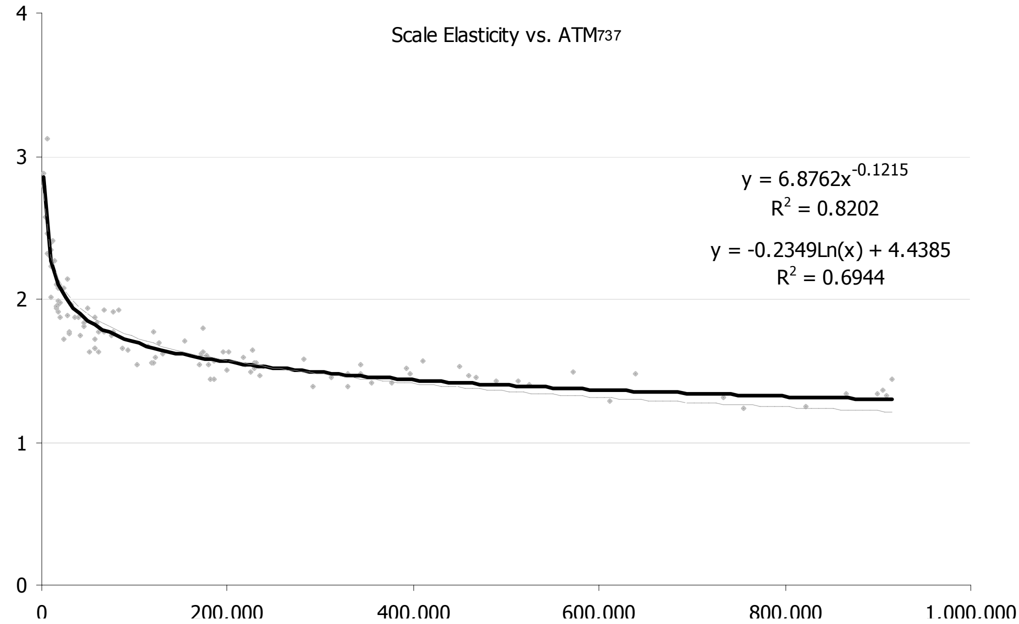
Hay un cierto grado de variación en las estimaciones de los coeficientes, sin embargo, estos valores medios son coherentes con la distribuciones a posteriori de los parámetros que se presentan en el anexo 7a, donde los intervalos de confianza estimados oscila entre [0.05-0.20] para los *atm*, y entre [0.19-0.36] para el coeficiente de *pax*. Por esa razón, la conclusión es que el uso de una amplia base de datos proporciona suficiente variabilidad para permitir el análisis estructural sobre los distintos coeficientes a pesar de la presencia de multicolinearidad.

g. Resultados y conclusiones

En esta tesis, el análisis de resultados se hace en tres capítulos separados, el capítulo 6 se centra en la determinación del grado de economías de escala en las operaciones aeronáuticas así como del cálculo aproximado de la escala mínima eficiente de la industria. El capítulo siete muestra las estimaciones de eficiencia, tanto técnica como asignativa centrando el análisis en ciertos aeropuertos seleccionados como estudios de caso. Finalmente, el capítulo 8 se ocupa de la obtención de los costes marginales de operación tanto de corto como de largo plazo, los cuales serán, con las debidas reservas, considerados como las tasas óptimas de uso de las instalaciones aeroportuarias. En la última sección se comparan éstas tarifas óptimas con los precios efectivamente cobrados por los aeropuertos en Europa, los Estados Unidos y Oceanía.

A modo de resumen, los resultados ofrecen evidencia empírica acerca de la existencia de fuertes IRS en las operaciones aeroportuarias, proporcionando justificación económica de la actual tendencia expansiva de la industria. Para el año 2006, las estimaciones de la elasticidad de escala para el vector de outputs varían entre 4.36 y 1.23 con un valor promedio de 1.75. Utilizando una metodología muy intuitiva, la escala mínima eficiente (MES) se calculó en 2.27 millones de ATMs. Véase Figure 6.2. La conclusión más interesante a sacar de este resultado es que, dentro de la actual frontera tecnológica, los principales aeropuertos del mundo de aeropuertos seguirán beneficiándose de economías de escala en la provisión de infraestructura para el transporte aéreo y actividades comerciales hasta que expandan entre dos o tres veces sus actuales niveles de producción.

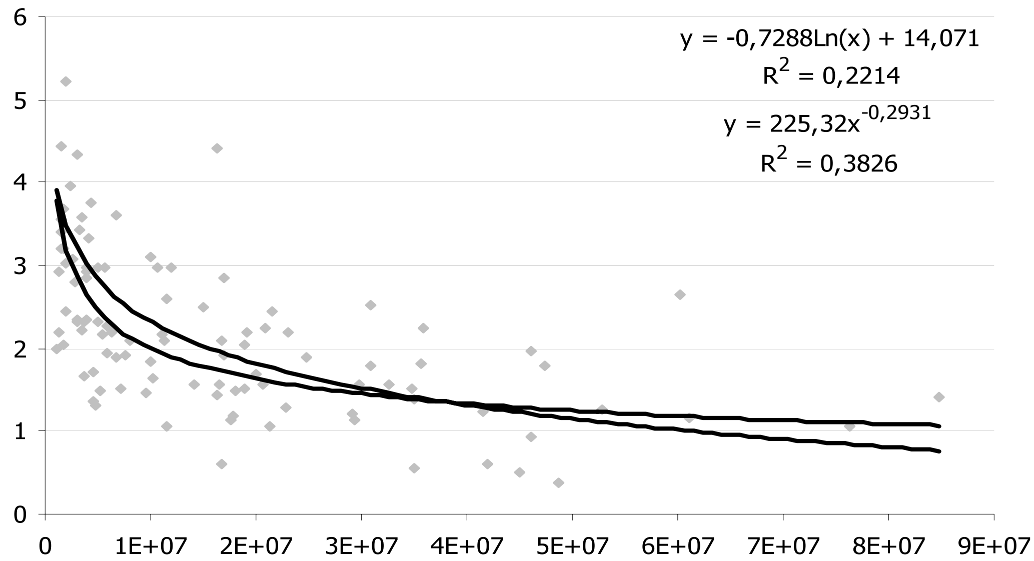
Figura 6.2 Estimaciones individuales de las elasticidades de escala.



Sin embargo, la frontera tecnológica de la industria del aeropuerto se considera que está en constante evolución y por esa razón, una estimación de la MES_t para cada año se obtuvo con el fin de prever una posible revisión de la MES en el futuro. La tendencia decreciente de la MES_t indica claramente que el valor estimado para el tamaño óptimo de los aeropuertos se ajusta continuamente a la adopción de los aviones más grandes y más costosos de utilizar así como a la aparición de nuevas operativas destinadas a agilizar el tránsito de pasajeros en las cada vez más grandes terminales.

Guiado por esa intuición se calculó el grado de economías de escala en la producción de pasajeros. Los resultados indican que los DRS pueden aparecer por encima de 61,5 mppa, que es la escala actual de, por ejemplo, LHR o DFW. Figura 6.3. Dadas las previsiones de tráfico para los próximos veinte años, la aparición de nuevas tecnologías requerirá la estimación de una nueva función de costes, resultando probablemente en una dramática revisión a la baja de la escala mínima eficiente de la industria que, llegado el momento, se encontrará con las escalas observadas en los aeropuertos más grandes.

Figura 6.3 Economías de escala en la producción de pasajeros.



Sin embargo, estos resultados se consideran altamente dependientes de las actividades comerciales. Hay que recordar que el signo negativo del parámetro al cuadrado relacionado con la mencionada variable expande el rango de IRS, dando incentivos a los aeropuertos a expandirse mucho más allá de lo debido gracias a: i) las aparentemente infinitas economías de escala en la producción de ingresos comerciales; ii) la complementariedad con la demanda de infraestructuras aeronáuticas.

Los resultados indican que sin apoyo comercial, la mera puesta a disposición de la infraestructura aeronáutica consume toda su potencial de escala aproximadamente en 1.65 millones de ATMs o 126 mppa. Por lo tanto, si sólo se consideran los costes operativos, la próxima generación de aeropuertos seguirá disfrutando de economías de escala en sus actividades aeronáuticas en el largo plazo.

En cuanto a estimaciones de la eficiencia, los resultados indican que la TE oscila alrededor de 15-18% para el aeropuerto promedio. Además, los costes asociados a la AI puede representar hasta 16% sobre los gastos eficientes, sin embargo, el nivel promedio se ubicó en 6,3%. Sorprendentemente, no se encontró correlación significativa entre el tamaño de los aeropuertos y la eficiencia operativa. Estimaciones individuales de cada aeropuerto en relación con los posibles ahorros de costes pueden ser fácilmente calculadas a partir de sus estimaciones de la IA y TE. Como indica la Tabla 7.1, un aeropuerto pequeño (hasta 5 millones de pasajeros al año) puede perder hasta 4.3 millones de dólares cada año. El típico aeropuerto internacional en Europa (CPH, BRU) puede esperar una pérdida de entre 45 a 80 millones de dólares. Por último, los principales aeropuertos internacionales pueden estar gastando hasta 146 millones de dólares por año por encima de la frontera de costes.

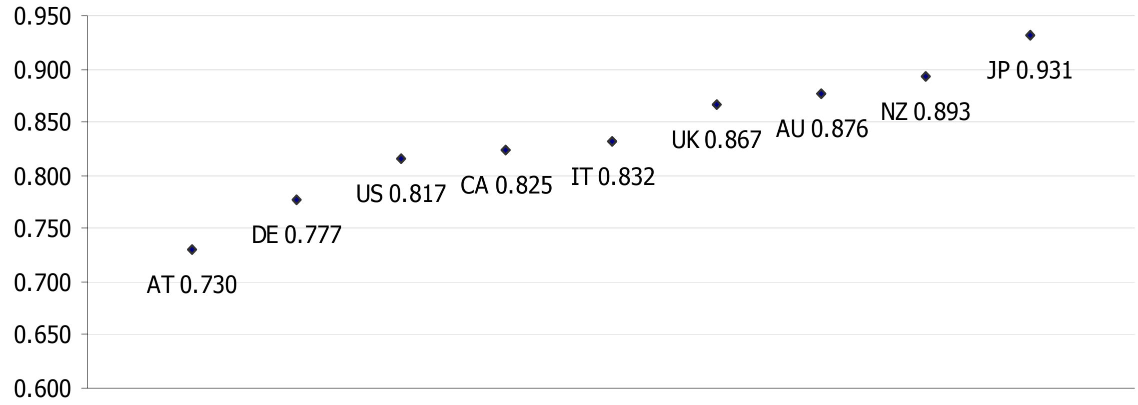
Tabla 7.1 Evolución de la TE y pérdidas estimadas

PAX (mppa)	Avg. TE		Avg. annual losses (million PPP USD)	
	mean	s.d.	mean	range
0 to 1	0.803	0.09	3.64	0.6 - 9.4
1 to 5	0.802	0.07	8.97	1.0 - 16.5
5 to 20	0.826	0.07	33.28	4.4 - 76.6
20 to 40	0.845	0.06	67.24	18.9 - 219.3
40 +	0.842	0.05	110.23	30.6 - 284.0

El análisis de las diferencias en el TE entre los nueve principales grupos geográficos que aparecen en la base de datos resulta en la clasificación de la Figura 7.4. Esto permite evaluar la influencia de muchas variables específicas de los países en la eficiencia operativa de los aeropuertos, como puedan ser la propiedad pública o privada del aeropuerto, su enfoque regulatorio (tasa de retorno vs. precios máximos) o el efecto de la mera localización geográfica sobre el tipo de aeronaves que operan en las instalaciones. Por ejemplo, los aeropuertos públicos (e.g. Austria o Alemania) presentan niveles de eficiencia significativamente menores que el resto del mundo, especialmente en comparación con aquellos países donde la mayoría de los aeropuertos ya se hallan privatizados.

De la misma forma, y de acuerdo con lo establecido en la teoría de la regulación, la imposición de una tasa de retorno máxima (e.g. Estados Unidos) no proporciona los incentivos necesarios para minimizar costes en comparación con el sistema de precios máximos (e.g. Reino Unido y Australia). El uso de mayores aeronaves, especialmente en el tráfico de mercancías también incrementa la eficiencia técnica mediante un más eficiente uso de la capacidad del aeropuerto.

Figura 7.4 Ineficiencia Técnica (media ponderada) por países (2006).



Dichos resultados, conjuntamente con los obtenidos en el análisis de la estructura industrial son contrastados utilizando datos de los 5 sistemas aeroportuarios (MAS) más importantes de Europa. Tabla 7.8. Los resultados indican que la eficiencia conjunta de los mismos ronda entre el 31% y el 74% como consecuencia de la redundancia de infraestructuras. Esto es especialmente grave para el caso de Berlín que cuenta con tres aeropuertos para servir un tráfico total de 18 millones de pasajeros, el cual puede ser asumido por cualquier aeropuerto de tamaño medio. Los costes observados están un 69% por encima de la estimación eficiente.

Table 7.8 Estimaciones de Eficiencia para MAS europeos.

City	Airports	ATM737	Technical Efficiency	Comparable airports	Estimated Savings (PPP USD)
BERLIN	TXL THF SXF	233,659	0.31	0.59 - 0.92	175,549,000
LONDON	LHR LGW STN	1,508,473	0.74	0.79 - 0.98	422,730,000
MILAN	MXP LIN	345,542	0.39	0.63 - 0.93	375,064,000
PARIS	CGD ORY	1,083,926	0.50	0.79 - 0.98	867,429,000
ROME	FCO CIA	391,407	0.50	0.63 - 0.93	315,469,000

Los costes marginales estimados (en promedio) son 304.08, 4.52 y 40.02 PPP USD para *atm*s, pasajeros y carga en toneladas. De la comparación con los precios actuales se concluye que la mayoría de los aeropuertos ejercen su poder de mercado de forma excesiva, apareciendo la necesidad de regulación de precios por parte de las autoridades públicas. De la misma forma se detecta un patrón de subsidios cruzados entre diferentes aerolíneas con el objetivo de crear barreras de entrada.

Finalmente, el coste marginal de producir una unidad adicional de ingresos comerciales (1000 PPP USD) es aproximadamente 160 PPP USD. El resultado indica claramente que los aeropuertos están todavía muy lejos de su nivel óptimo de desarrollo comercial, existiendo por tanto justificación económica para la fuerte tendencia observada hacia la diversificación de este tipo de actividades en las terminales de pasajeros.

h. Conclusiones

El objetivo de este trabajo es proponer una metodología fiable para la estimación de las tasas aeroportuarias óptimas a través de un acercamiento a la frontera tecnológica de la industria. La tarificación de este tipo de infraestructuras siempre ha sido tema central en las políticas de transporte, tanto dentro de la Comunidad Europea como en el resto del mundo. El enfoque más comúnmente aceptado es la tarificación de acuerdo a los costes marginales generados por el usuario. Así mismo, también se busca dar justificación económica a los proyectos de expansión de capacidad con el objetivo de ayudar a una mejor y más eficiente provisión de infraestructuras aeroportuarias. Para ello, un análisis apropiado de la tecnología, especialmente referido a la existencia de rendimientos de escala, es muy importante debido al explosivo crecimiento en la demanda de transporte aéreo. La literatura existente señala que, si el investigador dispone de suficiente información acerca de los precios de los factores productivos, la metodología más apropiada para la obtención de los costes marginales de operación y economías de escala es la estimación econométrica de la función de costes.

La ausencia de suficiente información financiera sobre aeropuertos es el principal problema al que se enfrenta el investigador. Esto explica la relativa escasez de estudios previos sobre este tema, los cuales no ofrecen resultados concluyentes debido al uso de muy distintas y limitadas bases de datos. Esta tesis se basa en un importante esfuerzo de recopilación de información con el objetivo de superar las mencionadas limitaciones. La base datos es un *pool* (no equilibrado) de 161 aeropuertos de todos el mundo entre 1990 y 2006, cubriendo todas las escalas de producción existentes en la actualidad. Las fuentes de información más importantes son los propios estados financieros de las autoridades aeroportuarias así como las estadísticas de tráfico aéreo publicadas por la

Organización de Aviación Civil Internacional (ICAO) y consultadas en el centro de documentación de AENA.

La falta de una metodología específica para la industria aeroportuaria es otro de los problemas que este trabajo intenta solucionar. Primero, la naturaleza multiproductiva de la actividad aeroportuaria se respeta en la especificación de la función de costes, lo cual permite obtener estimaciones de costes marginales específicas de cada uno de los procesos observados, i.e. operaciones de tráfico aéreo (*atm*), pasajeros y mercancías. La consideración de la variable *atm* de forma agregada genera un sesgo importante en las estimaciones debido a que distintas aeronaves imponen distintos costes. De esta forma, si el tráfico de distintas aeronaves es agregado como homogéneo, esto conducirá a una subestimación del grado de escala en la industria. Esto es debido a que el tamaño de aeronave siempre incrementa con la escala de producción (e.g. con el tamaño del aropuerto), imponiendo de esta forma, una estructura creciente en los costes medios. La solución a este problema es muy simple y se basa en homogeneizar las observaciones en términos de un modelo de aeronave que sirva de referencia. Respecto a los otros dos procesos, pasajeros y carga son especificados de forma separada en lugar de utilizar unidades agregadas de tráfico (*wlu*). Los resultados demuestran que el uso de la mencionada variable no es recomendable debido a que los procesos no generan los mismos costes sobre la infraestructura.

El cuarto output especificado son los ingresos comerciales *(rev)* recaudados por el aeropuerto mediante explotación directa o las concesiones que tenga otorgadas. Esto es necesario debido a que las cifras de costes incluidas en la base de datos incluyen los costes no sólo de los factores necesarios para las actividades aeronáuticas sino también los de las actividades comerciales (e.g. el uso de superficie de los edificios terminales). Las prácticas contables no permiten separar ambos tipos de costes y por tanto la inclusión del output mencionado tiene como objetivo minimizar el sesgo de estimación. De no hacerlo existiría un importante riesgo de sobretarificación basada en las estimaciones de costes marginales.

Otra novedad importante esta relacionada con el cálculo de los precios de los factores como input fundamental en la estimación de una frontera de costes. Este ha sido siempre un tema conflictivo en la literatura previa, debido a que los enfoques utilizados eran demasiado simples o carecían de fundamento teórico. En esta tesis, se propone un procedimiento que es consistente desde el punto de vista teórico, aunque también presente ciertas limitaciones relacionadas con los supuestos de competencia de los que parte. De esta forma los precios de los tres factores considerados (trabajo, materiales y capital) se obtienen dividiendo los costes respectivos por índices de cantidad que se asumen correlacionados con las demandas agregadas del factor en cuestión.

Sin embargo, la novedad más importante que este trabajo propone desde el punto de vista metodológico es la estimación de forma separada de las ineficiencias técnicas y asignativas siguiendo el modelo propuesto por Kumbhakar (1997). Dicho modelo utiliza un enfoque de precios sombra para obtener la estimación de las demandas de factor técnicamente eficientes (que son no observadas). Bajo la existencia de dichos precios sombra, las proporciones de factor serían también eficientes de forma asignativa y por lo tanto pueden derivarse mediante la apliación del lema de Shephard sobre la nueva función de costes.

La especificación trasnlogarítmica utilizada para describir la frontera de costes es complementada por las ecuaciones de participación que se obtienen mediante la aplicación del lema de Shephard. El modelo es estimado como un sistema de ecuaciones aparentemente no relacionadas (Zellner, 1962). No obstante, la consideración de la ineficiencia asignativa impone cierto nivel de no linealidad en. Por ello se hace necesario recurrir a métodos numéricos (MCMC) e inferencia bayesiana para llevar a cabo la estimación de los parámetros de la función de costes así como de aquellos relativos a las distribuciones de ineficiencia técnica y asignativa. El software utilizado para la estimación es el WinBUGS (Lunn et al., 2003), utilizando un código basado en Griffin and Steel (2007), donde se describen las bases para la estimación de fronteras de producción y costes utilizando el mencionado software.

Los resultados inciden en la presencia de importantes economías de escala en todos los niveles de producción considerados, no obstante, las mismas de agotan en niveles de producción superiores debido a la presencia de rendimientos decrecientes en la provisión de infrastructuras en el lado tierra (i.e. el tráfico de pasajeros). Este resultado se explica claramente por la necesidad de fuertes inversiones en infraestructuras para el tránsito de pasajeros que no son necesarias en aeropuertos más pequeños. A pesar de ello, la próxima generación de aeropuertos todavía seguirá disfrutando de economías de escala con o sin el apoyo de las actividades comerciales, hasta casi duplicar su capacidad actual.

Respecto a la eficiencia técnica, que sigue una distribución exponencial, los resultados varían (en promedio) entre el 82 y 85%. La comparación entre los distintos clústeres geográficos revela resultados muy interesantes sobre la influencia de ciertas variables de entorno sobre la eficiencia operativa. Por ejemplo, los aeropuertos públicos (e.g. Austria o Alemania) presentan niveles de eficiencia significativamente menores que el resto del mundo, especialmente en comparación con aquellos países donde la mayoría de los aeropuertos ya se hallan privatizados. De la misma forma, y de acuerdo con lo establecido en la teoría de la regulación, la imposición de una tasa de retorno máxima (e.g. Estados Unidos) no proporciona los incentivos necesarios para minimizar costes en comparación con el sistema de precios máximos (e.g. Reino Unido y Australia). El uso de mayores aeronaves, especialmente en el tráfico de mercancías también incrementa la eficiencia técnica mediante un más eficiente uso de la capacidad del aeropuerto. Dichos resultados, conjuntamente con los obtenidos en el análisis de la estructura industrial son contrastados utilizando datos de los 5 sistemas aeroportuarios (MAS) más importantes de Europa. Los resultados indican que la eficiencia conjunta de los mismos ronda entre el 31% y el 73% como consecuencia de la redundancia de infraestructuras.

Respecto a la ineficiencia asignativa, la distribución ajustada a los resultados indica un sobrecoste en torno a un 6% sobre la frontera eficiente. En aquellos países donde la regulación laboral es muy poco flexible, se observan distorsiones asignativas muy importantes en los factores trabajo y materiales. Los costes marginales estimados (en promedio) son 304.08, 4.52 y 40.02 PPP USD para *atm*s, pasajeros y carga en toneladas. De la comparación con los precios actuales se concluye que la mayoría de los aeropuertos ejercen su poder de mercado de forma excesiva, apareciendo la necesidad de regulación de precios por parte de las autoridades públicas. De la misma forma se detecta un patrón de subsidios cruzados entre diferentes aerolíneas con el objetivo de crear barreras de entrada.

Finalmente, el coste marginal de producir una unidad adicional de ingresos comerciales (1000 PPP USD) es aproximadamente 160 PPP USD. El resultado indica claramente que los aeropuertos están todavía muy lejos de su nivel óptimo de desarrollo comercial, existiendo por tanto justificación económica para la fuerte tendencia observada hacia la diversificación de este tipo de actividades en las terminales de pasajeros.