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Cost Allocation of TRansport INfrastructure cost

D9
Allocation of Infrastructure Cost in the Air Transport Sector

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0 Executive Summary

This report highlights the main results obtained in WP6 regarding the allocation of infrastructure cost in air transport sector.

In this deliverable, it has been shown that there are 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. 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, London Heathrow (LHR) or Dallas (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.

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 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 (allocative inefficiency) 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 (technical efficiency) 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.

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 \textit{pax} and \textit{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; and ii) high passenger charges that cross-subsidize the use of airside infrastructures.
1 Introduction

This deliverable follows the structure outlined in the description of work of the project. In particular, it aims to support policy makers and regulator in implementing efficient pricing strategies in the air sector. It is necessary to highlight here that these pricing strategies are based on the social marginal cost principle. As it has been previously explained in other deliverables, CATRIN focuses only on infrastructure costs, that is, on the costs of providing, maintaining, renewing and operating infrastructure, but some note will be made on scarcity and congestion costs whenever possible because it is well know that when airports are highly congested the opportunity costs associated to the scarce slots can be highly significant. A common approach has been used including three distinctive, though interrelated, parts namely: 1) review the current practice extracting lessons that can be studied and analyzed empirically; 2) develop a case study based on the estimation of marginal costs for a group of airports comparing different pricing regimes with actual landing charges; and 3) exchange findings with infrastructure managers synthesizing the results and proposing some policy recommendations.

This report will extend some results obtained in GRACE. First, the database has been extended and new estimations have been obtained with a more sophisticated output specification. The approach to calculate input prices has also been further modified. Second, in CATRIN, marginal cost estimates has been made by types of aircraft and a different output for freight or passenger has also been disaggregated. And finally, as economies of scale are anticipated, it is well known that pricing schemes based on these estimations will provoke commercial deficits in the aeronautical provision of airports. Thus, cross subsidization by commercial activities can be used by airport to get financial sustainability or a further analysis on the allocation of the part of the costs that are not covered by these landing charges can also be further analysed following the club theory approach, but this approach is only commented in theoretical terms and it is out of the scope of the present report.

This document is organised as follows. Chapter 2 summarises the current practices and lessons from D3. In chapter 3, the theoretical background and the previous literature will be presented and summarized. Chapter 4 will show the database, the model specification and the marginal cost estimations for a group of European airports. Chapter 5 will discuss the air traffic control charges and Eurocontrol organization. In chapter 6, congestion and scarcity costs will be discussed theoretically. Chapter 7 will conclude.
2 Aviation. Current practices and lessons\(^1\)

Many European cities and their surrounding regions see international airports as a vital infrastructure to maintain an important source of competitive advantage on the region. Airports provide essential infrastructure to support regional social and economic growth as well as being commercial entities in their own right, capable of generating returns on investment to their shareholders, and to society as a whole. Most Regional Governments understand that more air services in their region can generate substantial economic benefits. Nevertheless, even being certain all above mentioned, it is necessary to affirm that airports and of course charging systems have radically changed, and such a revolution has fundamentally three causes:

1. Airline liberalization at the beginning of the 1990s. It was inevitable that airline competition would lead to airport competition. Airport managers lost their market power, and it meant that pricing policies could no longer be presented to airlines on “take or leave” but on “whatever it takes” approach. That means: for new entrants the opening bid was frequently to seek zero charges or discounts as high as 90%.

2. Competition brought falling fares and also a huge increase of air traffic demand (The projected average annual rate of growth was 4.8% between 1998 and 2005, and will be 4.0% between 2005 and 2010, according to IATA’s European Air Traffic Forecasts 1985-2015)

3. Tendency to the privatization in airports’ property and management supposed a drastic withdrawal of public financing. So the urgent needs of undertaking capacity expansions along with the public constrained budgets promoted the private firms to take part, assuming for them a profit maximizing behaviour.

As a result, airports can not be considered nowadays like mere infrastructure providers, running under state protection, but more commercially-driven businesses, self financed and operating as if they were in the private sector. Deregulation of airlines in Europe has produced in the last years important changes in the evolution of the interface airline-airport. New routes of low-cost airlines have taken advantage of the excess of capacity that some secondary airports of Europe presented, and the European passengers have shown with their signals their willingness to move to these new airports for a considerable reduction of prices. The airports should respond to this trend recognizing that the easy life of the past days of non-competing airlines and airports before deregulation have gone. Barrett (2000) examined the economics of competition between airports in Europe in the context of airline deregulation. He discussed the history of airports in Europe not engaging in competition and the reasons proffered for non-competing airports before airline deregulation in Europe. The world of non-competing airlines was mirrored in the world of non-competing airports. However, it is true that the full agenda of the market forces may not be fully complied in the near future but this trend will be difficult to be stopped and competition between airports and terminals within airports will be the norm rather than the exception in the near future.

The privatization of the BAA in 1986 had an expanding effect in the rest of the world. Nichols et al. (1999) showed how the corporatization and privatization of airports has been increased since then, and that there were 60 privatized airports in 1999 and this figure will be increased in the following years. They found the process most advanced in Europe and Latin America, virtually complete in the UK, in full swing in Germany and Italy, and under way in Spain, Portugal, India, Thailand, Australia, the Caribbean and South Africa.

\(^1\) This chapter is partly based on the review conducted in GRACE (Bonsall et al., 2005)
Besides, and considering that the growth in air traffic demand is leading to capacity pressures, a strong response by airports is required in order to ensure sustainable development. And one of the capital questions which the sector has faced concerns to financing issues. The basic fund stream is obtained by charging the different activities that are developed inside the airport facilities, and the main clients using the airports are the airlines and their passengers. In some cases, revenues from aeronautical activities fall short of the costs incurred in providing these services. Hence, airports decided on new sources of income, giving the same importance to both aeronautical and non-aeronautical activities (shopping areas, restaurants, lodging, rent-a-car, and other concession activities.). The classical definition of an airport’s client has been radically altered to include the concessionary companies. Today, non-aeronautical revenues represent over 50% of total airport income in some airports.

The problem arises when these airports’ commercial revenues are generating the profits that are used to subsidize aeronautical charges levied on airlines. This phenomenon appears frequently when there exists price regulation on airports following a scheme known as single-till. Under this scheme the entire airport’s revenues are taken into account when setting levels of charges, thus, Regulatory Asset Base (RAB) incorporates all kind of airport’s assets. This formula was elaborated at a time when most airports were receiving state subsidies for expansion programs of infrastructure, but nowadays some authors consider it as outdated and inappropriate (Forsyth, 2003; Lu and Pagliari, 2004).

Many airports have become private companies or do operate as if they were. It is now widely accepted that the single-till mechanism is a disincentive to maximising non-aeronautical revenues, dually speaking, this mechanism may also dilute the airport’s incentive to minimise non-aeronautical costs. As a consequence, some important allocative inefficiencies appear for very congested airports, because the low aeronautical charges artificially exacerbates the scarcity costs of slots, appearing then a erroneous signals of lack of capacity (Starkie, 2001). Furthermore, it distorts investment decisions, because the existence of crossed subsidies makes difficult to estimate the “true” returns of the aeronautical assets.

The alternative mechanism to regulate prices in airports is the dual-till approach in which commercial revenues are not factored into the charges equation, resulting in higher and not subsidized prices for airlines. However, this method is more consistent with the new ICAO standards and the White Paper for 2010, which defends the user-pays principle, by means of which the optimal level of prices must exactly reflect the marginal cost of using the facilities. Thus, commercial activities cannot be used to cross-subsidy aeronautical activities and the allocation of costs is more concordant with the user-pays principle.

Looking at the four largest hub airports in Europe, we can see that Heathrow and Paris are airports regulated under the single-till approach; meanwhile Fraport and Schiphol Group operate on a dual-till scheme. At Frankfurt, although a dual till is in operation, airport charges do not fully cover costs and other revenues are used as subsidies. In the UK and Australia, there exists an important debate about the convenience of reviewing the present regulatory schemes. The UK’s CAA claims for dual-till arguing that such a system would deal efficiently with excess demand by setting prices that reflect both the costs and the scarcity of airport facilities. Although under the CAA's proposals, the Competition Commission stated that the single till philosophy should be maintained at Heathrow until Apr. 2008, but charges would be higher thereafter than under a pure single till approach.

There is always a tormentor relationship between airports and airlines. Airlines usually complain about the non-risk at airport business and that airports usually obtain profits in spite of the turbulence of the air transport business. As in many other industries that are characterized by consecutive markets, airports and airlines usually compete for the economic rents of the location advantages that exist in the “catchment’s area” of an airport. Airlines
want to share some of the revenues that are originated from retail activities that airports have recently developed. Normally, airlines have been favoured by the “single-till” approach paying low aeronautical prices. Grahan (2001) expressed the idea that in BAA airports, those airlines that carried long-haul passengers, who contributed more than short haul ones to non-aeronautical revenue, should logically enjoy greater single-till subventions, so in order to maximize revenues two issues have great importance: the demand complementarity between aeronautical and non-aeronautical activities vs. price discrimination.

Hence, the efficient management of an airport will always demand to maintain a balance between these two complementary activities: aeronautical and non-aeronautical, and it will always be under pressure and scrutiny of the airlines with respect to charges and investments. Airlines and airports’ business cycles diverge, and for this reason, it is necessary to coordinate airlines’ short-term investment plans (six months to two years) with airports’ long-term investment cycle (10-30 years); as well as to constantly improve the policy for setting airport charges.

In some airports within Europe, aeronautical charges are subject to a certain form of economic regulation. One of the most interesting forms of price regulation is the price-cap regime (also known as RPI-X regulation), which is currently applied in Ireland, London BAA airports, Manchester, Hamburg, Vienna and Copenhagen. It is a well-known form of price regulation that has been extensively applied to natural monopolies. Prices are calculated in the following way: the operator is forced to set charges within the maximum levels of increase/decrease determined by the formula (RPI-X). Where RPI represents the change in the retail price index, and X is generally considered to be a productivity factor, which could be positive if the industry is expected to operate more efficiently in the future, or negative if not.

In other countries, this price regulation is not applied and rates are established by national law, for example, in France, Spain and Portugal. And its evolution uses to obey, in many cases, to the different transport policies that are proposed by the local governments and approved by the Parliament after a consultation period. The logic behind this system is that airports have been traditionally considered as public services, and they had to run under national or regional government ownership and frequently were managed together as a national group such as AENA in Spain or ANA in Portugal.

2.1 A simplified overview of the current practice

The recommendations of international organizations (ICAO and IATA) regarding airport cost coverage include the application of average costs as the basic price. In addition, these organizations sought to establish a uniform fare structure for the whole industry. Dividing incurred costs by the number of processed traffic units provides a unitary tariff. Several fares for each service could be obtained with this procedure by distinguishing among the different components of total cost. Given that all users pay the same amount for the utilization of the same services, most airlines support this mechanism as objective and fair. However, the reality is that different operators impose different costs, and therefore should face different charges. For example, an airline that operates during peak periods imposes a cost (capacity cost) that is higher than others who operate during off-peak periods. There is a need to find a way to incorporate this and other industry particularities into the actual fare system within the context of regulation.

The similarity of fare structures found at the majority of airports rests on the fact that most countries follow ICAO and IATA guidelines. Both organizations seek a uniform pricing system, recommending the utilization of aircraft weight as the basis for the estimation of applicable charges. The basic airport pricing structure corresponds to a landing fee calculated according to aircraft weight, plus a departure fee for passengers.
UN’s International Civil Aviation Organization (ICAO) publishes periodically some guidelines. They are the only ones that provide financial and economic orientation for aviation service providers. These guidelines are not binding and represent the collected practices of a majority of the States and are used as authoritative guidance by airport operators worldwide.

Regarding to the establishment of independent mechanisms for the economic regulation of airports and air navigation services, “Such a mechanism, and its objectives could be drawn or adapted from, but need not be limited to, the following principles” (inter alia)

1. Non-discrimination in the application of charges;
2. No overcharging or other anti-competitive practice or abuse of dominant position;
3. Ensure transparency to determine the basis for charges;

Concerning charges collection it is essential that “a transparent cost recovery system with a fair and equal treatment of all users” be up-to-date. So “that the users shall ultimately bear their full and fair share of the cost of providing the airport”. In determining the cost basis for charging policies, the following should be applied:

1. The cost to be shared is the full cost of providing the airport, including cost of capital and depreciation of assets, maintenance, operation, management and administration.
2. Airport users should not be charged for facilities and services they do not use.
3. The cost of facilities exclusively leased or occupied and charged for separately should be excluded.
4. The proportion of costs allocable to various categories of users, should be determined on an equitable basis.

This should make possible, that airports’ revenues cover all direct and indirect operating costs and provide for a reasonable return on assets to contribute towards necessary capital improvements.

The increasing involvement of the private sector in airport activities has broken somehow the uniformity of pricing structures around the world, leading to a more efficient pricing system at privatized airports. For a private firm, coverage of actual costs, as well as the coverage of those costs generated by future investments in additional capacity is of critical importance. The actual pricing structure upon which regulatory devices are applied must be consistent with additional capacity investment so that corresponding costs are also covered. Since the allotted period to recover the investment is quite long, the regulator should permit price variations during the investment period with the aim of adjusting costs and generating revenue. However, among the various problems that a regulator might encounter are the difficulty of establishing credible commitments and the need to develop a deep knowledge of the operations and opportunities of a privatized airport.

The selection of the initial price structure will be the basis for the application of the regulatory mechanism. It should be an adequate guideline for future investment and also ensure the efficient allocation of resources. Economic theory states that if the price is established according to the service marginal cost, an efficient allocation of resources among users is obtained. The paid fare reflects the true service value, and those who are not willing to pay are not served. However, those airports that generally operate below available capacity present a very small marginal cost and are not to produce enough revenue to cover total costs. In the airport industry, a great number of costs are sunk, or there are historical costs that do not conform to the service marginal cost. Therefore, the strict application of a charging policy that
follows the marginal cost criterion would inevitably lead to financial losses for those airports that operate below available capacity, and optimal prices may be not possible to apply. Airport charges cover services and infrastructure which are related to the aircraft movement areas, that include aircraft parking areas, airfield lighting, airside roads lighting, airside safety and aviation supervision, fire brigade, grounds, runways, taxiways, aprons, nose-in guidance/visual navigation aids and signposting; and to the passenger processing areas, that include departure and holding lounges, immigration and customs service areas, landside roads and lighting, public areas in terminals, lifts/moving walkways, security systems, signage and flight information systems. These charges are usually differentiated from other activities, such as, ground-handling and purely commercial areas. To simplify and systematize the grade of differentiation that actually exists in the charges of the airports, we will classify these different charges into six broad categories, plus one additional with comprises those special discounts offered:

1. landing charges;
2. passenger charges;
3. parking charges;
4. other aeronautical charges;
5. handling charges;
6. non-aeronautical charges or commercial activities; and
7. rebates and incentives.

### 2.1.1 Landing Charges

In ICAO’s Airport Economics Manual, the landing charge is defined as follows: “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 and their associated vehicles and equipment, including the expense of all labour, maintenance materials, power and fuels”. These charges must be paid by airlines or any person or company who perceive the services described before, it levies either departing flights or arriving ones or both. Sometimes, a charge is paid at landing and it covers the subsequent take-off.

ICAO also states that “…Any noise-related charge should be associated with the landing fee, possibly by means of surcharges or rebates…” Sometimes, noise and emissions are levied separately of landing, but, there are many cases, wherein these concepts are indivisibly included in Runway charges formulas.

Generally, these charges are based on two main variables: The maximum take-off weight (MTOW\(^2\)) of the aircraft using the airport facilities, and other characteristic, such as the geographical location of the origin or destination of the flight\(^3\), the use of the aerobridge or a remote stand, or any other issue that discriminate the aircraft movements according to some specificity.

Regarding this last item, charges may differ for different periods of time or season (peak and off-peak charges), noise or emissions. Peak and off-peak charges are the result of the cost

\(^2\)The Maximum Total Weight Authorised of the aircraft is usually measured in metric Tons, but in some airports the formula is reduced to three different categories of aircraft that depend on this variable.

\(^3\) In the Spanish case of AENA, this categorization is done according to whether the flight is domestic (EU), international, mainland EU-island, or inter-insular connection.
differences that exist for different periods of time. Usually, the runway fees are considerably higher during peak periods, as a result of the asymmetric distribution of traffic movements that regularly congest the airport during peak hours (raising operational costs\(^4\)). Besides the main purpose of peak pricing that is to reflect the opportunity cost of the slots during the peak periods, other important consequence of applying this pricing policy is to make a better use of the existing capacity. It also helps in managing new capacity investments signals levying the WTP users, and so avoiding discrimination and cross-subsidization of one airport user group by another.

Regarding noise and emissions differences it can be seen that in some airports a different landing fee is charged by day and night flights\(^5\), and that this measure is often combined with noise categorizations of the aircraft. Engine NOx and Hydrocarbons emissions of aircraft (measured in Kg and published by ICAO) are used by BAA airports to charge landing fees. ICAO establishes the following principles for noise charging:

1. It should be levied only at airports experiencing noise problems and should be designed to recover no more than the costs applied to their alleviation or prevention.

2. Noise-related charges should be non-discriminatory between users and not be established at such levels as to be prohibitively high for the operation of certain aircraft.

The general purpose of such a tax, however, seems to be similar for all the countries where it is of application. It is imposed for financing “Noise Protection Programs” passing all incomes generated from this surcharges to a separate fund segregated from the airport charges account. We can find it in Germany\(^6\) (Düsseldorf, Frankfurt or München), in Sweden, or in Amsterdam Schiphol, where this fee is collected on behalf of the national treasury. It is used for installing noise monitoring systems, as well as insulation programs for buildings in particularly affected zones.

Noise violations across Europe will be hard penalized by surcharging. In Manchester, as an example, aircraft not meeting the chapter 3 requirements will not be scheduled at night. Apart of this a noisy surcharge is also levied over certain limits measured in PNdB (Perceived Noise Levels). In France, “les coefficients de modulation acoustique” are applied on the base runway fee. They depend on aircraft noise levels and five weighting factors corresponding to aircraft groups.

Usually, the basic charging schemes calculate the landing fees as a charge per metric ton or part thereof, and as an exceptional case, the Airport of La Valetta (Malta) declares that its two-part runway fee will be assessed in “per 500 kgs or part thereof”.

Another possibility is that charges were expressed in terms of fixed rates for each weight category, depending on a classification of aircrafts. This scheme is also very common in the calculus of the noise surcharges, for example in the BAA airports.

\(^4\) An interesting estimation of this difference states that an international peak passenger costs at Heathrow were £25.69 - £29.52 while off-peak passengers would only cause costs of £0.76 - £0.92 (in 1982/83 prices). Source: CAA (2001)

\(^5\) As an example, in Riga and Milan an additional 20% or 50% of runway charge is levied, respectively, for each landing made during night hours (23.00-06.00).

\(^6\) Frankfurt was the first airport in Germany to introduce noise landing fees on the basis of data captured by its own aircraft noise-monitoring system. Under the new pricing system, aircraft have been assigned to seven different noise categories. The fees charged increase significantly from categories 1 to 7. [from 33 to 25.200 €]. The goal of this charge is to give the airlines an adequate signal to serve with the quietest and most modern aircraft.
In Sweden, we find a two-part tariff, with a fixed section and then a unitary charge per ton which varies depending again on a classification of the aircraft according to their weight. In Köln we find that the variable part of the runway charges includes also a weight factor.

In Italy we found a two MTOW steps and Portugal network gives a three MTOW steps rule. In this way, only the exceeding tons pay a higher unit rate. In Greece, LC are assessed by a “weight factor” (WF) system. In France and Brussels, “multifactor schemes” are applied and the airports use different noise and environmental coefficients.

In summary, the Table 1 shows the different variables included in the calculus of the landing charges and the basic schemes that are applied for some European airports.

### Table 1. Summary of Landing Charges

<table>
<thead>
<tr>
<th>Summary of variables</th>
<th>Summary of commonest schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Relatives to the aircraft:</td>
<td>1) &quot;per ton or part thereof&quot; or “per commenced” one.</td>
</tr>
<tr>
<td>• MTOW (metric tons)</td>
<td>$RC = R \cdot (MTOW)$</td>
</tr>
<tr>
<td>• Noise level (PNdB)</td>
<td></td>
</tr>
<tr>
<td>• Emissions (Kg NOx)</td>
<td></td>
</tr>
<tr>
<td>• Propelled or Jet Aircraft</td>
<td></td>
</tr>
<tr>
<td>2) Relatives to the flight</td>
<td>2) “fixed rates” $RC = R$</td>
</tr>
<tr>
<td>• Origin or Destination:</td>
<td>3) “two part” ($V$ is a fixed amount) $RC = F + \left[ V \times (MTOW) \right]$</td>
</tr>
<tr>
<td>• Domestic International</td>
<td>Kölnere Variation: $V = W \times (400-MTOW)$</td>
</tr>
<tr>
<td>• Type: Passenger or cargo</td>
<td>Sweden: “two part” $RC \times E$ (emissions coef.)</td>
</tr>
<tr>
<td>• Scheduled / Out of hours</td>
<td>4) “by steps” $RC = A \times R + (B - A) \times S + (MTOW - B) \times T$</td>
</tr>
<tr>
<td>3) Relatives to the time:</td>
<td>5) “weight factor” (Athens) $RC = W \times R; \quad W = MTOW \times (120 / MTOW)^{0.4}$</td>
</tr>
<tr>
<td>• Peak/ off peak</td>
<td>6) “multifactor” $N= noise \ coefficient; \quad D = Day/night \ factor [1 \ or \ 2]$</td>
</tr>
<tr>
<td>• Day/ night</td>
<td>French Airports (also in Munich): $LC = R \times (MTOW) \times N$</td>
</tr>
<tr>
<td></td>
<td>Brussels: $R \times MTOW \times N \times D$</td>
</tr>
</tbody>
</table>

### 2.1.2 Passenger Charges

Passenger charges are related to the infrastructure and the services provided at terminals either as facilitation or as security charges. (ACI Europe, 2003). They are also cost based charges, intended for recovery purposes.

Infrastructure charges are also known as “Passenger facility charge” (PFC), and they are applied by the use of areas inside the terminal buildings that are non-accessible to the visitors, as well as by the complementary facilities. The security charges are applied by the provision of the inspection and control services 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 that are used for the calculus of these charges are the boarding passenger and their destination. Regarding this last item, in Portugal or Paris an interesting passenger classification exists, in which the passengers are divided according to Schengen flights, Non-Schengen intra-EU, International and flights between islands.
In Italy, it is common to apply a rebate in the infrastructure part for children (2-12). Transfer and transit passengers\(^7\) pay different fees in the majority of the airports. In other cases, passenger fees may vary depending on the flight type (Regular or Charter), or the season (Summer or Winter). In some other cases, passenger fees may be differentiated by different existing terminals inside the airport facilities.

A unit rate per boarding passenger is the commonest scheme. Today it is very common that these charges appear in the airline ticket.

### 2.1.3 Parking Charges

These charges are applied by the use of the aircraft’ parking zones or hangars qualified to this end. It is a necessary condition that, during the parking or hangar periods, the aircraft does not conduct any ground operation.

ICAO recommends that Maximum permissible take-off weight and/or aircraft dimensions (area occupied) and length of stay should be used so far as possible as the main variables that reflect the cost drivers. In Ireland, a two-variable typology, differentiating between “Wide or Narrow body” aircraft\(^8\) and the “contact” or “remote” stand location, is used.

The basic schemes use different unitary rates depending on the MTOW of the aircraft or two part tariffs, in which number of hours or days are common variables. For example, in Spain, light aircraft has “2 MTOW steps-fixed rates”, and heavy aircraft “3 steps - unit rates per ton”. In UK, the basic scheme follows a “two-part” tariff based on the number of parking hours, or a unitary daily rate that depends on aircraft’s weight. In most of the airports consulted in the sample, the airlines enjoy a free parking period that varies across Europe from the first 90 min. to six hours.

Hangar charges are calculated as unit rates per m\(^2\) per day, but it must be remarked that, in most airports, a maximum hangar period of 3-6 months exists. Other schemes consist in calculating the parking fees as a percentage of the corresponding landing fees.

### 2.1.4 Other Aeronautical Charges

These charges are applied by the provision and utilisation of infrastructure facilities and installations which are used for the traffic control or for the supply of ground handling services (Navigation, 400hz, 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 air traffic control services within the different Flight information regions (FIR), but these fees will be further explained in the respective chapter.

The use of lighting will be usually included in the runway charge, but this makes reference to the special equipments. Milan airports distinguish between to types: “Centre lighting” and “touch-down zone” with fixed amounts per landing /movement.

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\(^7\) A Transfer Passenger means a passenger arriving from another airport (‘airport of origin’) on one flight who departs aboard a different flight number on the same ticket to an airport or city other than the airport or city of origin, provided that the scheduled time of departure of the second flight is not more than 5 hours after the scheduled time of arrival of the first flight. A Transit Passenger means a passenger who arrives in and departs from the airport on the same flight number and aircraft (except in the event of aircraft substitution due to operational problems).

\(^8\) A wide-body aircraft has a fuselage diameter of about 5 to 6 metres. Passengers are usually seated 7 to 10 abreast and two aisles are common. For comparison, a traditional narrow-body airliner has a diameter of 3 to 4 metres, a single aisle, and seats arranged 4 to 6 abreast. Typical wide-body aircraft can accommodate between 200 and 600 passengers, where the largest narrow-bodies carry about 280.
The aerobridges are charged by the use of those infrastructures destined to facilitate boarding and disembarkation of passengers to/from the aircraft through telescopic aerobridges. Regarding the variables, we find peak/off peak considerations, and a standard turnaround time has been defined for different aircraft, such as narrow body (60 minutes) and wide body (90 minutes). The basic scheme is commonly expressed as a “fixed rate for the first 60 (NB) or 90 minutes (WB)” plus an “unit rate per each of the following 15 minutes period or fraction”. In some cases, it is also levied by fixed rates per flight.

The provision of 400 Hertz transformed electrical energy to the aircraft is usually calculated depending on aircraft MTOW. However, it is also expressed as a “fixed rate for the first hour” plus an “unit rate per each of the following 15 minutes period or fraction”. In Switzerland it is charged depending on the wingspan category.

### 2.1.5 Handling Charges

Council Directive 96/67/EC on access to the ground handling market at Community airports ensures minimum standards of access to ground handling at all European airports with at least two million passengers annually. However, the Directive does not ensure free and unimpeded access to any interested supplier because it only prescribes that the number of third party providers should not be fewer than two, of which at most one may be controlled by an incumbent airline.

Since this Directive, many airports have outsourced these activities to independent companies, and for this reason, these charges may be seen in the corresponding section of commercial activities. However, there are also an important number of airports that still retain these activities on their hands. In these cases, airports usually perceive all-inclusive fixed charges per aircraft (taking into account its MTOW), and per departing passenger (Central infrastructure charges). Ramp Handling, Passenger Transport Services, Cargo Handling and Baggage Handling are services included in this category.

Ramp Handling include the provision of stairs (Fixed or hydraulic), ballast sacks, security personal, start up equipments, and push back services. The charges are usually expressed as “unit rates per flight”, “per sack” or “per person-hour”. Some German airports establish different unit rates per type of aircraft depending on its number of seats.

Transport Services provide transport at ramp (by bus or microbus). Here, two schemes are the most popular, one consists in a fixed renting charge for the vehicle, and the other applies different unit rates per type of service depending on 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 for outbound/inbound freight. The basic unit is the air waybill (AWB) - air consignment note, distinguishing between Export and Import activities.

And finally, baggage handling comprises different activities such as, baggage classification, Check-in Desks Services, Common User Equipment Charge, Baggage Security (X-ray screening). The charges are usually paid by each departing terminal passenger or directly “per bag”.

### 2.1.6 Non-Aeronautical Charges. Commercial Activities

We have seen that some activities can be classified as aeronautical(handling) or non-aeronautical depending on the form in which the activities are organized. For example, we saw that 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 under a scheme that may be seen in this section.
Table 2 shows how the different non-aeronautical activities may be furthered classified into administrative concessions, commercial concessions, licences of use and supplies.

Lands and paved surfaces are charged for the use of land surfaces, urbanized or not, as well as the paved surfaces yielded in concession, being on behalf of the concessionaire any other cost by consumptions, services or provisions derived from his activities. The main variable distinguishes between urbanized and not-urbanized lands and paved surfaces, as well as the airport’s category (in networks cases). Basic scheme supposes the payment of an “unitary rate per month per m2”.

Offices, premises and commercial desks are usually charged for annual periods, taking into account the location of the premises (preferential vs. not-preferential). The basic scheme is also based on unit rates per square meter. There are also some surcharges for shorter periods of time. In the larger airports day-hiring is also allowed, and in these cases, two-part tariffs are common in which the fixed part covers a first period of time (usually two hours) and the variable part charges an additional unit rate for every hour or part thereof.

Check-in desks’ charges include the use of weighing conveyor, counters and screens that check-in personnel use. The scheme is based on standard annual charges that are expressed as “unit rate per month per desk”. Sometimes there are price differentiation by type of desks than include the image of the airline, or some other premises.

The commercial concessions rights are commonly regulated by private contractual agreements. But, regarding commercial activities some airports apply a “two part” price scheme. The fixed part is usually based on the land/office/desks lease charges, and then, every activity has its own variable part that is normally calculated as some x per cent of the turnover per employee of the concessionaire. Travel Agencies and Rent a Car offices follow this scheme.

The basic price scheme of Vip/cip business lounges is a two-part tariff, in which the variable part depends on the number of passengers that use the lounge.

The Left- luggage charge depends on the type of the locker (big or small) and the time period of use.

Filming follows a two part tariff scheme, in which the variable part depends on the total amount of time. The fixed part usually covers the administrative procedure to allow access to the personnel of the company, and high surcharge for filming and recording at runway or apron areas are usually applied. Portuguese airports even differentiate between publicity, cinema/TV or institutional recordings.

Advertising charges usually depend on the advertising support and it is usually paid by fixed fees on a monthly basis, except for those supports that are susceptible to be charged according to their dimensions and potentially impact, in which unit rates per m2 per day/month are usually common.
Access to restricted zones is charged according to a fixed fee per entrance, but, in some airports, it is also common to charge by annual or monthly tickets. Most airports issue ID cards, with fixed amounts for renewal or lost/stolen replacement.

The charges for car/bus parking are usually based on a two-part tariff scheme, in which the fixed part usually cover a minimum period of time (1-2 hours) and the variable part is charged according the rest of the time used in the facility. There are also airports that differentiate according to the distance to the airport between different parking lots: remote and terminal side. In Sweden, the parking price for the buses that stop at the terminals depends on the size of the vehicle and its environmental classification (Euro class). For buses that arrive more than X-times per year, it is possible to sign special agreements.

The supplies are charged depending on a surcharge of the real value of supplies, services, materials and products provided directly or indirectly by the airport, and the use of the airport property and the facilities and equipment needed to render them. They are usually measured and charged for periodic periods of time.

2.1.7 Rebates and Incentives.
In all the airports included in the study, it has been observed that managers have always the discretion to abate or waive any charge for any specified category of traffic and/or when they consider it is in the interest of the airport company to encourage the development of traffic at the airport. For example, the Runway Charges may be reduced for specific flight purposes, such as, crew training or test flights.

BAA has also rebates in some short distance or double stop flights in Scotland). In BAA airports an automatic rebate in passenger charges for all aircraft using remote stands exists. Manchester reduces off 25% of parking charges for those airlines scheduled to operate at least 364 days a year. Aircraft operators performing flights to/from smallest airports can even obtain reductions depending on the number of passengers carried during a year. A similar rebate may also be found in Berlin-Schönefeld.

There are also special rebates for new routes, the replacement of the aircraft used in some specific routes, more frequent flight to the same destination and the transfer to new facilities or other terminal buildings.

2.2 Marginal social costs and the relationship with congestion and scarcity costs.
There is clear evidence that efficient prices are more likely with airports and airlines operating under the pressure of market forces. The prices are not monopoly prices and an airport does not have unfettered control over prices for a number of reasons. An airport provides services to a broad range of customers with differences in their demand elasticities. Just as airlines practice yield management, the practice of segmenting the market by placing restrictions on fare classes and being able to vary fares with the number and type of restrictions, so too could and would airports. They have to allocate their costs, traceable and non-traceable, across all user groups. Second, airport services are a derived demand by carriers and other commercial aviation interests. Their demand is contingent on the demand for their product. To the extent they operate in competitive markets, which airlines do, the ability of airports to increase prices is limited. At a practical level, airports face competition from other airports and other modes, in the short to intermediate term. In the longer run, communications is a substitute. Third, there is inter-airport competition for many of the airports in Europe as we have seen in the introduction, for example, Heathrow, Stansted, Gatwick, Luton and City; Glasgow and Prestwick, Manchester, Liverpool and Leeds, Brussels and Charleroi, and Rome and
Ciampino. The ability of an airport to increase its prices will be constrained by an airline's ability to move to another airport and simply feed from the previous centre. Having a uniform price for all users does simply create a structure of cross-subsidies that is difficult to sustain. So the differentiation that may be necessary to

However, insufficient runway capacity cause major airports delay problems around the world. Disequilibrium between capacity and demand has been explained by failure to properly price runway use. Charges at most airports are proportional to aircraft weight and invariant with respect to time of day. This practice disincentives airlines to consolidate traffic onto large planes, and also ignores the loss in capacity that comes from the greater in-trail separation requirements and slower approach speeds of small aircraft.

Airport slot allocation is necessary when demand for airport’s services exceeds its capacity. This may be resolved in different manners, through congestion causing important economic inefficiencies, or through more efficient mechanisms to allocate the scarce capacity, such as slot auctions. Slot allocation issues have been discussed greatly in the literature, while these issues are really important it is necessary to take into account the strong links that exist between slot allocation and slot pricing mechanisms. Many airports have been privatised and subsequently disposed to regulation to avoid the exertion of monopoly power. Price regulation restrains the levels of prices an airport may charge, and for this reason it may not be possible to rely entirely on price mechanisms to ration the airport capacity.

Levine (1969) argues that pricing is a better means of allocating scarce airport capacity than other mechanisms being considered at the time, such as slot allocation. However, the literature review shows that aeronautical charges are usually far from being optimal and for this reason airport prices are not a good mechanism to allocate the scarce capacity of airports. Carlin and Park (1970) estimated the marginal delay costs at various airports, concluding that in many cases these exceed actual charges by a factor of 10. Morrison (1983) computed optimal landing charges and investment levels at several US airports, finding similar disparities between actual charges and short-run marginal costs, but somewhat smaller ones when long-run marginal costs (which assume optimal runway capacity) are considered.

Doganis (1991) examines the impacts of peak pricing at London Heathrow Airport on airline schedules, finding that changes in the time period when peak charges were in effect resulted in the anticipated shift in flight schedule. Barret et al. (1994) considers the effect of a hypothetical peak-period pricing scheme –in which all capacity-related airline costs are allocated to peak period operations- on airline schedules for Boston’s Logan Airport. They argue that effects on jet airline schedules would be negligible because the cost differences would be less than $1.00 per passenger. Commuter flights, on the other hand, would face substantial increases in cost per passenger during peak periods, which would in some cases lead to flight cancellations. Altogether, they estimate that the proposed pricing scheme would decrease peak period flights by 7 percent but peak period seats by only 3 percent. Daniel (1995), focusing on hub airports where flight schedules of arrivals and departures are more complex, proposes a bottleneck model (as originally proposed by Vickrey (1969)) in which airlines trade delay against the cost of scheduling flights away from peak times. The model assumes that, in the absence of differential pricing, the sum of delay and schedule deviation cost is equal throughout the peak. Adding a fee that reflects external congestion costs (as estimated using a stochastic queuing model with time-dependent demand) induces a more even schedule and a 50 percent reduction in delays. Hansen (2002) analyzed runway delay externalities at Los Angeles International Airport (LAX) using a deterministic queuing model. The model estimates the delay impact of each specific arriving flight on each other specific arriving flight. He found that, despite being only moderately congested (average queuing delay only 4 min per arriving flight), individual flights can generate as much as 3 aircraft-
hours of external delay impact on other flights, with an average impact of 26 aircraft-minutes and 3400 seat-minutes. About 90 percent of this impact is external to the airline as well as the flight, a consequence of the lack of a dominant airline at LAX. He also compared the delay impact of each individual flight to its contribution to schedule convenience by determining the amount of "schedule delay" that would result if the flight were eliminated and its passengers forced to use the previous flight flown by the same airline from the same origin, finding that a number of commuter flights serving high density, short-haul segments generate much more queuing delay than they save in schedule delay, with the ratio exceeding 10 in several cases. Thus, he argued that social welfare would increase if such flights were eliminated, upsizing others as necessary to accommodate the displaced loads.

So the above examples show that airport need to internalize some externalities that are not internalized by the private airlines, and passengers, such as, delays and noise externalities. For this reason, it is necessary that the costs models have an input of these issues for each aircraft that lands or takes-off at/from the airport. So the differentiation on different aircraft, based on noise, emission, congestion and different costs of use of runways is necessary in order to calculate prices that allocate the resources efficiently. In the same way, different passengers’ charges may be applied to departing, arriving and transit passengers. However, a discussion in the chapter of the empirical model will be provided showing that the econometric approach is not a satisfactory method due to the restrictions of data availability. The estimation of a cost function considering all the characteristics of inputs and output is an utopia, so this can be seen as a first approximation and other methods based on engineer processes can be used to complement this approach.

### 2.3 Slot allocation mechanisms

It is relevant to mention that current slot allocation schemes are really controversial, and airport charges that cleared the market for landing slots are frequently invoked as a better mechanism to promote more efficient outcomes.

However this issue is not exempt from criticisms, because it is not necessarily true that airport operators are the best option to reap the scarcity rents, and other important facts are not analyzed in this context, such as, congestion externalities and revenue complementarities for non-aeronautical activities.

So, it is necessary to explore in more detail some issues relating to efficient rationing of scarce airport slot capacity. Though allocation of slots has particular relevance to congested airports, where airports experience excess demand for some facilities at certain times of day; capacity constraints will become of greater importance to almost all the airports in the future whether due to exogenously-imposed air traffic movement limits (e.g. curfews), environmental air traffic movements limits (e.g. noise restrictions) or possible consequences of price regulation on new investment.

Nowadays, traffic at most busy airports outside US is rationed by slot allocation systems. The most common system is based in the creation of scheduling or slot coordination committees, where some capacity limit for the airport is declared to reduce congestion to a certain level. The problem then is how to allocate slots or how airlines bargain with each other for use of them. Typically this issue is resolved by “grandfathering ”, whereby slots are allocated giving incumbent airlines some privileges according to a prior use of the airport in previous periods. This method has been one of the most controversial topics in air transport economics and not exempt of strong criticism for anti-competitive concerns. For this reason, some countries have introduced some special clauses “use it or lose it”, where airlines lose the slot if they do not use it above 80 percent of the time. This clause tries to impede some strategic action of incumbent airlines in order to deter the entry of new competitors. However there are four
airports in the US that have gone further, where slots for domestic flights were auctioned and can be bought and sold for money. The airports following this approach are Chicago O’Hare, New York Kennedy, New York La Guardia and Washington National.

We will probably see a more increased emphasis on market forces as a way of organizing production and distribution within the airport industry. A great number of countries will move in the direction of privatizing their airports. In 1987 the British government converted the BAA into a private company, BAA plc. However, since then several different forms of privatization have taken place in other countries. These include long term leases of airports to private firms, contract operations of airports, creation of new terminal facilities by private sector builder/operators, development of local airport authorities (LAA), and the creation of new airports as private business ventures.

A concern and argument of those opposed to privatization is that capital costs will be higher than those of government owned airports. The use of tax-exempt municipal, regional or state bonds that are used in some countries reduces interest expense and hence overall capital costs. However, while the tax exempt status represents a financial saving, it does not represent a true economic saving. It has simply distorted the relative returns between airport investment and other investments; the result may be too much airport capacity in a given region vs other type of investments.

So, the rationale for the move to privatization, or one of the variants discussed earlier, is the market forces should signal, finance, and create new airport investments as well as expansion of existing capacity. Future developments will facilitate new mechanisms to achieve operating cost savings with improved efficiency and reduce capital costs through more efficient pricing while at the same time being sensitive to the needs of customers, passengers, and airlines. Of course, there would be contrary voices which will signal that market forces cannot be advocated to organize airports sector because of important market failures will prevail in this sector, such as, externalities, monopoly, and "public good" issues even in spite of alleged efficiency gains from privatization.

The allocation of landing and taking-off slots at Community airports is regulated by Council Regulation No. 95/93. The purpose of which is to ensure an efficient distribution of slots in a transparent and open manner. This regulation, which is still in force today, is broadly based on well-established slot scheduling procedures devised by the International Air Transport Association (IATA). However, the Commission has recently proposed a modification of the Regulation in order to:

- clarify the legal nature of slots.
- promote efficient allocation of slots through clear rules on methods and procedures, better definition of airport capacity and transparent, neutral procedures of consultation and mediation.
- encourage the efficient use of slots.
- enhance competition between incumbent carriers and new entrants.

The problem with most allocation systems is that they are arbitrary, and for this reason there is no guarantee that the scarce slots are allocated to those who have the highest willingness to pay for them, so it is possible that some allocation systems could create some allocative inefficiencies. However, it has been argued that auctioning and trading are preferable to “grandfathering” because competition could be more effective due to the fact that new airlines could enter into the market without having any existing slot; and it gives the airlines the option of trading into the market some slot rather than deliberately running an unprofitable route so as to avoid application of the “use it or lose it” clause.
2.4 Summary and lessons learned.

The recommendations of international organizations (ICAO and IATA) regarding airport cost coverage include the application of average costs as the basic price. In addition, these organizations sought to establish a uniform fare structure for the whole industry. Dividing incurred costs by the number of processed traffic units provides a unitary tariff. Several fares for each service could be obtained with this procedure by distinguishing among the different components of total cost. Given that all users pay the same amount for the utilization of the same services, most airlines support this mechanism as objective and fair. However, the reality is that different operators impose different costs, and therefore should face different charges. For example, an airline that operates during peak periods imposes a cost (capacity cost) that is higher than others who operate during off-peak periods. There is a need to find a way to incorporate this and other industry particularities into the actual fare system within the context of regulation.

The increasing involvement of the private sector in airport activities broke the uniformity of pricing structures around the world, leading to a more efficient pricing system at privatized airports. For a private firm, coverage of actual costs, as well as the coverage of those costs generated by future investments in additional capacity is of critical importance. The actual pricing structure upon which regulatory devices are applied must be consistent with additional capacity investment so that corresponding costs are also covered. Since the allotted period to recover the investment is quite long, the regulator should permit price variations during the investment period with the aim of adjusting costs and generating revenue. However, among the various problems that a regulator might encounter are the difficulty of establishing credible commitments and the need to develop a deep knowledge of the operations and opportunities of a privatized airport.

There still exists an important debate about the pros and cons of the different approaches that have been applied in the past to the economic regulation of airports. In fact, many of the most important private airports have been re-regulated in Australia, the UK and New Zealand in the last years. Policy makers and regional planners are usually confronted to whether it is preferable to adopt a single-till or dual-till approach.

However, the convenience of such regulatory schemes has been put under scrutiny. It has become evident that some price-caps at congested airports have resulted in a reduction of price-capped charges for aeronautical activities to levels below short-run marginal costs. Other problems are more implicitly linked to the retail activities which can be or not formally excluded from the scope of the price caps. The range of airport activities subject to regulation may be extended without an explicit mention if the price caps take into account the retail revenues when determining the admissible charges. And finally, at non-congested airports the price-caps may not be effective and charges could be optimal.

As we have also seen, airports essentially have three sources of revenue. Land rental for industrial use on or adjacent to the airport is relatively stable from year to year. Similarly, concession revenue, generally a percentage of sales, does not vary significantly from year to year in congested hub airports. Airport/terminal revenue does vary with the volume of traffic. At most major airports this does not vary much. Therefore, revenue in aggregate is relatively stable over time. Hence, since airports cannot affect revenue except over the longer term, they must focus on costs as a means to increase profits.
3 The theoretical background and the state of the art of the econometric approach

3.1 The theoretical background

3.1.1 The technology

The technology is the most basic concept that represents the productive process of a firm. Given a vector $X$ of $r$ inputs available to the firm and a vector $Y$ of $n$ possible outputs, the technology available to the firm $T$ is defined as the set of feasible pairs such that $Y$ can be produced from $X$. More precisely:

$$T = \{(X,Y) / Y \text{ can be produced from } X \}$$  \hspace{1cm} (1)

The technology is a nonempty closed subset of $\mathbb{R}^r \times \mathbb{R}^n$ that satisfy the regularity properties: i) $(0,Y) \in T$ if and only if $Y = 0$, and ii) if $(X,Y) \in T$, $X^1 \geq X$ and $Y^1 \leq Y$ then $(X^1,Y^1) \in T$. These two conditions state that positive inputs are required to produce positive outputs and that an increase in input use makes possible at least a weak increase in output. Given these conditions, there exists a continuous transformation function $F(X,Y)$, non decreasing in $X$ and non increasing in $Y$ such that $F(X,Y) \geq 0$ if and only if $(X,Y) \in T$ (see McFadden (1978)). The technical optimality is reached in 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 (see Jara-Díaz, 1982).

In the case of single output production, $Y$ is represented by an scalar and the transformation function can be expressed in terms of the production function $f(X)$, thus $F(X,Y) = f(X) - Y$.

3.1.2 The cost function

If we assume that firms in the industry are price takers in input markets, the multiproduct cost function is defined as the minimum cost incurred by the firm to produce the output $Y$ at input prices $\omega$ given the technology $T$. Thus the firm faces the problem of finding the set of inputs that minimize the expenditure needed to produce $Y$.

$$\text{Min}_{X} \omega X = \omega_1 X_1 + .... + \omega_r X_r$$

subject to:

$$F(X,Y) \geq 0 \quad \text{or} \quad ((X,Y) \in T)$$

The solution of this problem is represented by the vector of conditional input demands $X^*(\omega,Y)$ and it is reached in the boundary of $T$, i.e., when $F(X,Y) = 0$. Thus the multiproduct cost function is obtained by replacing $X^*$ on the objective function in problem (2).

$$C(\omega,Y) = \omega X^*(\omega,Y) = \omega_1 X^*_1(\omega,Y) + .... + \omega_r X^*_r(\omega,Y)$$  \hspace{1cm} (3)
This is usually known as the long run cost function, that means that all inputs may vary in the time period considered. If some inputs are restricted to be fixed, then the short run cost function \( C(\omega, Y, \mathbf{X}) \) is obtained from problem (2).

### 3.1.3 Economies of scale.

Let us consider the case of one single output and the production function in the frontier \( Y = f(X) \), i.e., \( Y \) is the maximum output obtained from \( X \). If all the inputs are expanded proportionally in the factor \( \lambda \) with \( \lambda > 1 \), the amount of output obtained can be represented by \( f(\lambda X) = \lambda^S Y = \lambda^S f(X) \). Thus, returns to scale in the technology are classified into the following categories:

i) Increasing returns to scale (or scale economies) when \( \lambda > 1 \). This means that the output increases in a proportion higher than \( \lambda \), i.e., \( f(\lambda X) > \lambda f(X) \).

ii) Decreasing returns to scale when \( \lambda < 1 \). This means that the output increases in a proportion lower than \( \lambda \), i.e., \( f(\lambda X) < \lambda f(X) \).

iii) Constant returns to scale when \( \lambda = 1 \). This means that the output increases in the same proportion \( \lambda \), i.e., \( f(\lambda X) = \lambda f(X) \).

Therefore, the size of \( S \) determines the degree of scale economies in the technology.

The concept of returns to scale can also be interpreted looking at the cost function. Thus, if the firm uses \( \lambda X \) to produce \( \lambda^S Y \) then, the cost incurred by the firm is:

\[
C(\omega, \lambda^S Y) = \sum_r \omega_r \lambda X_r, (\omega, Y) = \lambda \sum_r \omega_r X_r, (\omega, Y) = \lambda C(\omega, Y)
\]

Differentiating (4) with respect to \( Y \) yields:

\[
\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} \frac{\partial (\lambda^S Y)}{\partial Y} = \lambda \frac{\partial C(\omega, Y)}{\partial Y}
\]

\[
\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} \lambda^S = \lambda MC(\omega, Y)
\]

\[
\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} = \lambda^{1-S} MC(\omega, Y)
\]

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

Differentiating (4) with respect to \( \lambda \) yields:

\[
\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} \frac{\partial (\lambda^S Y)}{\partial \lambda} = \lambda^S C(\omega, Y)
\]

\[
\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} S \lambda^{S+1} Y = \lambda^S C(\omega, Y)
\]

\[
\frac{\partial C(\omega, \lambda^S Y)}{\partial \lambda^S Y} = \lambda^{1-S} C(\omega, Y) \left( \frac{\partial C(\omega, Y)}{\partial Y} \right) = \lambda^{1-S} \frac{AC(\omega, Y)}{S}
\]

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

From (5) and (6) we obtain
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:

$$\frac{\partial AC(\omega,Y)}{\partial Y} = \frac{\partial (C(\omega,Y)/Y)}{\partial Y} = \frac{1}{Y^2} \left( \frac{\partial C}{\partial Y} Y - C \right) = \frac{1}{Y} \left( \frac{\partial C}{\partial Y} - \frac{C}{Y} \right) < 0 \iff$$

$$\left( \frac{\partial C}{\partial Y} - \frac{C}{Y} \right) < 0 \Rightarrow \frac{\partial C}{\partial Y} < \frac{C}{Y} \iff$$

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

It is worth mentioning that it is not quite correct to analyze the existence of economies of scale based upon whether the average cost is decreasing\(^9\). (see the example shown in Panzar (1989) where a decreasing average cost function for a given level of output exhibits constant returns to scale). Thus we can state that increasing (decreasing) returns to scale implies decreasing (increasing) average cost, but the converse is, in general, not true.

An important consequence of the existence of economies of scale is that producing the total output with two or more firms generates a higher cost than producing it with one single firm. 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, if $Y^M$ is the amount of output that represents the size of the market, the cost of producing $Y^M$ with a single firm is represented by:

$$C(\omega,Y^M) = AC(\omega,Y^M) \cdot Y^M$$

Let us consider $j$ firms producing $Y^M$ with $Y^M = \sum_j Y^i$ being $Y^i$ the output produce by firm $j$.

The total cost of producing $Y^M$ with $j$ firms is represented by:

$$\sum_j C(\omega,Y^i) = \sum_j AC_j(\omega,Y^i) \cdot Y^i$$

In the presence of scale economies, the average cost is decreasing and therefore for a given firm $AC_j(\omega,Y^i) > AC(\omega,Y^M)$, thus:

$$\sum_j C(\omega,Y^i) = \sum_j AC_j(\omega,Y^i) \cdot Y^i > \sum_j AC(\omega,Y^M) \cdot Y^i = AC(\omega,Y^M) \sum_j Y^i = AC(\omega,Y^M) \cdot Y^M = C(\omega,Y^M)$$

yielding:

$$\sum_j C(\omega,Y^i) > C(\omega,Y^M)$$

Therefore, the cost of producing the total output with a single firm is lower than producing it with two or more firms.

In the case of multiple output the concept of marginal cost is defined for each different product, thus,

\(^9\) An equivalent argument can be stated for the case of decreasing and constant returns to scale.

\(^{10}\) Note that a function $f$ is decreasing if and only if $f' \leq 0$. 

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represents the marginal cost of product \( Y_i \). However, the average cost is not defined in this case provided \( Y \) is a vector. In this case, it is possible to analyze variations in the production of a composite good represented by an output vector.

Let the vector \( Y^0 \) represent a basic unit of output level, then the vector \( \lambda Y^0 \) with \( 0 < \lambda < \infty \) represent an output level which keeps the proportion of output components constant and equal to \( Y^0 \), i.e., \( \lambda Y^0 \) lies in the ray through the origin and \( Y^0 \) in the output space. The ray average cost represents the behavior of the cost function when the output vector is expanded proportionally according to the factor \( \lambda \) (i.e., along the ray \( \lambda Y^0 \)) and is defined as:

\[
RAC = \frac{C(\omega, \lambda Y^0)}{\lambda}
\]

(11)

Let us define \( r \) such that \( (X, Y) \in T \Rightarrow \exists r > 0 \) such that \( (\lambda X, \lambda^r Y) \in T \) with \( \lambda > 1 \). Then the multiproduct degree of scale economies \( S \) is defined as the maximum proportionate growth rate of outputs along their ray, as all inputs are expanded proportionally. In other words, \( S \) is the supreme of \( r \) in the former expression. Increasing, constant or decreasing returns to scale exist when \( S \) is greater, equal or less than 1.

The multiproduct degree of economies of scale \( S \) can be obtained from the cost function as follows:

Differentiating (4) with respect to \( Y_i \) yields:

\[
\frac{\partial C(\omega, \lambda Y)}{\partial \lambda Y_i} \frac{\partial (\lambda^s Y_i)}{\partial Y_i} = \lambda \frac{\partial C(\omega, Y)}{\partial Y_i}
\]

\[
\frac{\partial C(\omega, \lambda Y)}{\partial \lambda Y_i} \lambda^s = \lambda MC_i(\omega, Y) = \lambda m_i
\]

\[
\frac{\partial C(\omega, \lambda Y)}{\partial \lambda Y_i} = \lambda^{1-s} m_i \quad (12)
\]

Differentiating (4) with respect to \( \lambda \) yields:

\[
\sum_{i=1}^{n} \frac{\partial C(\omega, \lambda Y)}{\partial \lambda Y_i} \frac{\partial (\lambda^s Y_i)}{\partial \lambda} = C(\omega, Y)
\]

replacing (12),

\[
\sum_{i=1}^{n} \lambda^{1-s} m_i \lambda^{s-1} Y_i = C(\omega, Y)
\]

\[
S \cdot \sum_{i=1}^{n} m_i Y_i = C(\omega, Y)
\]

\[
S = \frac{C(\omega, Y)}{\sum_{i=1}^{n} m_i Y_i} = \frac{C(\omega, Y)}{\sum_{i=1}^{n} \frac{\partial C(\omega, Y)}{\partial Y_i} Y_i}
\]

(13)

It is straightforward to show that in the case of one single output expressions (13) and (7) coincide.
From (13), the multiproduct degree of economies of scale can be expressed in terms of the elasticities of the cost function as follows:

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

Where \( \eta_i \) is the elasticity of the cost function with respect to product \( Y_i \).

Complementarity in production refers to the convenience or not of producing two or more outputs in conjunction. Thus, it is interesting to study the behavior of \( C(\omega, Y) \) as the level of production of a particular product \( Y_i \) varies keeping the rest of the bundle at some positive level, i.e., the incremental analysis. Hence, the incremental cost of producing \( Y_i \) in addition to a given bundle is defined as:

\[ IC_i(\omega, Y) = C(\omega, Y) - C(\omega, Y_{-i}) = C(\omega, Y) - C(\omega, Y_{i},..., Y_{-i}, 0, Y_{i+1},..., Y_N) \]

(14)

The average incremental cost is defined as:

\[ AIC_i(\omega, Y) = \frac{IC_i(\omega, Y)}{Y_i} \]

(15)

and the degree of scale economies specific to product \( Y_i \) is defined as:

\[ S_i(\omega, Y) = \frac{IC_i(\omega, Y)}{Y_i \frac{\partial C(\omega, Y)}{\partial Y_i}} = \frac{AIC_i(\omega, Y)}{AIC_i(\omega, Y)} = \frac{AIC_i(\omega, Y)}{m_i} \]

(16)

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

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

(17)

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

### 3.1.4 Economies of scope and subadditivity.

The cost function \( C(\omega, Y) \) is said to be subadditive at \( Y \) if for any vectors \( Y^1, Y^2, ..., Y^k \) such that \( \sum_{i=1}^{k} Y_i = Y \) we have \( C(\omega, Y) < \sum_{i=1}^{k} C(\omega, Y^i) \). Subadditivity then means that one firm can produce \( Y \) cheaper than any combination of two or more firms, that is, a natural monopoly exists.

Economies of scope (see, Panzar and Willig, 1975) are said to exist over the product set \( N \) at \( Y \) if and only if

\[ C(\omega, Y) < \sum_{i=1}^{k} C(\omega, Y_i) \]

where \( R \) 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
Thus $SC_R(\omega,Y) > 0$ implies the existence of economies of scope, i.e., it is not convenient to split the output vector into $Y_R$ and $Y_{N-R}$, and $SC_R(\omega,Y)$ can take a value between -1 and 1 (note that $0 \leq C(\omega,Y_R), C(\omega,Y_{N-R}) \leq C(\omega,Y)$).

From (17) and (18) we can find the following relationship between economies of scale and scope:

$$S(\omega,Y) = \frac{\alpha_RS_R(\omega,Y_R) + (1-\alpha_R)S_{N-R}(\omega,Y_{N-R})}{1 - SC_R(\omega,Y)}$$

(19)

Where $\alpha_R = \frac{\sum_{j \in R} Y_j \frac{\partial C(\omega,Y)}{\partial Y_j}}{\sum_{j \in N} Y_j \frac{\partial C(\omega,Y)}{\partial Y_j}}$.

Equation (19) indicates that in the absence of economies of scope, scale economies could be represented by a weighted average of product specific scale economies. However if $SC_R(\omega,Y) > 0$, the denominator in (19) is less than one 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 increasing returns to scale. Finally, the existence of sufficiently big scope economies could yield scale economies even in the case of decreasing returns to scale specific to $R$ and $N-R$.

3.1.5 Cost complementarity

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 $\bar{Y}$ if

$$\frac{\partial^2 C(\omega,Y)}{\partial Y_i \partial Y_j} = \frac{\partial m_i}{\partial Y_j} = C_{ij}(\omega,Y) \leq 0, \ i \neq j \text{ for all } 0 \leq Y \leq \bar{Y},$$

with the inequality strict over a set of output levels of nonzero measure.

The presence of weak cost complementarity implies that the marginal cost of producing any one product $j$ does not increase with increases on the quantity of any other product $i$; therefore the production of $j$ is favored with the production of $i$ and conversely. It can be shown that the existence of weak cost complementarity is a sufficient condition for economies of scope to be present at $\bar{Y}$ (see the demonstration in Panzar, 1989).

\[\text{Note that } C_{ij} = C_{ji}\]
3.1.6 Transray analysis

Another way to deal with cost advantages of output bundle is through the analysis of $C(Y)$ on a hyperplane defined by $\sum_i \mu_i y_i = \mu$ with $\mu_i > 0$ and $\mu > 0$. We will say that a cost function is transray convex at $Y$ if

$$C(kY^a + (1-k)Y^b) < kC(Y^a) + (1-k)C(Y^b) \quad 0 < k < 1$$

For $Y^a$ and $Y^b$ contained in the hyperplane through $Y$ (Jara-Díaz, 1983). The presence of transray convexity favors the production of many products by one firm instead many firms producing a subset of products. Geometrically, this consist in analyzing the convexity of the cost function restricted to the hyperplane through $Y^a$ and $Y^b$. Transray convexity works in favor of cost subadditivity while transray concavity works against it.

3.2 The state of the art

Only a few studies have dealt with the costs of airport infrastructure services, and that the use of very different data and methodologies provides inconsistent findings, mainly related to a partial view of the airport activity, especially while dealing with the output definition; and the difficulty in collecting comparable data across different airports size and location. As a very first approach, Keeler (1970) estimated two Cobb-Douglas partial cost functions for both capital and operating costs, using air transport movements (ATMs) as the output variable. He used 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 by the study’s partial rather than total approach. Doganis and Thompson (1973, 1974) estimated a Cobb-Douglas cost function, and also parameterized models for capital and operating costs separately, using work load units (WLUs) as the output variable. They used a cross-section of 18 British Airports for 1969. However, this work suffers of the same limitations as Keeler.

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. 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 labour, equipment, and residual factors, capital stock, passengers per ATM, percentage of international passengers, percentage of terminal capacity used, and a time trend.

Main et al. (2003) estimated four Cobb-Douglas cost functions, using WLUs or passengers as the output measure, and including depreciations or not. Other explanatory variables were the 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 used 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.

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 an output index. Additionally, he used a similar aggregated input index (excluding capital costs) and a cost-of-living index as a proxy for the factor price. This study used a cross-sectional

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12 Tolofari (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.

13 1 WLU is equivalent to 1 passenger or 100kg of cargo (Doganis, 1992).

A recent study (Oum et al., 2008a) analyses the effect of ownership forms on airport cost efficiency by applying Stochastic Frontier Analysis over 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 was estimated using a similar procedure to the one used in this paper through MCMC under a Bayesian framework.

### Table 3: Cost function studies in the airport industry

<table>
<thead>
<tr>
<th>Study</th>
<th>Functional form</th>
<th>Data</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tolofari et al. (1990)</td>
<td>Translog</td>
<td>Panel of 7 BAA airports, 1979-1987</td>
<td>WLU</td>
</tr>
<tr>
<td>Main et al. (2003)</td>
<td>Cobb-Douglas</td>
<td>Cross-section, 27 UK airports, 1988</td>
<td>Passengers or WLU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panel of 44 airports worldwide, 98-00</td>
<td></td>
</tr>
<tr>
<td>Jeong (2005)</td>
<td>Translog</td>
<td>Cross-section, 94 US airports, 2003</td>
<td>Passengers or WLU or Output index</td>
</tr>
</tbody>
</table>

Source: Jeong (2005) and own elaboration.

Table 3 summarizes all the previous literature, helping to place the proposed contribution within the airport cost function research. This work features a long-run stochastic cost frontier with a multi-product specification (including commercial revenues), which allows a broader view of the airport operations. Additionally, the use of a much bigger database comprising airports of different size allows us to obtain results that are more credible.
4 The in-depth case study

4.1 The econometric estimation of cost functions

The estimation of the cost function \( C(w, Y) \) requires observations on costs, outputs \((Y)\) and input prices \((w)\) associated to firms whose behavior is assumed to be cost-minimizing. Some functional form has to be postulated in the stochastic specification of the cost function. The transcendental logarithmic “translog” (Christensen et al., 1973) is one of the most popular and has been applied extensively in the past. It provides a local approximation to any cost structure allowing a great variety of substitution patterns. Linear homogeneity can also be imposed by including certain linear restrictions to the parameters, which also reduce the number of them to estimate. It presents this general structure, with logged variables:

\[
\ln C = \alpha + \sum_j \beta_j \ln y_j + \sum_j \gamma_j \ln w_j + \frac{1}{2} \sum_{j,k} \delta_{jk} \ln w_j \ln w_k + \sum_k \rho_k \ln y_i \ln y_k + \varepsilon_j
\]  

The translog cost equation is linear in parameters and can be estimated using classical least squares regression techniques upon making the necessary assumptions about the applicable stochastic error terms. Nevertheless, the translog function is commonly estimated jointly with the cost minimising input cost share equations by means of a seemingly unrelated equations (SUR) regression (Zellner, 1962) and using maximum likelihood estimators. Cost minimising factor shares \( s_i \) can be obtained by applying Shephard’s lemma. This procedure allows researchers to including \((r-1)\) additional equations to the cost function where \(r\) is the number of inputs that have been considered in the model specification. As no additional parameters are included, the estimation becomes more efficient, i.e.

\[
s_i = \frac{w_i X_i}{C} = \frac{\partial C}{\partial w_i} C = \frac{\partial \ln C}{\partial \ln w_i} = \beta_i + \sum_{j \neq i} \delta_{ij} \ln w_j + \sum_{j \neq i} \gamma_j \ln y_j .
\]  

In addition, the equation model is estimated by deviating the explanatory variables with respect to an approximation point (usually the mean value of the sample). In the translog case, all the variables can be normalized as follows:

\[
\tilde{y}_i = \ln(y_i) - \bar{\ln}(y_i)
\]  

The present methodology is complemented with the consideration of cost inefficiencies. This arises from the certainty that the minimum cost estimations do not fit well with the firms’ actual expenditures. In the real world, some firms deviate from the optimizing behaviour. 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)\(^{14}\). This paper makes use of SFA as the natural extension of the above-mentioned cost function methodology. SFA is an econometric method that estimates a cost frontier as follows:

\[
C = f(y, w) + u_i + v_i
\]  

where \(v\) 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 inefficiencies.

\(^{14}\) A comprehensive survey of airport productivity and efficiency studies can be found in Oum and Yu (2004).
inefficiency of each airport. Note that it should follow a one-sided distribution, since inefficiency can only take positive values within the cost approach. Nevertheless, under this first approximation, $u$ captures not just the technical inefficiencies but also incorporate the allocative inefficiency and potential influence of other variables that have not been fully specified in the model and that do not usually change over the sample period (e.g. the type of ownership and the geographic location of each airport).

Recent results in Kumbhakar and Wang (2006) show that failure to include the cost of AI explicitly in the cost function biases the estimates of the function parameters. However, the 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 deviation from optimal factor shares are complicated functions of AI (Kumbhakar and Tsionas, 2005). 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” 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. Thus, the relevant prices to the firm are:

$$w^* = [w_1, w_2 \exp(\xi_2),..., w_j \exp(\xi_j)]$$  \hspace{1cm} (24)

where $\xi_j \neq 0$ represents the allocative inefficiency for the input pair $(j,1)$. Following the notation of Kumbhakar (1997), the translog cost system can be rewritten as follows:

$$\ln C^o(w, y) = \ln C^o(w, y) + \ln C^{al}(\xi, w, y) + u + \nu$$

$$S^o_i = S^o_i + \lambda_i$$  \hspace{1cm} (25)

where $u$ now accounts only for technical inefficiency; $\nu$ is the usual white noise; and $lnC^{al}$ represents the percentage increase in costs due to allocative distortions, which depends on the estimation of the allocative inefficiency parameters ($\xi$). The empirical estimation of this kind of models is restricted to panel data in which both technical and allocative inefficiency are either assumed to be fixed parameters or functions of the data and unknown parameters. In Kumbhakar and Tsionas (2005), 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. AI is modelled via price distortions from which firm-specific inferences are drawn on input over- or underutilization.

### 4.2 Methodological issues

#### 4.2.1 Output vector

Airports do not provide transportation directly, but provide all the necessary infrastructures for air traffic. Their multi-product nature is related to the very different use that aircraft, passengers/baggage and freight make of airport facilities. Hence, this 3-dimensional output vector could be considered the starting point to the study of airport cost functions.

Air traffic movements (ATMs) are generally defined as either a landing or take-off movement, mostly performed by a commercial carrier. 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 take-offs which may not be fully comparable in terms of infrastructure usage.

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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).
Since landings and take-offs 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-take-off (LTO) cycle.

The specification of aircraft operations leads to a problem of output separation, as aircraft may be completely different, having a different impact on infrastructure damage, and hence on the airport’s capital expenditure (Link and Nilsson, 2005). Heavier and larger aircraft require longer, wider and stronger runways, take up more space on the aprons, and deliver more passengers to use the terminal facilities (AIAL, 2006). Aircraft operations at small airports should not be weighted equally as those performed at major hubs where the average aircraft size is larger. Voltes-Dorta (2008) shows that the plain aggregation of ATMs underestimates the degree of economies of scale. The obvious solution is the standardisation of aircraft operations in “base aircraft” units. The total number of ATMs (landings) will be scaled by the proportion of each airport’s average landed MTOW with respect to the base aircraft’s MTOW. The Boeing 737-400, with an MTOW of 68 metric tons, was chosen as “base aircraft”\(^{16}\). Hence, the ATMs were standardised in “737-equivalent” aircraft operations (ATM\(_{737}\)), which were specified in the cost function as comparable outputs.

The second output to be included in the cost function is the provision of infrastructure for passengers and baggage (PAX). 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 \((w,Y)\). Dropping one of the variables produces a loss of information and biased coefficients for the remaining explanatory variables. Therefore, this paper keeps the multi-product specification and assumes the presence of multicollinearity, though it also tries to minimize its impact by increasing the sample size, which can produce more precise parameter estimates. 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.

Freight and mail operations are the third output considered in the provision of infrastructure, the unit of observation being the metric ton (1000 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.

In addition, airport financial reporting standards (the major source of information in the present database) and the likely presence of cost complementarities neither allow nor advise input separation of non-aviation activities. For that reason, the fourth output included is the provision of infrastructure for commercial activities such as retail, food and beverage, parking, real estate and many others. The unit of observation was defined as thousands of PPP USD (2006) of non-aviation revenues.

4.2.2 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

\(^{16}\) The assumption of a linear relationship between the aircraft’s MTOW and its marginal cost makes the election of the base aircraft a trivial issue. Of course, this approach is not perfect and is only intended to serve as a first approximation to the standardisation of aircraft operations for cost function research.
work follows the categorisation 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. Thus, 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.

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 this work, a new approach is carried out. Assuming that airports operate in competitive input markets, optimal input prices are equal to the value of the marginal product (MP) for each input. The next step is defining a set of proxy factors \( x_i \) whose demand should directly explain the aggregated factor expenditure. Then each factor’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, i.e.

\[
Q = Ax^b x^c \quad \iff \quad \ln Q = \ln A + b \ln x_i + c \ln x_i
\]

\[
MP_i = (\frac{\partial \ln Q}{\partial \ln x_i}) \cdot (Q / x_i)
\]

\[
MP_i / MP = \alpha
\]

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

\[
C^*_i = P \cdot MP_i \cdot (x_i + \alpha \cdot x_i) = w^*_i (I_q)
\]

\[
w^*_i = C^*_i / I_q
\]

Therefore, the quantity index is calculated in order to synthesize all information in a single price. The quantities of the proxy factors are weighted according their marginal productivities \( (\alpha) \) in order to convert them into uniform base factor units (e.g. factor 1). The more and uncorrelated proxy factors considered, the more precise the estimated equation will be, and therefore better estimations of can be obtained.

The proxy inputs considered for the calculation of the price of materials were both the number of boarding gates (GAT) and the number of check-in desks (CHK). These variables were chosen because they were considered to be highly correlated with the airport’s overall demand for energy, utilities and maintenance. The marginal productivities were calculated with respect to the aggregated output variable work load units (WLU). 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). 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\(_{737}\) variable because this output is specially capital intensive\(^{17}\).

### 4.2.3 Bayesian Estimation

The Winbugs software will be used for the estimation. 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

\(^{17}\) The estimated extensions of the Cobb-Douglas production functions are:

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

\[
\text{Ln}(ATM) = -12.83 + 2.67*\text{LOG}(RUN) + 0.88*\text{LOG}(TER) - 0.12*\text{LOG}(RUN)^2 + 0.04*\text{TIME} - 0.007*\text{TIME}^2 ; R^2=0.86
\]
be normally distributed, with a standard translog specification as the mean and $\sigma^2_v$ 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 $t$. The firm-specific average technical inefficiency $u_i$ is assumed to be exponentially distributed with mean $\lambda^{-1}$, and a negative $\eta_i$ indicates increasing efficiency over time of the firm $i$.

$$\ln C^o_{it} \sim N(\ln C^o_{it} + \ln C^u_{it} + u_{it}, \sigma^2_v)$$

$$u_{it} \sim \exp\{\eta_i(t-T)\}u_i, \quad \text{where} \quad u_i \sim \exp(\lambda)$$

Prior distributions are assigned to the parameters, such as the multivariate normal with mean zero to the vector of regressors $\beta$, a gamma distribution $(a_0,a_1)$ for the white noise precision $(\sigma^2_v)$, and another exponential for the $\lambda$ parameter which allows us to impose our prior ideas about mean efficiency ($\bar{r}$) in the airport industry. Allocative distortions $\zeta$ were specified as normal variables with zero mean representing the prior notion that average allocative inefficiency is likely to be small (Kumbhakar and Tsionas, 2005). The presence of $\ln(G_i)$ in the specification of $C^d_i$ (see Kumbhakar, 1997) requires the use of very tight priors for $\zeta_j$ in order not to sample negative values for $G_i$, which may interrupt the iteration process. The prior distribution of $\eta_i$ was also chosen to be a zero mean normal distribution representing the prior indifference between increasing and decreasing efficiency.

$$\beta \sim N(0,\Sigma) \quad \sigma^{-2}_v \sim G(a_0,a_1) \quad \lambda \sim \exp(-\lambda) \quad \xi_j \sim N(0,\sigma^2_j) \quad \eta_i \sim N(0,\sigma^2_\eta)$$

Factor share equations and linear restrictions are specified in a similar fashion as the cost frontier, being also normally distributed and assuming that their errors are likely to be highly correlated. As Bayesian estimators benefit from the addition of all available information to the system, all factor share equations were included.

### 4.2.4 The database

The database is mostly composed of financial data directly collected from balance sheets and income statements published by the Airport Authorities (AA). No external effects such as noise, scarcity and congestion are featured in the data and thus results can hardly be interpreted in terms of social costs or benefits. The database used in this work is an unbalanced panel of 161 international airports. It was intended to comprise airports of all sizes, and hence it features many of the world busiest airports in terms of either passengers/aircraft operations or cargo tonnage. The geographical breakdown of 161 sample airports is as follows: 94 from Europe, 45 from North America, 11 airports 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 Annex 1). In the European sample, 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 could be 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-m²), total runway length (RUN-m),

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18 The choice of an exponential distribution for $u$ was based on the deviance information criterion (DIC) as presented in Spiegelhalter et al. (2002).
number of gates (GAT), and check-in desks (CHK); d) Other: time (t), full-time equivalent employees (FTEE), and total landed MTOW. All the variables related to costs and revenues were converted to 2006 Purchasing Power Parity (PPP) USD using OECD published indicators. Table 4 provides the range, mean and std. deviation of each variable. Airport size ranges between 1000 passengers at ODB (Spain) in 1993 and 85 million at ATL in 2005. The mean airport serves about 155,000 737-equivalent movements, 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 of the world. Regarding input prices, the extreme diversity of airports and countries featured explains the significant variability of input prices. 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 Database overview (monetary variables expressed in 000's PPP USD)

<table>
<thead>
<tr>
<th>Total Cost</th>
<th>PAX</th>
<th>ATM</th>
<th>737</th>
<th>CGO</th>
<th>REV</th>
<th>FTEE</th>
<th>TERR</th>
<th>SFA</th>
<th>Wc</th>
<th>Wm</th>
<th>Wp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max.</td>
<td>1,739,326</td>
<td>85,907,423</td>
<td>1,190,887</td>
<td>3,692,081</td>
<td>690,051</td>
<td>13,979</td>
<td>761,300</td>
<td>24,505</td>
<td>65.7</td>
<td>8,947</td>
<td>191.6</td>
</tr>
<tr>
<td>Min.</td>
<td>692</td>
<td>1,000</td>
<td>66</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>918</td>
<td>1,127</td>
<td>0.02</td>
<td>3.9</td>
<td>15.6</td>
</tr>
<tr>
<td>Mean</td>
<td>151,036</td>
<td>11,339,733</td>
<td>155,299</td>
<td>253,847</td>
<td>66,005</td>
<td>651</td>
<td>112,391</td>
<td>5,847</td>
<td>3.59</td>
<td>727.3</td>
<td>52.99</td>
</tr>
<tr>
<td>Gm</td>
<td>-</td>
<td>4,703,044</td>
<td>48,764</td>
<td>28,496</td>
<td>15,543</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Sd</td>
<td>219,379</td>
<td>14,417,880</td>
<td>207,709</td>
<td>534,132</td>
<td>97,777</td>
<td>1,069</td>
<td>140,278</td>
<td>4,017</td>
<td>6.33</td>
<td>776.3</td>
<td>23.32</td>
</tr>
</tbody>
</table>

Source: 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. Regarding the figures 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, 2004), 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 the Airport Capacity and Demand profiles (IATA, 2003).

### 4.3 Estimation and results

The decision on whether a long- or short-run specification should be estimated will be now briefly discussed. The previous literature does not provide any further help on this issue, except for Tolofari (1990) which clearly decided for short-run - all other studies simply estimated both equations, but 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, at first sight, be 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, but then capital costs are sharply related to the level of production and hence cannot be considered as fixed costs. The fact that accounting practices allow, for the sake of simplicity, that structures 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 practices.
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. 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 hold for all observations in the database: 57 out of the featured 161 airports have already expanded either their runway system or the terminal buildings (or both) during the time span considered. In addition, most of these expansions are justified by a significant development in both aircraft and passenger operations. With a few exceptions, the remaining airports tend to show moderate traffic increases. The weighted average annual growth rate for the airports that have been expanded is 6.9 percent compared with a 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, this is because the wide variation across firms allows the consideration of all factors as variable, and hence, even the most fixed capital expenditures can be assumed to be fairly adjusted to their optimal scale of production. For quantitative reasons, the pooled database used in this work should be regarded as a cross-section rather than time-series. Hence, the long-run model is the chosen approach.

The significant complexity of the model contrasts with the extreme simplicity of the Winbugs software. Thus, the estimation procedure comprises two stages. In the first phase, a good fitting and parsimonious specification should be chosen from an estimation of the cost frontier system made with Eviews. 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 first phase will serve as initial values for the sampling process in Winbugs.

Therefore, to begin with, the estimated cost frontier included all second-order interactions between the explanatory variables. Some control variables were selected which were mostly related to the outputs, as shown in Table 5. Note that the first-order atm parameter is not significantly different from zero, and this result is not really satisfactory if the researcher want to calculate marginal costs related to this output. This was clearly produced by both multicollinearity and overparametrisation 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. It was decided to keep only one out of these three second-order parameters between atm and pax in order to minimise 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 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 and marginal costs.

### Table 5. First specification control variables in the long-run model

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. error</th>
<th>t-Statistic</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>atm</td>
<td>0.012191</td>
<td>0.021993</td>
<td>0.554305</td>
</tr>
<tr>
<td>pax</td>
<td>0.302167</td>
<td>0.021814</td>
<td>13.85221</td>
</tr>
<tr>
<td>cgo</td>
<td>0.080699</td>
<td>0.006147</td>
<td>13.12850</td>
</tr>
<tr>
<td>rev</td>
<td>0.140641</td>
<td>0.011012</td>
<td>12.77208</td>
</tr>
<tr>
<td>$0.5*\text{atm}^2$</td>
<td>-0.254608</td>
<td>0.042756</td>
<td>-5.954961</td>
</tr>
<tr>
<td>$0.5*\text{pax}^2$</td>
<td>-0.275698</td>
<td>0.034434</td>
<td>-8.06606</td>
</tr>
<tr>
<td>$0.5*\text{cgo}^2$</td>
<td>0.019469</td>
<td>0.003332</td>
<td>5.842135</td>
</tr>
<tr>
<td>$0.5*\text{rev}^2$</td>
<td>0.082867</td>
<td>0.006907</td>
<td>11.99795</td>
</tr>
<tr>
<td>atm*pax</td>
<td>0.341914</td>
<td>0.034776</td>
<td>9.831897</td>
</tr>
<tr>
<td>atm*cgo</td>
<td>0.061547</td>
<td>0.011216</td>
<td>5.487427</td>
</tr>
<tr>
<td>atm*rev</td>
<td>-0.137347</td>
<td>0.025658</td>
<td>-5.35306</td>
</tr>
<tr>
<td>pax*cgo</td>
<td>-0.047148</td>
<td>0.011221</td>
<td>-4.201598</td>
</tr>
<tr>
<td>pax*rev</td>
<td>0.073453</td>
<td>0.025658</td>
<td>3.559165</td>
</tr>
<tr>
<td>cgo*rev</td>
<td>-0.042312</td>
<td>0.007496</td>
<td>-5.644881</td>
</tr>
</tbody>
</table>

Once estimated three different models using in each case one of the potential second order interactions between these two variables, that is, $\text{pax}^2$, $\text{atm}^2$ or $\text{pax*atm}$, it was finally decided to choose the interaction between $\text{pax}$ and $\text{atm}$. The reason can be found in the partial derivatives that correspond to each alternative. They are shown below. These partial derivatives represent each output’s cost elasticity and they are used in the calculation of the scale elasticity and marginal costs. The selected option is featured on the right of the equation, 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 degree of scale 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.

$$
\frac{\partial \ln C^{\alpha}}{\partial \text{atm}} = a_2 + w' \gamma + \rho_{22} \text{atm} \quad \frac{\partial \ln C^{\alpha}}{\partial \text{pax}} = a_3 + w' \gamma \\
\frac{\partial \ln C^{\alpha}}{\partial \text{atm}} = a_4 + w' \gamma + \rho_{22} \text{pax} \quad \frac{\partial \ln C^{\alpha}}{\partial \text{pax}} = a_5 + w' \gamma + \rho_{22} \text{atm}
$$

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 ($u_t$) 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 reduced only in less than 1 percent ($R^2 = 0.961$). Hence the final long-run specification features 29 variables with the following estimated values:

### Table 6. Initial values for the Winbugs sampling in the long-run model

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. error</th>
<th>t-Statistic</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>10.70048</td>
<td>0.01450</td>
<td>738.117</td>
</tr>
<tr>
<td>atm</td>
<td>0.10614</td>
<td>0.03018</td>
<td>3.51720</td>
</tr>
<tr>
<td>pax</td>
<td>0.30430</td>
<td>0.02756</td>
<td>11.0402</td>
</tr>
<tr>
<td>cgo</td>
<td>0.07477</td>
<td>0.00938</td>
<td>7.96782</td>
</tr>
<tr>
<td>rev</td>
<td>0.05290</td>
<td>0.01564</td>
<td>3.38309</td>
</tr>
</tbody>
</table>

40
An approximation of what will be obtained in the Bayesian estimation is shown in Table 6. The model performs very well and the most relevant parameters are significantly different from zero. 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, the capital has been chosen as the base input, hence the relevant input price vector for the allocative inefficient cost minimizing airport is:

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

(30)

where $\xi$ indicates the allocative inefficiency for the input pair $(j$, capital). For ease of exposition, the polynomial expression containing all $\xi$ parameters ($ln C_{ij}$) is separated from the efficient cost frontier ($ln C_i$). This expression represents the percentage increase in total costs because of allocative inefficiency. In a very similar way, the input share equations are directly derived from the cost frontier, resulting in this more convenient expression:

$$S_i^{oa} = S_i^{aw}(w_i, y) + S_i^{aw}(\xi_i, w_i, y) / G_i \exp(\xi_i)$$

(31)

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, as it is closely related to the factor share equations (Kumbhakar, 1997). Finally, the 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 Annex 2. 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 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 ($\sigma_\eta^{-2}$) 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 (\(\sigma^2\)) 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 allocative distortions in the airport industry.

The white noise for both cost frontier and factor share equations (\(\sigma^2\)) 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 \(\lambda\). Prior ideas on the industry’s median efficiency can be added to the system by means of the \(\lambda^*\) parameter in the lambda distribution. This was set at 0.82, as obtained in a previous study (Martín and Voltes-Dorta, 2008) using a very similar but small 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 only 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 6) were used. In addition, it is highly advisable that other variables such as \(\eta\) or the allocative effects are initialized at zero. 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 7, which reports the posterior mean, standard deviation, and a 95 percent posterior confidence interval.

| Table 7. Long-run cost function parameter estimates |
|-------|-------|-------|-------|-------|-------|-------|
|       | 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  |
| ego     | 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 | 0.3701 | 0.3701 | 0.3807 | 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  |
| ego*wc  | -0.0008 | 0.0034 | 1.79E-05 | -0.0074 | -0.0008 | 0.0060 | 4001  | 30000  |
| ego*wm  | -0.0082 | 0.0026 | 1.36E-05 | -0.0133 | -0.0082 | -0.0031 | 4001  | 30000  |
| ego*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 | 0.0035 | 0.0365 | 0.0158 | 4001  | 30000  |
| wc*wc   | -0.0949 | 0.0059 | 3.46E-05 | -0.1064 | -0.0949 | -0.0853 | 4001  | 30000  |
| wm*wm   | 0.1089 | 0.0078 | 3.95E-05 | 0.0936 | 0.1089 | 0.1241 | 4001  | 30000  |
| 0.5*wm*wm | 0.0876 | 0.0090 | 5.30E-05 | 0.0701 | 0.0875 | 0.1054 | 4001  | 30000  |
| 0.5*wc*wc | -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*ego*ego | 0.0066 | 0.0033 | 1.89E-05 | 0.0062 | 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  |
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. Finally, the robustness of the first-order atm and pax parameters has been checked. The same specification has been 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 8 shows some degree of variation on the estimated coefficients. However, these average values are consistent with the results presented in Table 7, 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 structural analysis of the individual coefficients in spite of the presence of near multicollinearity.

Table 8. Long-run cost function parameter estimates

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

Therefore it can be concluded that a reliable methodology to estimate the airports’ cost function has been provided. From the estimated parameters important conclusions in term of scale elasticities, marginal operating costs, efficiency and productivity in the airport industry can be drawn. This is expected to shed some light about “best practices” regarding the provision of infrastructure for air transport. This deliverable fills the existing literature gap by proposing the first long-run multi-product specification of the cost function in the airport industry. There are also some other specific characteristics which are worth to highlight. 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 to estimate the basic parameters of the airport industry is one of the most flexible ones: a translog cost stochastic frontier model has been used including both technical and allocative inefficiencies. Finally, a Bayesian model has been estimated using Winbugs.

### 4.4 Analysis of the airport industry

In this section, the main findings of the airport industry will be discussed using the estimation of the long run cost function explained before. Average results for economies of scale, allocative inefficiencies and temporal dimension will be discussed.

#### 4.4.1 The economies of scale

The analysis of the economies of scale is based on the first- and second-order output parameters of the estimated cost frontier \((\ln C)\), without including the interactions related to the two specified allocative effects \((\ln C^a)\). 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.

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

(32)

43
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 (α + α + α + α ). 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. Therefore, the node scale was created to measure the scale elasticity at the mean airport (Table 9). In addition, a graphic representation of the standard 95 percent confidence interval is also provided. As seen in the Figure 1, all probability mass lies in the IRS zone around the 1.85 value, clearly rejecting CRS, as expected.

\[
\begin{align*}
\frac{\partial \ln C^o}{\partial atm} &= \alpha_2 + \gamma_{10} wc + \gamma_{11} wm + \gamma_{12} pax \\
\frac{\partial \ln C^o}{\partial pax} &= \alpha_3 + \gamma_{13} wc + \gamma_{14} wm + \gamma_{15} atm \\
\frac{\partial \ln C^o}{\partial cgo} &= \alpha_4 + \gamma_{16} wc + \gamma_{17} wm + \gamma_{18} cgo \\
\frac{\partial \ln C^o}{\partial rev} &= \alpha_5 + \gamma_{19} wc + \gamma_{20} wm + \gamma_{21} rev.
\end{align*}
\]

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 variable also has a small effect in the same direction. However, the negative sign of the rev parameter is of much more interest. In spite of not being significantly distinct from zero, the fact that a higher probability density 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 more than simple airfields to become large “shopping malls”.

For the sake of exposition, all airport-specific estimations of the scale elasticities for the whole sample are not presented, but Table 10 summarizes this information by featuring the average estimations for a wide range of output levels.

Table 10. Scale elasticities at different production levels

<table>
<thead>
<tr>
<th>PAX (mil.)</th>
<th>Avg. Scale</th>
<th>ATM737 (thousands)</th>
<th>Avg. Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.5</td>
<td>4.032</td>
<td>0 to 5</td>
<td>4.430</td>
</tr>
<tr>
<td>0.5 to 1</td>
<td>2.756</td>
<td>5 to 15</td>
<td>2.467</td>
</tr>
<tr>
<td>1 to 5</td>
<td>2.086</td>
<td>15 to 75</td>
<td>1.917</td>
</tr>
<tr>
<td>5 to 20</td>
<td>1.685</td>
<td>75 to 200</td>
<td>1.636</td>
</tr>
<tr>
<td>20 to 40</td>
<td>1.475</td>
<td>200 to 500</td>
<td>1.515</td>
</tr>
<tr>
<td>40+</td>
<td>1.430</td>
<td>500+</td>
<td>1.374</td>
</tr>
</tbody>
</table>

The scale elasticities vary between 4.36 at AAR and 1.23 at PEK. These values are plotted against the number of ATM737. 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 ATM737 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 ATM737 (ATL, ORD, LHR). Hence, 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.

Figure 2. Scale elasticities for both aeronautical and non-aeronautical production
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. 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\(^\text{19}\) 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).

4.4.2 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.

The calculation of the degree of scale economies for a subset \( R \) of outputs was introduced in Chapter 2, i.e.

\[
S_{R}(\omega, Y) = \frac{C(\omega, Y) - C(\omega, Y_{N=R})}{\sum_{j \in R} \frac{\partial C(\omega, Y)}{\partial Y_j}} = \frac{IC_{R}(\omega, Y)}{\sum_{j \in R} \frac{\partial C(\omega, Y)}{\partial Y_j}}
\]  
(34)

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). This incremental costs of the passenger output were estimated using a “small value” approach\(^\text{20}\), because the translog is not analytic at zero. 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:

\[
\ln(1) - \text{avg.}\ln(\text{rev}) = -9.709.
\]

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). This extreme value produced very odd results, including negative scale elasticities at several airports. Hence, in a second approach, the \( \text{rev} \) 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

\(^{19}\) 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.

\(^{20}\) 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.
The 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\textsubscript{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 3). Using a logarithmic fit, the aeronautical MES was found to be located between 1.54 and 1.76 million ATM\textsubscript{737}, with a mean value of 1.65 million\textsuperscript{21}. As an example, ORD’s modernization program (OMP, 2005) will expand the airport’s capacity to over 1.36 million ATM\textsubscript{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\textsuperscript{22}. 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\textsuperscript{23}.

A nice example of such a congested airport can be found at AMS (Figure). 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\textsubscript{737} or 56 mppa. However, with the important support of its leading non-aviation sector\textsuperscript{24}, AMS can theoretically serve much more traffic even though it is already congested. In spite of that, AMS is consistently ranked

\begin{equation}
y = -0.2661\ln(x) + 4.8101 \\
R^2 = 0.7241
\end{equation}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{scale-elasticity.png}
\caption{Scale elasticities for aeronautical operations (ATM\textsubscript{737})}
\end{figure}

\textsuperscript{21} Confidence intervals were obtained using Eviews software.
\textsuperscript{22} Scale = \(-0.2667\ln(PAX) + 5.9752\) \[R^2 = 0.6832\].
\textsuperscript{23} 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.
\textsuperscript{24} The Schiphol group is well known for being one of the most profitable airport companies, and has successfully expanded its scope of activities out of AMS.
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.

\[ y = -0.35 \ln(x) + 5.9556 \]
\[ R^2 = 0.9843 \]

\[ y = -0.5949 \ln(x) + 8.9963 \]
\[ R^2 = 0.9723 \]

Figure 4. Evolution of scale elasticities at AMS (ATM737)

4.4.3 Technical and allocative efficiency

Before presenting the results, a word of caution is made in order that neither the individual estimations of the \( \eta \) parameter nor the single allocative effects be interpreted in terms of quantity. Hence, 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 \( \xi_j \) parameters will allow us to determine whether the airport is underusing or overusing some production input.

Technical efficiency results are based on the selected exponential distribution for the error component because it shows a better fit than a truncated normal and it was similar to the gamma specification. 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.

Another important result is the absence of a significant correlation between airport size and operational efficiency. 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 ofmppa 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 11).

<table>
<thead>
<tr>
<th>PAX (mppa)</th>
<th>Avg. TE</th>
<th>Avg. annual losses (million PPP USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>s.d.</td>
</tr>
</tbody>
</table>

Table 11. Technical inefficiency average annual costs at different production levels
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.

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. In order to put this figure into perspective, this is approximately the estimated cost of the recently launched expansion project at PEK.

In order to provide reference values for the industry, Table 11 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 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.

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. Thus, each airport’s actual price vector (\( w^\ast \)), which generates all the above-mentioned technically-efficient input combinations, is compared with the underlying optimal price vector featured on the cost frontier (\( lnC^\ast \)). The difference represents the \( lnC^{al} \), which are the extra costs related exclusively to the presence of allocative inefficiency (AI). The average values for these allocative effects are \( \xi_n = -0.03 \) and \( \xi_p = 0.00 \). 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 proportion. As in the previous case, no significant correlation between the allocative effects and airport

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25 Throughout this chapter the term “billion” refers to thousand million.

26 This is the average A380 investment (De Neufville and Odoni, 2003).

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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 $\ln C_{al}$, i.e. $^{27}$

$$\ln C_{al} = \beta_1 l_t + \beta_2 l_p + \gamma_{11} A_t + \gamma_{12} A_p + \gamma_{13} P_t + \gamma_{14} P_p + \gamma_{15} C_g + \gamma_{16} C_m +$$

$$\gamma_{21} C_g + \gamma_{22} R_e + \delta_{21} C_m + \delta_{22} W_m + \delta_{23} W_p + \delta_{25} W_m + \delta_{26} W_p + 0.5 \beta_2 \xi_m +$$

$$\xi_m + \ln(G_i).$$

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 from the minimum cost frontier. The mean and variation were obtained from the individual $C_{al}$ estimations (Table 12). The average AI level in the industry was therefore estimated at 6.3 percent covering the expected range of variation.

### Table 12. Posterior statistics of the $C_{al}$ node

<table>
<thead>
<tr>
<th>Node</th>
<th>Mean</th>
<th>SD</th>
<th>2.5%</th>
<th>Median</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{al}$</td>
<td>1.063</td>
<td>0.04232</td>
<td>1.004</td>
<td>1.057</td>
<td>1.159</td>
</tr>
</tbody>
</table>

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.

In order to provide reference values for the industry, Table 13 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.

### Table 13. Allocative inefficiency average annual costs at different production levels

<table>
<thead>
<tr>
<th>PAX (mppa)</th>
<th>Avg. AI</th>
<th>Avg. annual losses (million PPP USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>s.d.</td>
</tr>
<tr>
<td>0 to 1</td>
<td>1.066</td>
<td>0.037</td>
</tr>
<tr>
<td>1 to 5</td>
<td>1.046</td>
<td>0.024</td>
</tr>
<tr>
<td>5 to 20</td>
<td>1.044</td>
<td>0.031</td>
</tr>
<tr>
<td>20 to 40</td>
<td>1.043</td>
<td>0.033</td>
</tr>
<tr>
<td>40 +</td>
<td>1.039</td>
<td>0.037</td>
</tr>
</tbody>
</table>

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 recently expanded or not, show increasing TE, and so do some geographical clusters.

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27 Note that the consideration of $\ln(G_i)$ requires the computation of the predicted cost shares according to the original Kumbhakar (1997) formulation.
4.5 Marginal costs as signals of first best pricing policies

4.5.1 Marginal cost estimations

In this section, a comparison between the actual airport charges and the estimated marginal costs (MC) as an indication of how far optimal pricing is from current practices will be made. 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; 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; and finally because in some of the most congested airports the opportunity costs for the scarcity of costs could hinder some of our results.

The first part will develop 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:

\[
\frac{\partial \ln C^o}{\partial \ln Y^i} = \frac{\partial C^o}{\partial Y^i} \frac{Y^i}{C^o}; \quad MC^i = \frac{\partial C^o}{\partial Y^i} = \frac{\partial \ln C^o}{\partial \ln Y^i} \frac{Y^i}{C^o}
\]  

(35).

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 labelled as such for the sake of exposition. In addition, it is worth noting here that only the first part of the cost frontier (\(\ln C^o\)) is going to be used when predicting total costs. Otherwise, the estimated values could not be used in the analysis of optimal airport pricing.

Individual estimates of MC for all specified outputs in the long-run model were calculated for all the airports included in the sample. 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.

The MC for the ATM737 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 aircraft28. 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 14.

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28 Note that this assumption makes 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\textsuperscript{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\textsuperscript{29}.

Table 14. Average long-run marginal costs at different production levels

<table>
<thead>
<tr>
<th>ATM737 (000)</th>
<th>MC mean</th>
<th>MC range</th>
<th>PAX (mppa) mean</th>
<th>MC range</th>
<th>CGO (mmtc) mean</th>
<th>MC range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 5</td>
<td>425.0</td>
<td>415.9-439.2</td>
<td>0 to 1</td>
<td>4.11</td>
<td>4.03-4.21</td>
<td>0 to 0.1</td>
</tr>
<tr>
<td>5 to 15</td>
<td>392.3</td>
<td>373.9-411.4</td>
<td>1 to 5</td>
<td>3.75</td>
<td>3.52-4.03</td>
<td>0.1 to 0.5</td>
</tr>
<tr>
<td>15 to 75</td>
<td>285.8</td>
<td>247.9-370.0</td>
<td>5 to 25</td>
<td>3.47</td>
<td>3.17-3.68</td>
<td>0.5 to 1</td>
</tr>
<tr>
<td>75 to 300</td>
<td>278.3</td>
<td>249.3-288.9</td>
<td>25 to 50</td>
<td>4.04</td>
<td>3.68-4.33</td>
<td>1 to 1.5</td>
</tr>
<tr>
<td>300 to 500</td>
<td>301.3</td>
<td>289.0-314.9</td>
<td>50 to 60</td>
<td>4.42</td>
<td>4.33-4.51</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>500 to 900</td>
<td>350.3</td>
<td>315.0-390.9</td>
<td>60 to 85</td>
<td>4.74</td>
<td>4.51-4.98</td>
<td>2.5 to 4</td>
</tr>
</tbody>
</table>

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. It has been previously shown 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 \textit{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 own facilities, and thus have less impact on the AA’s total costs. In this context, the service of a single \textit{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 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 \textit{pax} and the \textit{cgo} variables instead of the usual WLU\textsuperscript{s}. 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

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\textsuperscript{29} Of course, these practices would not be possible if dual-till price regulation is enforced.
production levels will eventually show that the aggregation is unsatisfactory. As shown in Figure 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 values are very similar. 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 might be provided by the freight companies under special agreements. 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.

![Figure 5. Comparison between PAX and CGO (100Kg) long-run average marginal costs (in million wlus)](image)

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 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\(^{30}\) 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

\(^{30}\) The development of the SkyPlaza at HKG (golf course included) is a perfect example of that.
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.

4.5.2 Optimal (first best prices) 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, three European 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.

This analysis will be focused exclusively on landing (atm) charges, and taking into consideration the linear assumption on MTOW that has been made in the study. For this reason only those airports featuring constant or increasing unit rates per metric ton MTOW could 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. This was one of the main goals of CATRIN. In this section, six very common airliners are contemplated which represent the overall performance of all the aircraft operating nowadays (three of them wide-bodies (see Table 15)). 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>
<thead>
<tr>
<th>Aircraft</th>
<th>MTOW (metric tons)</th>
<th>Takeoff distance (m)</th>
<th>Wingspan (m)</th>
<th>Seats</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATR72</td>
<td>22</td>
<td>1,290</td>
<td>27</td>
<td>72</td>
</tr>
<tr>
<td>B737-300</td>
<td>57</td>
<td>2,109</td>
<td>29</td>
<td>128</td>
</tr>
<tr>
<td>A320-200</td>
<td>75</td>
<td>2,090</td>
<td>34</td>
<td>150</td>
</tr>
<tr>
<td>B767-300</td>
<td>171</td>
<td>2,850</td>
<td>48</td>
<td>210</td>
</tr>
<tr>
<td>B777-200</td>
<td>267</td>
<td>3,170</td>
<td>61</td>
<td>305</td>
</tr>
<tr>
<td>B747-400</td>
<td>377</td>
<td>3,600</td>
<td>64</td>
<td>416</td>
</tr>
</tbody>
</table>

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 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 cancelled 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.

\[ LC = R \times MTOW \times N \times D. \]

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 16\(^{31}\). 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.

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>
<thead>
<tr>
<th>Table 16. Marginal costs and actual landing charges at BRU (in EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>unit rate</strong></td>
</tr>
<tr>
<td><strong>Optimal</strong></td>
</tr>
</tbody>
</table>

\(^{31}\) 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 17 presents the optimal and actual charges, expressed in euros\(^{32}\). 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>
<thead>
<tr>
<th>Aircraft Type</th>
<th>MC1 (Optimal)</th>
<th>MC2 (Short-run)</th>
<th>MC3 (Actual)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATR72</td>
<td>79.86</td>
<td>21.34</td>
<td>78.0</td>
</tr>
<tr>
<td>B737-300</td>
<td>206.91</td>
<td>55.29</td>
<td>177.8</td>
</tr>
<tr>
<td>A320-200</td>
<td>279.51</td>
<td>74.69</td>
<td>240.2</td>
</tr>
<tr>
<td>B767-300</td>
<td>620.73</td>
<td>165.87</td>
<td>533.5</td>
</tr>
<tr>
<td>B777-200</td>
<td>969.21</td>
<td>258.99</td>
<td>546.0</td>
</tr>
<tr>
<td>B747-400</td>
<td>1368.51</td>
<td>365.69</td>
<td>546.0</td>
</tr>
</tbody>
</table>

Table 17. Marginal costs and actual landing charges at CPH (in 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 labour markets (that is characteristic of these countries) generates very

\(^{32}\) The currency conversion was based on historic rates (DKK/EUR).
important allocative distortions, in the sense that too much of its own labour 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.

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.

\[
\text{Table 18. Marginal costs and actual landing charges at STR (in EUR)}
\]

<table>
<thead>
<tr>
<th>unit rate</th>
<th>6.57</th>
<th>2.55</th>
<th>6.80</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimal</td>
<td>Short-run</td>
<td>Actual</td>
</tr>
<tr>
<td>ATR72</td>
<td>144.54</td>
<td>56.1</td>
<td>149.6</td>
</tr>
<tr>
<td>B737-300</td>
<td>374.49</td>
<td>145.35</td>
<td>387.6</td>
</tr>
<tr>
<td>A320-200</td>
<td>505.89</td>
<td>196.35</td>
<td>523.6</td>
</tr>
<tr>
<td>B767-300</td>
<td>1123.47</td>
<td>436.05</td>
<td>1,162.8</td>
</tr>
<tr>
<td>B777-200</td>
<td>1754.19</td>
<td>680.85</td>
<td>1,815.6</td>
</tr>
<tr>
<td>B747-400</td>
<td>2476.89</td>
<td>961.35</td>
<td>2,563.6</td>
</tr>
</tbody>
</table>
5 Eurocontrol and air traffic control charges

5.1 Introduction

Airlines are charged at various points for using aviation infrastructure and services. Two major types of infrastructure usage charges can be distinguished: First, airlines pay charges and fees for the use of airport infrastructure and services (landing fees, fees for the provision of ground services, trucking fees, rental and leasing fees, parking fees etc.). These charges are usually collected by the airport provider or airport authorities. Second, special charges are levied for the use of air corridors and for the provision of air traffic control services, referred to as air navigation services charges (ANS charges). Depending on the flight phases of an aircraft, ANS charges are further subdivided into: i) charges for en-route services (en route charges), and ii) charges for air navigation services provided during the approach and aerodrome phase.

This section addresses the determination of ANS charges and examines how cost responsibility is reflected in the level and structure of ANS charges. It relates to WP 6 (Aviation and infrastructure cost allocation) of CATRIN. This chapter is organised as follows: Section 2 defines the scope of air navigation services and categorises the types of services relevant for ANS charges. Section 3 gives the institutional background of air navigation services. Section 4 summarises the main principles of determining air navigation services both for en-route charges and for approach and aerodrome charges.

5.2 Scope and categorisation of Air Navigation Services

Depending on the flight phases of an aircraft, Air Navigation Services are provided for

- movements at and around the aerodrome (aerodrome control)\(^{33}\),
- approach and departure of flights including climbing and descending (approach control)\(^{34}\),
- movements en-route.

The provision of air navigation services for these flight phases involves different actors at facilities located at different places with a varying institutional and organisational background between countries. Furthermore, parts of these services are also provided for non-aeronautical use, and the extent to which countries finance these services from the public budget varies from country to country.

The ICAO recommends that approach and aerodrome control charges are to be distinguished from en-route air navigation services charges. In Europe, since 1981 this distinction has been realised by the responsibility of Eurocontrol to collect en-route charges based on a harmonised en-route charging scheme. With the adoption of the EC regulation 1794/2006 (EC 2006) also the calculation of terminal charges has been based on common principles.

Within the Eurocontrol area, the borderline between the en-route phase and the approach and aerodrome phase is defined as the 20 km radius of the flight closest to the airport. However, over the recent years it has been debated whether the 20 km rule provides a correct separation of costs associated with the approach phase and the en-route phase of an aircraft. For example, PriceWaterhouse (2001) suggests an amendment of the Eurocontrol rule at an 80km

\(^{33}\) Approach and aerodrome control charges are often referred to as terminal charges.

\(^{34}\) Approach and aerodrome control charges are often referred to as terminal charges.
radius at airports where there is a separate approach control phase, and at a 40 km radius at airports where approach and aerodrome control are provided as an integrated service.

The basis for determining and raising ANS charges are two ICAO documents (ICAO1997 and ICAO 2001) which are for the Eurocontrol member states specified in more detail in CRCO 2003 and CRCO 2007. The categorisation of air navigation services and facilities given in this section is based on ICAO 1997 which forms the basis for cost determination and cost allocation for these services in all international aviation including Eurocontrol.

Air navigation Services refer to the following five broad categories of facilities and services:

1. **Air Traffic Management (ATM).**
   These services include:
   a. Air Traffic Services for en-route operations and for approach control (ATS),
   b. Air traffic flow management (ATFM),
   c. Airspace management (ASM).

   Air Traffic Services (ATS) constitute the major component of Air Traffic Management Services. The facilities operated for en-route operations relate to area control centres (ACCs), including oceanic control centres (OACs) and to flight information centres (FICs). ATS facilities for approach control comprise either separate approach control units or working positions integrated in ACCs or aerodrome control towers.

2. **Communications, Navigation and Surveillance (CNS).**
CNS services consist of:
   a. aeronautical fixed services (AFS),
   b. aeronautical mobile services (AMS, radio communication between aircraft and ground or between aircraft stations),
   c. ground-based radio navigation equipment,
   d. satellite-based navigation equipment (mainly GNSS),
   e. primary/secondary surveillance radar, surface movement radar etc.

3. **Meteorological services for air navigation (MET).**
MET services for air navigation comprise the following range of services:
   a. meteorological observations, reports and forecasts,
   b. briefing and flight documentation,
   c. SIGMET and AIRMET information,
   d. world area forecast system (WAFS),
   e. forecasts for computerised flight planning,
   f. meteorological information for inclusion in broadcasts,
   g. data link services,
   h. aeronautical meteorological telecommunications,
   i. any other meteorological data required from states for aeronautical use.

   The facilities which are necessary to provide these services comprise world area forecast centres, volcanic ash advisory centres, tropical cyclone advisory centres, meteorological watch offices, aerodrome watch offices, aeronautical watch stations and supporting facilities and services for general meteorological services.

4. **Search and Rescue (SAR).**
These refer to rescue and search services provided for aviation and relate to the costs occurred for the following facilities:
a. rescue coordination centres and subcentres,  
b. mobile facilities such as aircraft including helicopters, rescue boats and vessels, mountain rescue units etc.

5. Aeronautical information services (AIS).
These services are performed to provide information which is necessary for the safety, regularity and efficiency of air navigation. They comprise amongst others
a. the Publication of Aeronautical Information  
b. Notices to Airmen  
c. Aeronautical Information Circulars  
d. the provision of plain-language pre-flight information bulletins to flight crews.

5.3 Institutional background in Europe
While in Europe a harmonised procedure for determining and collecting en-route charges has already been introduced in the 60es, there has been no equivalent system for approach and aerodrome charging for a long time. Only in 2006, an EC regulation on a common calculation scheme for both en-route and terminal charges was adopted. This regulation shall apply from 2007 onwards, however, member states can defer its application with regard to terminal charges until 2010.

In general, en-route charges are collected by the Central Route Charge Office (CRCO) of Eurocontrol, the European Organisation for the Safety of Air Navigation. Eurocontrol was founded in 1960 by six European countries (Belgium, Germany, France, Luxembourg, the Netherlands and the UK) with the objective to create a common European environment for Air Traffic Control services. Currently, 38 European countries are members of Eurocontrol. With the so-called Multilateral Agreement relating to Route Charges, the Eurocontrol member states have decided to adopt a common policy, to create a joint system for the calculation, billing and recovery of their route charges and to use for this purpose the services of Eurocontrol. The participating states of Eurocontrol provide air traffic control (ATC) facilities and services to ensure the safe, efficient and expeditious flow of air traffic through their airspace. The airspace in the Eurocontrol area is divided into charging zones that may extend across the airspace of several States (see figure 6). The adopted basic principles for a harmonised regional en-route charging system guarantee that one single charge per flight has to be paid instead of a number of charges for each national airspace used during a flight.

35 These are: Albania, Armenia, Austria, Belgium, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, the former Yugoslav Republic of Macedonia, Malta, Moldova, Monaco, the Netherlands, Norway, Portugal, Romania, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

36 The common principles adopted by the Contracting States for the calculation of costs are defined in CRCO 2007.
Eurocontrol offers, as an additional service to Member States, the billing and collection of air terminal charges (e.g. approach and aerodrome control charges) on the basis of bilateral agreements. This additional service is currently used by 10 Eurocontrol member states. Since the same permanent and flight data transmitted for the purpose of en-route charges can be used for calculating terminal charges, collection costs are minimised.

---

37 These are Croatia, Denmark, Hungary, Ireland, Italy, Lithuania, Moldova, the Netherlands, Slovenia and France.
5.4 Determination of ANS charges

5.4.1 Cost categories considered

The ICAO rules require that the costs to be recovered by ANS charges are determined in accordance with generally accepted accounting principles. National accounting practices (for the treatment of interests, the taking over of write-offs and the provision of doubtful accounts) can be applied as far as they do not deviate from generally accepted accounting principles. Depreciation rules relating to taxation purposes have to be disregarded wherever they differ from the common principles. The Eurocontrol charging schemes for en-route and terminal charges follow these rules.

Both en-route charges as well as charges for approach and aerodrome control are based on a full-cost principle. Given the EU charging policy which postulates the social marginal cost principle as the leading charging principle, the potentials of introducing the SMCP principle in particular for terminal charges has been discussed (see for example PriceWaterhouse (2001)).

The types of costs eligible for recovery via air navigation serves charges are

- staff costs,
- other operating costs (purchase of goods and services to provide navigation services, in particular outsourced services),
- depreciation costs relating to the total fixed assets in operation for the respective navigation service,
- cost of capital calculated as the average net book value of fixed assets and the weighted average of the interest rate on debts and of the return on equity,
- exceptional items such as non-recoverable taxes and custom duties paid.

The Eurocontrol member states report a forecast of these costs in their country for the subsequent year t+1 to the CRCO. The costs of EUROCONTROL are added and the costs for exempted flights are deducted. The obtained costs are divided by the service units forecasted for t+1 in order to yield the unit rate for the respective charging zone.

Details for determining and calculating these cost categories are given in CRCO 2003 and are not discussed further in this paper. CRCO 2003 gives also further explanations on the treatment of write-offs, provisions for doubtful accounts, the issue of high inflation and on the application of the methods of Current Cost Accounting (CCA).

5.5 Calculation of ANS charges

5.5.1 En-route charges

En-route charges constitute remuneration for i) the costs incurred by States and Air Navigation Service Providers in respect of en-route services, ii) the costs incurred by Eurocontrol.

The en-route charges are calculated by considering three basic elements:

- the aircraft weight factor,
- the distance factor,
- the unit rate of charge for each charging zone.

The total en-route charge per flight is the sum of all charges collected in each charging zone i (i = 1... n)
The charges to be paid in each charging zone are calculated as
\[ r_i = d_i \sqrt{\frac{MTOW}{50}} t_i \]
where \( d_i \) is the distance factor, \( MTOW \) is the maximum take-off weight\(^{38} \) and \( t_i \) is the unit rate of charge for each charging zone \( i \).

Distance factor
The distance factor \( d_i \) is calculated as \( 1/100 \) of the great circle distance, expressed in kilometres, between the aerodrome of departure within the charging zone \( i \) and the aerodrome of first destination within that charging zone. The entry and exit points are the points at which the lateral limits of the charging zone are crossed by the route described in the flight plan. The distance to be taken into account is reduced by a notional twenty kilometres for each take-off and for each landing within a Charging zone \( i \) (see section 5.2).

Weight factor
The weight factor is given by the second term in formula (37). The division of the maximum take-off weight by 50 was introduced because the average take-off weight of the most frequently flown aircraft at that time was 50t. The division by 50 implies that for a flight with an aircraft of 50t and a distance factor of 1 (100 km) the en-route charge equals the unit rate.
According to ICAO, the weight factor should be taken into account with a digressive effect in air navigation charges which is achieved by using the square root formula. However, in terms of cost responsibility, the principle of applying a weight factor at all is still debated as, for a controller, a blip is a blip on the radar screen with no difference of cost causation between aircraft types. Other proxies such as time in flight have been studied but rejected. The weight factor was introduced to reflect the capability to pay with a digressive effect, e.g. larger and heavier aircrafts with more passengers and cargo pay a higher charge than smaller and lighter aircrafts. The power factor itself has also been debated. For terminal charges, some states apply a 0.9 factor which gives an advantage to light aviation (below 50 tons), generally performing short flights. For en-route charges with a power factor of 0.5, this advantage is reduced, which corresponds better to the “a blip is a blip” philosophy.

Unit rate
The unit rate \( t_i \) for flights in a charging zone \( i \) is the charge in Euro applied to a flight operated by an aircraft of 50 metric tonnes (weight factor of 1.00) and flying 100 kilometres (distance factor of 1.00) in the charge area of the respective country responsible for that charging zone. It is determined for specific periods and is published by Eurocontrol on its website and by the member states. It consists of two parts:
- The unit rate.
It is obtained by dividing the forecasted cost base for the en-route facilities of the Charging zone concerned for the reference year by the forecast number of service units to be generated in the airspace of that Charging zone during the same year.

\(^{38} \) Where the maximum take-off weight authorised of the aircraft is not known to the CRCO, the weight factor is calculated by taking the weight of the heaviest aircraft of the same type known to exist
The purpose of the administrative unit rate is to recover the costs of collecting route charges (CRCO costs). It is obtained by dividing these costs by the number of service units generated in the Eurocontrol charging area as a whole. The component of the unit rate representing the CRCO costs therefore is identical in all Charging zones.

\[
p_i = \left( \frac{MTOW}{50} \right)^p
\]

with \( p = 0.7 \).

During a transitional period of five years following the calculation of the first terminal unit rate under the regulation it is allowed to vary the exponent \( p \) between 0.5 and 0.9.

**Figure 7. Average Unit Rates as part of ANS charges in 2007**

**5.5.2 Terminal charges**

Terminal charges are raised to recover the costs of air navigation services during the aerodrome and the approach phase of flights. With the EC regulation 1794/2006 a harmonised calculation scheme also for terminal charges has been adopted. According to this regulation, the terminal service unit rate shall be equal to the weight factor for the aircraft concerned whereby the weight factor \( w_i \) is determined by a formula similar to the weight factor calculation for en-route charges as

\[
w_i = \left( \frac{MTOW}{50} \right)^p
\]
6 Congestion and scarcity costs

The relationships between congestion and scarcity are easy to understand from a theoretical point of view. In fact, congestion refers to the costs arising from crowding effects (i.e. too many users in the system), while scarcity effects occur in a situation of exclusion of some firms from the system due to lack of capacity.

However, the practical disentangling of congestion and scarcity causal relationships with the delays suffered by airport users is by far more complex, since delays are not only driven by airports capacity constraints such as the scarcity of slots, but also by demand factors (e.g. that fact that airlines operate in waves). This implies that delays are the consequence of system overload, which is linked, in many cases, to profit maximizing decisions of airport managers and airlines, e.g. airlines may have the interest in accommodating as much demand as possible and pushing therefore airports to exploit capacity till the upper limit.

According to a research paper, “the airline companies themselves are by far the main contributors for delays, causing in Europe approximately 50% of late departures. Airports are considered to be responsible for delays in 19% of the cases, en route problems account for 11%, adverse weather is a serious factor with 13%, security procedures are responsible for 4% of the delays and a residual 3% for all other problems. The relative share of airport related delays compared to en route delays tends to increase by the years”39.

The difficulties in disentangling scarcity and congestion lead in practice to cope with delays without differentiating between the two causal factors. For example, congestion at airports is generally addressed through the application of peak and off-peak charges that are generally only related to scarcity.

Such practices also lead to ignore the evaluation of congestion in terms of opportunity costs (i.e. the value of time and resources lost due to delays). Concerning scarcity, recent trial experiments in the United States Airports have developed market based slot allocation as a way to solve scarcity problems. If primary auctioning of slots happens, then secondary trades can take place and the system could go towards an increasing transparency. However, it is underlined that devoting efforts to solve scarcity not necessarily leads to solving congestion problems: in fact it might happen that, if capacity is increased, a newly generated demand appears and congestion is not eased.

Summing up, delays in airports are the results of several factors, i.e. mismanagement at airport level, delays in airspace operations, capacity constraints, etc. The current evaluation practices are mainly based on peak/ off peak charges (an indicator of scarcity), neglecting a proper evaluation of congestion costs in terms of monetary evaluation of delays imposed to passengers and airlines.

This chapter provides an assessment of the various components of congestion and scarcity costs, namely:

- an assessment of congestion costs based on the value of time and delays per passenger and aircraft (section 6.1)
- an assessment of scarcity costs based on an evaluation of the implementation of the secondary trade for slot allocation (section 6.2)
- an assessment of the airspace congestion costs (section 6.3)

The congestion costs are assessed through a modelling approach, the assessment of scarcity costs and delays from airspace operations rely on literature review.

6.1 Congestion costs

6.1.1 The model

The modelling approach adopted for the assessment of congestion costs in airports, i.e. congestion costs for passengers and airlines, identifies the following key variables: a) the air traffic movements (arrivals and departures) and b) the airport capacity.

In order to evaluate the effect of a marginal aircraft movement in terms of delays, it is necessary to estimate an equation of the minutes of delay as a function of the number of aircraft traffic movements (ATMs) and other possible determinants which can explain the phenomenon of delays.

Regarding this issue, the modelling approach tries to incorporate the capacity of the airport and whether the airport is operating under congestion conditions or not. In order to evaluate the volume of total costs, the modelling approach performs then a second step using some average number of passengers and ATMs to multiply by a value of time of passengers involved and a value of time of the airplanes which cannot be used optimally by the airline.

In this exercise, the model has omitted considerations about network or spill-over effects, to complex to be taken into account. This implies that a more detailed analysis of the effect of delayed flights using data on average delays calculated over time-frame interval would be necessary, because it is well known that each delayed flight generates an impact that lasts significantly during at least two hours since the moment the flight is authorized to use the airport out of the initially planned schedule.

The data sets of the model uses a database with 360 observations from Airline Service Quality Performance (ASPQ) database. The US Department of Transportation (DOT) is in charge of this database which is designed to measure whether carrier flight performance meets published carrier schedules, either from OAG or carrier reservation systems. The ASQP contains data provided by the airlines by flight for airlines that carry at least 1% of all domestic passengers. They have been required to report on-time performance data since 1987. As of mid-2003, the airlines began reporting data on the cause of delays as well. Therefore, flight data are required to be reported for major carrier operations to and from the 31 large hubs. In practice, the carriers report all scheduled service flight data. It is important to realize that the ASQP data is only available for the airlines required to report on time performance. As such, regional carriers are not included in this data set; however, the ASQP data generally accounts for approximately 50 percent of the IFR flights at the busiest airports in the country each day and about 85 percent of the domestic operating revenues. The number of airlines providing data has varied from 10 to 20.

Each record of this database corresponds to a non-stop flight, which is counted as delayed when it does not pull back from the departure gate within 15 minutes of scheduled departure time, or if it does not arrive at the arrival gate within 15 minutes of the scheduled arrival time. Actual and scheduled time is available for gate departure and gate arrival. The airlines also provide the actual wheels-off time so that taxi-out time can be computed and wheels-on time so that taxi-in time can be computed. This is often referred to as Out, Off, On, In (OOOI) data. By looking at the time between the scheduled and actual pushback times, the actual amount of gate delay can be calculated, once adjusted for different time zones. Additionally, it
also accounts for the causes of delay, which include categories such as the Airline, Extreme Weather, National Aviation System, Security, and late arriving flight. The data is available from June 2003 and is updated on a monthly basis.

The 360 observations correspond to 30 airports for each of the 12 months included in the sample for the year 2005. For each observation, we have obtained the number of minutes of schedule delay, the maximum capacity of the airport and the number of ATMs. (drivers and dependent variable (delay))

Another simplification of the model consists in supposing that there is not any significant difference looking at the time of the day. However, it is well known that the number of flights and passenger varies at each hour-interval H of the period in which the airport is open. Therefore the impact of a delayed flight entering the airport at 10:00 am is different to that of a delayed flight at 21:00 pm (the impact is much lower for the latter, because airport activity slows down after 22:00 pm).

It is important to stress that the output of the model estimates marginal congestion for an addition ATM, but it is out of the scope of our model to study and analyze the process and the causes of airport congestion generation. For this reason, we have followed a pragmatic approach and we estimate a simple model of the effects of each ATM over the total delay minutes for all flights, taking complete months as the unit of observation. We have also included the effect of whether the airport is operating near declared capacity or not by a variable named congestion. The model presents the following analytical form:

\[
delays_{am} = \alpha + \beta_1 atm_{am} + \beta_2 atm_{cong_{am}}
\]

where delays is the total number of minutes of delays for all the flights which land at the airport during each month for the year 2005; atm is the number of aircraft traffic movements that land at the airport during the month; and finally congestion is a continuous variable defined as the quotient between atm and the declared peak capacity of the airport, i.e. is the average utilization of the airport.

Before estimation, one can expects that both coefficients were positive, indicating that large and congested airports suffer more congestion. All the variables were transformed to logarithms.

The model was estimated for arrivals using monthly samples for the 30 busiest airports included in the sample. Results indicate that both determinants affect positively to the total delayed minutes of flights.

Table 19 shows the results obtained for the congestion model, which is estimated through a simple linear model. It can be seen that the model fits adequately, and approximately 86% of the dependent variable’s variance can be explained by the independent variables included in the model. All regression coefficients have the expected signs and they are all statistically significant at a 95% level of confidence.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log(atm)</td>
<td>1.289</td>
<td>288.45</td>
</tr>
</tbody>
</table>
Its important to remark that the model is not linear in the parameters. For this reason we can estimate point elasticities for each observation. Both coefficients are statistically significant, and they reflect that the total delayed minutes for each airport is directly related to number of air traffic movements and the level of congestion measured by the proportion of use with respect to the declared capacity of the airport.

The estimated coefficients presented in Table 19 can be used to derive marginal congestion costs and elasticities for air transport. Multiplying those coefficients by the total number of flights and passengers using some airport on average during one month of each of the periods of reference, it is possible to calculate the amount of total extra time that one aircraft movement imposes on airlines and passengers.

Figure 8 shows the ATMs elasticities of the total delayed minutes. It can be seen that the figures are quite stable in the interval 1.44-1.54, and it seems to be an increasing function of ATMs, so large airports present a higher elasticity.

Figure 9 shows the marginal costs estimation (in minutes) for an additional ATM. Now, it can be seen that the figures are not as stable as in the previous figure. However, the tendency seems to be an increasing function of ATMs, so large airports present higher marginal costs, and 20 minutes seem to be a reasonable figure for the whole sample.
So, in summary the modelling approach for the assessment of congestion is quite simple. The user only needs to provide the following inputs:

- Expected arrivals
- Peak hour arrival capacity
- Closed at night? (0 for no, 1 for yes)
- Days in the month

Once the information has been provided it is possible to calculate the ATM elasticity of the total delayed time, and the marginal congestion cost calculated as minutes per additional arrival movement.

### 6.1.2 The results

The modelling approach described in the above section has been embedded in the GRACE tool, developed in the context of the EC research project GRACE in the Sixth Framework Programme\(^\text{40}\). The tool provides short-cut approaches and methods for the estimation of marginal external costs of transport where all the required information is not available.

For the airports of Madrid Barajas and Rome Fiumicino the following data have been collected:

- Expected yearly arrival
- Peak hour arrival capacity
- Closed at night? (0 for no, 1 for yes)
- Days in the month
- Passengers (arrivals)

---

Concerning the quality of data collection, it is important to remark the following caveats:

- Data have different time reference years: an average between 1997 and 2000 for the Madrid Airport and 2007 for the Rome Airport.
- Passengers arrivals have been estimated on the basis of the proportion of the number of flights (arrival and departures) only available for the Madrid Airport (1997-2000).
- The Peak hour declared capacity refers to 2004\(^{41}\), before the opening of the new Madrid airport terminal.

The results in terms of marginal congestion costs per passenger and airlines are the following:

### Madrid Barajas airport

<table>
<thead>
<tr>
<th>Marginal congestion cost</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger (€)</td>
<td>6.27</td>
</tr>
<tr>
<td>Airline (€)</td>
<td>1970</td>
</tr>
<tr>
<td>Marginal arrival delay (minutes)</td>
<td>23.6</td>
</tr>
</tbody>
</table>

### Rome Fiumicino airport

<table>
<thead>
<tr>
<th>Marginal congestion cost</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger (€)</td>
<td>5.53</td>
</tr>
<tr>
<td>Airline (€)</td>
<td>1740</td>
</tr>
<tr>
<td>Marginal arrival delay (minutes)</td>
<td>20.9</td>
</tr>
</tbody>
</table>

---

\(^{41}\) EUROCONTROL, “Report on Punctuality Drivers at Major European Airports” Prepared by the Performance Review Unit - May 2005
The Madrid airport shows higher passenger and airlines congestion costs, respectively €6.2 and €1970 per aircraft compared to €5.5/passenger and €1740/aircraft in the Rome airport. A decisive parameter is the declared peak hour capacity; after the opening of the new terminal in Madrid when the peak hour capacity was doubled from 40 to 80, the corresponding results reduce the average delays and marginal costs for passengers and airlines, as shown in the following table.

<table>
<thead>
<tr>
<th>Madrid Barajas airport capacity double</th>
<th>Marginal congestion cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger (€)</td>
<td>5,20</td>
</tr>
<tr>
<td>Airline (€)</td>
<td>1636</td>
</tr>
<tr>
<td>Marginal arrival delay (minutes)</td>
<td>19,6</td>
</tr>
</tbody>
</table>

The monetary evaluation of congestion costs is based on the UNITE project\(^{42}\), taking as reference the following rates per hour: 15.9 € for passengers and 5,000 € for airlines.

The marginal congestion costs per passengers are consistent with the UNITE case study in the Madrid airports\(^{43}\), estimating average congestion costs per passenger between €4.5 and €5.

### 6.2 Scarcity costs

Scarcity costs are related to the existence of demand excess, leading to potential revenues lost by airlines, sub-optimal use of landing slots and limited competition among incumbents.

The direct estimation of scarcity costs is difficult because one would need to determine the opportunity costs of each slot, i.e. what is the foregone revenues by potential users compared to revenues earned by airlines that currently use them. Furthermore, when the next best use is by the same operator, scarcity costs are internalised, because the incumbent airline will already have considered the alternative uses of the slot.

As mentioned in the section 6.1, the introduction of secondary trade of slots in the US and UK airports of London Heathrow and London Gatwick in 2005 is a potential measure for the determination of the economic value to the slot for the users, through his willingness to pay for that, improving in such a way the overall transparency.

On the cost side, an interesting approach has been developed by the assessment study carried out by Mott Mac Donald in 2006 on behalf of the EC DG TREN\(^{44}\).

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42 UNITE (2002) “UNIfication of account and marginal Transport costs Estimates”, Del 7i
43 UNITE (2002) “UNIfication of account and marginal Transport costs Estimates”, Del 7i
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The study aims at providing an evaluation of the scarcity costs indirectly, i.e. through the assessment of the total economic impacts (benefits and costs) arising from the full development at 2025 of the secondary trading of slots in the European airports.

In such a way, the scarcity costs can be interpreted as the loss of benefits determined by the misallocation of the slots. This is probably only a fraction of the true scarcity costs, i.e. the costs of having less flights compared to the potential demand. However, it may provide an insight towards the evaluation of the order of magnitude of the scarcity costs.

The first step is the assessment of the impacts of the development of secondary market for slots in all the European most congested airport at 2025, on the basis of the Eurocontrol forecasts45.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ATM's - flights</td>
<td>2,705,000</td>
<td>2,705,000</td>
<td>5,841,000</td>
<td>5,841,000</td>
<td>-</td>
</tr>
<tr>
<td>Passengers per flight</td>
<td>107.9</td>
<td>106.7</td>
<td>122.6</td>
<td>131.4</td>
<td>+7.2%</td>
</tr>
<tr>
<td>Passengers (mm)</td>
<td>291.9</td>
<td>288.7</td>
<td>716.0</td>
<td>767.6</td>
<td>+7.2%</td>
</tr>
<tr>
<td>Revenue Pax Kms (mm)</td>
<td>870,347</td>
<td>836,403</td>
<td>2,475,224</td>
<td>2,897,722</td>
<td>+17.1%</td>
</tr>
<tr>
<td>Passenger Revenue ($mm)</td>
<td>70,092</td>
<td>74,236</td>
<td>211,104</td>
<td>241,861</td>
<td>+14.6%</td>
</tr>
</tbody>
</table>

Source, Mott MacDonald (2006), chapter 9, page 30

The table shows that the development of the secondary market for slots will determine the increase of the loading factors (+7%) of the flights and the corresponding major revenues. The higher occupancy rates are the resulting evidence from the practical implementation of the mechanism, for which the substitution of short-haul services operated by small aircraft with long-haul, large aircraft services with more seats have been observed.

Other direct and indirect impacts for which a quantification has been made possible are the following:

- Welfare effects. The effects in terms of total welfare are estimated to increase by up to €32.2bn per annum as a result of more revenues (producer welfare) and lower fares (consumer welfare), as consequence of flights often with larger aircraft, becoming available on existing crowded routes and to new destinations. Airport commercial revenues are predicted to increase as well.
- Emissions. The changes in flight mix triggered by the introduction of slot trading will increase CO2 emissions directly from aircraft as well as from the transport used by additional passengers accessing airports. The additional CO2 emissions from aircraft are forecast to be around 8%. The impact cost of this is estimated to be between €1bn and €7bn depending on which impact cost scenario is adopted.

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- Noise. Trading will have a marginal impact, increasing the noise of an average plane by up to 0.52 decibels, including the transfer of displaced routes to secondary airports.

The following table summarises the results:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer welfare</td>
<td>€31 bn</td>
</tr>
<tr>
<td>Producer welfare</td>
<td>0 to €1.2 bn</td>
</tr>
<tr>
<td>Competition</td>
<td>Neutral to slight negative</td>
</tr>
<tr>
<td>CO₂</td>
<td>- €1.3 bn to - €6.7 bn</td>
</tr>
<tr>
<td>NOₓ</td>
<td>- €50 mn to - €134 mn</td>
</tr>
<tr>
<td>Noise</td>
<td>Neutral</td>
</tr>
<tr>
<td>Local economy</td>
<td>Neutral to slight positive</td>
</tr>
<tr>
<td>Thin community routes</td>
<td>Slight negative</td>
</tr>
</tbody>
</table>

Source, Mott MacDonald (2006), chapter 10, page 45

6.3 Airspace congestion costs

As mentioned in the introduction, en route problems account for 11% of the delays. The causes are manifold. In particular, the presence of inefficient air traffic control (ATC) system can be a hidden cause of this problem. In fact ATC services should be as homogeneous as possible in order to optimize the capacity of airspace. The optimum situation in the EU would be the existence of a very limited number of functional blocs of airspace. But Europe suffered traditionally from a heterogeneous ATC system and from delays in the implementation of more efficient Functional Airspace Blocks46.

The assessment of the costs of congestion from airspace mismanagement ranges from delays to major environmental damages.

According to the Eurocontrol’s Performance Review Commission (PRC)47 estimated the cost to users in the European ATM system to be in the order of three billions euro per annum, as shown in the figure below.

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11% of flights in Europe in 2007 were delayed – up from 10% in 2006. Air traffic flow management (ATFM) delays increased from an average of 1.9 minutes per flight in 2006 to 2.1 minutes per flight in 2007, leading to a total system delay of some 21 million minutes.

The European Low Fares Association estimated that unnecessary route extensions, sub optimum flight profiles, delays, holding patterns, and other inefficiencies of the system, result in some 12 million tonnes of avoidable CO2 emissions annually (or roughly 12% of current emissions in EU airspace)\(^48\).

7 Summary and conclusions

This deliverable 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.

The main goal of this deliverable was to provide marginal cost estimation for the use of airport infrastructure by different airliners and users. This was achieved by the estimation of a 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 other important external costs (congestion, 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 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, and we expect that the Commission could use these values as reference figures for the future.

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 (= ATM737). 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.
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Annex 1. Sample airports

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Annex 2. Long-run model specification

\[
\ln T^{\alpha}_{it} = a_1 + a_2 atm + a_3 pax + a_4 cgo + a_5 rev + \beta_6 wc + \beta_7 wm + \beta_8 wp + \gamma_9 atm*wc + \\
+ \gamma_10 atm*wm + \gamma_11 atm*wp + \gamma_12 pax*wc + \gamma_13 pax*wm + \gamma_14 pax*wp + \\
+ \gamma_15 cgo*wc + \gamma_16 cgo*wm + \gamma_17 cgo*wp + \gamma_18 rev*wc + \gamma_19 rev*wm + \gamma_20 rev*wp + \\
+ \delta_21 wc*wc + \delta_22 wc*wm + \delta_23 wc*wp + \delta_24 wc*wm + \delta_25 wc*wp + \\
+ \delta_26 wc*wp + \rho_{27} atm* pax + \rho_{28} 0.5*cgo * cgo + \rho_{29} 0.5 * rev*rev + \\
+ \rho_7 \xi_m + \rho_8 \xi_p + \gamma_9 atm* \xi_m + \gamma_10 atm* \xi_m + \gamma_11 atm* \xi_m + \gamma_12 atm* \xi_m + \\
+ \gamma_14 pax* \xi_m + \gamma_16 cgo * \xi_m + \\
+ \gamma_17 cgo* \xi_p + \gamma_19 rev* \xi_p + \delta_21 \xi_m * wc + \delta_22 \xi_m * wc + \delta_23 \xi_m * wc + \delta_24 \xi_m * wc + \\
+ \delta_22 \xi_m * wc + \delta_23 \xi_m * wc + \delta_24 \xi_m * wc + \delta_25 wc* \xi_m + \delta_26 wc* \xi_m + \delta_26 0.5* \xi_m * \xi_p + \\
+ \ln(G_{it}) + u_{it} + v_{it}
\]

\[
S^c_{C} = \frac{\beta_6 + \gamma_9 atm + \gamma_12 pax + \gamma_13 cgo + \gamma_18 rev + \delta_21 wc + \delta_23 wc + \delta_23 wp + \delta_26 \xi_m + \delta_26 \xi_p}{G_{it}}
\]

\[
S^c_{M} = \frac{\beta_7 + \gamma_10 atm + \gamma_13 pax + \gamma_16 cgo + \gamma_19 rev + \delta_22 wc + \delta_24 wc + \delta_24 wp + \delta_26 \xi_m + \delta_26 \xi_p}{G_{it} * \xi_m}
\]

\[
S^c_{P} = \frac{\beta_8 + \gamma_11 atm + \gamma_14 pax + \gamma_17 cgo + \gamma_20 rev + \delta_24 wc + \delta_26 wc + \delta_26 wp + \delta_26 \xi_m + \delta_26 \xi_p}{G_{it} * \xi_p}
\]

\[
G_{it} = \left[\beta_6 + \gamma_9 atm + \gamma_12 pax + \gamma_13 cgo + \gamma_18 rev + \delta_21 wc + \delta_23 wc + \delta_25 wp + \delta_26 \xi_m + \delta_26 \xi_p\right] + \\
+ \left[\beta_7 + \gamma_10 atm + \gamma_13 pax + \gamma_16 cgo + \gamma_19 rev + \delta_22 wc + \delta_24 wc + \delta_24 wp + \delta_26 \xi_m + \delta_26 \xi_p\right] / \xi_m + \\
+ \left[\beta_8 + \gamma_11 atm + \gamma_14 pax + \gamma_17 cgo + \gamma_20 rev + \delta_24 wc + \delta_26 wc + \delta_26 wp + \delta_26 \xi_m + \delta_26 \xi_p\right] / \xi_p
\]

\[
\beta_6 + \beta_7 + \beta_8 = 1
\]

\[
\gamma_9 + \gamma_{10} + \gamma_{11} = 0
\]

\[
\gamma_{12} + \gamma_{13} + \gamma_{14} = 0
\]

\[
\gamma_{15} + \gamma_{16} + \gamma_{17} = 0
\]

\[
\gamma_{18} + \gamma_{19} + \gamma_{20} = 0
\]

\[
\delta_{21} + \delta_{23} + \delta_{25} = 0
\]

\[
\delta_{21} + \delta_{22} + \delta_{24} = 0
\]

\[
\delta_{24} + \delta_{25} + \delta_{26} = 0
\]