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Scale economies and marginal costs in Spanish airports

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ABSTRACT

In this paper, we estimate alternative specifications of the Spanish airports' cost function with the objective to provide a comparative analysis on several technological features such as output-specific marginal costs, economies of scale, and the Allen elasticities of substitution. We found evidence of significant and unexhausted scale economies as well as technological development in the Spanish airport industry. The results suggest that traffic consolidation in multi-airport areas such as the Basque Country or Catalonia will result in lower costs for the public operator.

1. Introduction

Airports have been (and still are, in many cases) under public ownership and have been commonly seen as natural monopolies which do not compete with airports in other regions or cities. They were supposed to produce efficiently and apply optimal prices in the interest of the community. Nowadays, however, airport ownership and regulation structures vary widely around the world, and several new managerial approaches are recognized. The impact of airport ownership on cost efficiency was addressed by Oum et al. (2008), which showed that for-profit airports are more efficient[3] than those under other forms of governance and that mixed ownership with a government majority should be avoided in favor of even 100% public airports.

The widely established consideration of transport activities as public services led authorities and regulators to gain interest in issues such as optimal pricing and industry structure. In the airport industry, the choice of any pricing alternative has a direct effect on demand and congestion, and if prices are not optimally set, false capacity investment signals in the long run may be present. The growing economic importance of airports and the budget restrictions imposed by governments on infrastructure investment explain, to great extent, the interest in airport pricing policies. In the same line, main regulatory decisions upon industry structure are usually based on the correct identification of the degree of returns to scale. In such sense, the estimation of cost functions is a suitable approach if adequate data is available.

The econometric estimation of cost functions using aggregated output has been used mainly to analyze the cost structure of the industry, notably whether or not there are economies of scale. These are important for assessing the feasibility of

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[3] In this paper, we suppose that all the airports operate efficiently because we are more interested in dealing with the issue of economies of scale and marginal costs. However, we are aware that our restricted model is somewhat limited in this sense, as other methodologies which impose other restrictive assumptions. For example, DEA imposes constant return to scales and provides misleading results for airports that do not operate at minimum efficient scale. Some other researchers estimate variable factor productivity assuming also constant returns to scale and excluding airport size as an important variable in the calculations. A further discussion of these issues can be consulted at Morrison (2009).

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competition between firms of different size, and the long-run equilibrium of an industry (Oum and Waters, 1996). In the present case, the estimation of the Spanish airports' cost function is aimed at addressing the questions: how many airports would optimally serve a certain region? Will multiple airport systems (MAS) be a better solution to serve a region like Catalonia or the Basque country? Do economies of scale exist? If so, to what extent, or when they are exhausted?

The rest of the paper is organized as follows. The next section describes the econometric issues of the paper. A brief literature review on the estimation of cost functions in the airport industry is discussed in Section 3. The Spanish airport database is described in detail in Section 4, which also focuses on the subject under study: AENA, as the public corporation that owns and manages most of the Spanish airport system. The estimated cost function parameters, from three alterative specifications, are presented and discussed in Sections 5 and 6 summarizes the major findings of this study.

2. The econometric estimation of airports' cost function

The economic theory asserts that economies of scale and marginal costs can be obtained from the industry's cost function. The cost function is defined as the minimum expenditure incurred by the firm to produce the output set Y at input prices ω given actual technology. Thus the firm faces the following problem:

$$\begin{aligned} &\underset{X}{Min}\,\omega X' = \omega_1 X_1 + \cdots + \omega_r X_r \\ &s \cdot t \cdot F(X, Y) \geqslant 0 \end{aligned} \tag{1}$$

where X is the set of inputs.

The solution of (1) is represented by the vector of conditional input demands $X^* = X^*(\omega, Y)$. The cost function is obtained by replacing X^* on the previous objective function, i.e. $C(\omega, Y) = \omega_1 X_1^*(\omega, Y) + \cdots + \omega_r X_r^*(\omega, Y)$, resulting in a long-run (LR) cost function, provided that all inputs may vary in the time period considered. If some inputs are fixed, then the short-run (SR) variable cost function $VC(\omega_v, Y, \bar{X})$ could also be obtained by only considering variable factor prices.

The estimation of C requires observations on costs, outputs and input prices associated to firms whose behaviour is assumed to be cost-minimizing. Some functional form has to be postulated in the stochastic specification of the cost function. Of all functional forms tested over the last 30 years, the transcendental logarithmic "translog" (Christensen et al., 1973) is the most frequently used. It provides a local second order approximation to any cost structure and allows a great variety of substitution patterns. Linear homogeneity can be imposed via linear restrictions to the parameters. It presents this general structure (LR):

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

In addition, the usual practice is to deviate all explanatory variables from an approximation point (usually the mean of the sample). This procedure allows a simple calculation of outputs' cost elasticities (η_j) and the Hessian values (ρ_{ik}), which are essential in identifying scale economies (S) and cost subadditivities (Jara-Díaz, 1983).

The degree of global economies of scale S is a technical property of the productive process which is defined in the transformation or production functions. However, dual relations allow the calculation of S directly from the cost function (Panzar and Willig, 1977) as:

$$S = \frac{C(\omega, y)}{\sum_i \frac{\partial C(\omega, y)}{\partial y_i} y_i} = \frac{1}{\sum_i \eta_i} \tag{3}$$

Analogously, the inclusion of an indicator of capital stock in the short-run variable cost (VC) function allows the calculation of economies of capacity utilization (ECU). Following Caves and Christensen (1988), ECU are defined as the proportional increase in VC resulting from a proportional increase in outputs, holding capital fixed.

$$ECU = \frac{VC(\omega, y, K)}{\sum_i \frac{\partial VC(\omega, y, K)}{\partial y_i} y_i} = \frac{1}{\sum_i \eta_i^{VC}} \tag{4}$$

The translog cost equation is linear in parameters and susceptible to the application of least squares regression techniques. Nevertheless, the translog cost function is commonly estimated jointly with its cost minimizing input cost share equations (obtained via Shephard's lemma) by means of a seemingly unrelated regression (SURE), and using maximum likelihood estimators (Zellner, 1962). This procedure allows researchers to include $(r - 1)$ additional equations to the cost function where r is the number of inputs that have been considered in the model specification.

$$s_i = \frac{w_i X_i}{C} = \frac{\partial C}{\partial w_i} \frac{w_i}{C} = \frac{\partial \ln C}{\partial \ln w_i} = \beta_i + \sum_{j=1}^{m} \delta_{ij} \ln w_j + \sum_{j=1}^{s} \gamma_{ij} \ln y_j \tag{5}$$

Additionally, if time series data is available, a time trend (t) is incorporated into the model in order to account for technical development in the airport industry.

3. Previous studies on airports

Jeong (2005) highlights that only a few studies have dealt with the costs of airport infrastructure services. Nevertheless, the use of very different data and methodologies provides inconsistent findings, mainly related to: (1) major limitations about capital costs and input levels, (2) a partial view of the airport activity, especially while dealing with output definition and (3) the difficulty in collecting comparable data across different airports.

Keeler (1970) estimated two Cobb–Douglas (C–D) partial cost functions[4] for both capital and operating costs, using air transport movements (ATM) as output. He found constant returns to scale (CRS) in airport operations using pooled time series and cross sectional data from 13 US airports between 1965 and 1966. Doganis and Thompson (1973, 1974) also estimated a C–D[5], with separate models for capital and operating costs. They used work load units (WLU)[6] as the output variable. They found increasing returns to scale (IRS) up to 3 million WLU using cross sectional data from 18 British Airports for 1969. However, both studies are limited by a very small database, and, as mentioned, by their partial rather than total approach.

Tolofari et al. (1990) used a pooled database of seven British Airport Authority airports for 1979–1987 to model a short-run total cost (SRTC) function with fixed capital stock. They adopt the translog functional form with WLU as the output; the prices of labor, equipment and residual factors; capital stock; passengers (PAX) per ATM, percentage of international passengers and percentage of terminal capacity as qualitative indicators used in a hedonic approach; and a time trend. Using SURE estimators, they found the existence of IRS up to 20.3 million WLU. This was a significant finding at that moment; however, this result could not be easily generalized because, in the sample, there was only one airport (Heathrow) which operated more than 20 million WLU.

Main et al. (2003) constructed four C–D, alternating between WLU or PAX as the single output, and between including depreciations or not in the calculus of input prices. Other variables are the labor price, price of "other costs", PAX per ATM, the percentage of international passengers, and total assets. The price of labor was estimated by dividing labor costs by the number of full-time equivalent employees. The price of "other costs" was estimated as the relevant expenditure divided by the value of tangible assets. They found IRS till 5 million WLU or 4 million PAX, using a dataset of 27 airports in the United Kingdom for 1988 and other dataset of 44 airports worldwide between 1998 and 2000.

Pels et al. (2003) estimated separate frontiers for both ATM and PAX, using the first predictions as an intermediate input for the second. They found that airports displayed constant returns to scale in ATMs but exhibited increasing returns to scale in APMs. They used data from 34 European airports between 1995 and 1997.[7]

In order to examine economies of output scale under the given state of capital infrastructure and facilities, Jeong (2005), estimated a translog specification for total operating costs, using three different output definitions: passengers, WLU 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.[8] This study found that economies of output scale in the airport industry were present up to 2.5 million PAX or 3 million WLU, using a cross-sectional database from 94 US airports for 2003.

Regarding the literature on marginal cost estimations, a first example is Morrison (1983), who estimated various cost functions in order to compute optimal long-run prices. He obtained $12.34 (1976 dollars) per ATM as the marginal airport cost for maintenance, operations and administration. Link et al. (2006) specified a seasonal autoregressive moving average model (SARMA) to identify a relationship between the number of scheduled person-hours in service area and the traffic measured as ATM. They report an estimation of the marginal cost for an extra ATM of €22.60. However, for international departures this marginal cost ranges between €25 and €72.[9]

4. The spanish airport system

In this study we used data obtained from the public entity that owns and manages the vast majority of the Spanish airport system, including nine of the 50 largest European airports. Aeropuertos Españoles y Navegación Aérea (AENA) enjoys a special statutory regime that allows it to function as a private company in specific areas. As such, AENA is not subsidized by the State, and for this reason, the company has shifted during the last years towards a more commercial orientation.

AENA operates the largest and most geographically diverse airport network in the world. The geographical and climatic diversity of the country, and the variety of industrial, commercial and tourist activities carried out in the different regions, results in each airport having its own peculiarities with respect to the demand they serve. The structure of the Spanish airports is really diverse, and there are different types of airports depending on the traffic they handle. Madrid/Barajas and Barcelona are the main hubs for international and domestic flights. Other important airports are dominated by a high percentage of non-scheduled tourist flights. These are mainly located in the Canary Islands, Balearic Islands and Malaga.

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[4] Tolofari et al. (1990) argued that the separate estimations would result in biased estimates because the error terms are likely to be correlated, and the separate model fails to adequately represent this.

[5] They categorized expenses into total, capital, maintenance, labor, administrative and operating costs. Besides, they considered investments in development and air traffic control services into the cost figures.

[6] WLU is equivalent to one passenger or 100 kg of cargo (Doganis, 1992).

[7] However, they did not consider labor inputs into the model.

[8] As he mentions, an important shortcoming of this study is that consumer rather than producer prices are used in the calculus of the factor price.

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

Table 1
Database overview (monetary variables expressed in thousands 1997 Euros).

	TC	VC	ATM	WLU	PAX	CGO	REV	FTE	RUN
Max.	11,157,601	6582,985	252,428	25,646,280	23,122,000	265,801	9621,676	746	7350
Min.	73,195	47,703	205	3050	1000	0	2249	8	1127
Mean	1446,629	942,602	27,006	2798,349	2528,289	12,203	719,096	162	2897

Although these tourist-dominated airports share common features with respect to peak and off-peak periods, they also have significant seasonal differences. The Balearic and Malaga airports have a peak concentration during the summer months. Meanwhile, the traffic in the Canary Islands is more evenly distributed throughout the year due to the warmer climate conditions that the islands enjoy during winter. In addition, these medium-sized airports also feature a decent amount of scheduled flights to other domestic and international destinations, with frequent connections to Madrid and Barcelona.

Our sample is a balanced pool of 36 airports observed between 1991 and 1997. The data set was collected and compiled by the Economic Central Office of AENA. It provides a wide range of information on some of the important variables required in our study. As the airports differ considerably in size, some of them were excluded from the sample. The number of ATM served at the airport as well as WLU processed in the aircrafts conform the aeronautical output vector (y) in our model.

The aggregate WLU assumes that a passenger (with the luggage) imposes the same costs to the airport infrastructure than 100 kg of cargo. However, according to Doganis (1992), while such a weight relationship seems logical for airlines as it affects aircraft payloads, its relevance to airports is questionable since the same weight of passenger and freight does not require the use of similar resources. However, the quantification of the aggregation bias associated to the WLUs is still to be addressed in the literature. The separate specification of passengers and cargo outputs is not feasible since the latter is not produced in many sample airports and the chosen translog equation is not analytic in zero.

However, as the available data may include the cost of providing non-aviation services, the commercial revenues (REV) were specified as the third output in order to avoid estimation biases. The unit of observation was defined as thousands of Euros of non-aviation revenues. Table 1 provides some descriptive statistics of the estimating sample. The average airport serves 2.8 million annual WLUs and 27,000 annual ATMs with a single runway.

Three variable inputs have been considered in this study for the long-run model, namely, labor, capital and materials. In the short-run version, we have dropped the costs of capital and included the length of runways (measured in meters) as a fixed input. Apart from these variable inputs, we have included the time variable to assess the possible technological changes observed in the period analyzed.

We obtained the price of labor by dividing the total labor costs by the number of full-time equivalent employees of each airport. Due to the scarcity of information, calculation of both capital and materials prices have been considered a very delicate issue in past literature and no satisfactory solution has been proposed to date. In other works, prices were obtained by dividing the respective expenses by an output measure, but this is widely regarded as a very imprecise method. In this work, a slightly more elaborated approach is carried out. We will assume that competitive tendering[10] airports is effective in bringing competition to the airport input markets. Thus, a well known microeconomic result assesses that optimal input prices (profit maximizing) are equal to the value of the marginal product (*MP*) for each input that is obtained by multiplying the *MP* by the output price (P_i). The next step is to search a set of proper proxy factors whose demands should directly explain the aggregated factor expenditure. For example, in the case of a set conformed by two inputs, it can be seen that:

$$C_j^* = w_1^* x_1 + w_2^* x_2 = P_i \cdot MP_1 \cdot x_1 + P_i \cdot MP_2 \cdot x_2 \tag{6}$$

Then each input marginal productivity can be roughly estimated using a primal specification of the *i*-output production frontier.[11]

$$Q_i = Q(x_i); MP_j = (\partial Q_i / \partial x_1); MP_2/MP_1 = \alpha \tag{7}$$

And finally:

$$C_j^* = P_i \cdot MP_1 \cdot (x_1 + \alpha \cdot x_2) = w_1^* I_q w_1^* = C_j^*/I_q, \quad \text{where} \ \ I_q = (x_1 + \alpha \cdot x_2) \tag{8}$$

Therefore, the quantity index I_q is calculated as a weighted sum of input factors taking into account the ratio of the relative marginal productivities of the inputs (α). The more and uncorrelated proxy factors considered, the more precise the estimated equation will be, therefore obtaining better estimations of marginal productivities.

The category of materials includes supplies, maintenance, repair and administration costs as well as outsourced services. The proxy inputs considered for the calculation of the price of materials were both the number of boarding gates (GAT) and

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[10] Capital and supply contracts are usually awarded through competitive tendering. This practice is common both in public and in privatized airports (e.g. BAA). In addition, the new technologies provide larger coverage of the market, giving the airports access to information on potential suppliers on a worldwide basis.

[11] For simplicity reasons, the estimated production frontiers were specified in the Cobb–Douglas form.

Table 2
Monoproduct LR cost function. Estimation results.

Variable	Coefficient	Std. error	t-Statistic	Prob.
Constant	13.49210	0.009275	1454.693	0.0000
WLU	0.697650	0.005211	133.8917	0.0000
Capital	0.328634	0.006147	53.46017	0.0000
Materials	0.254692	0.009928	25.65500	0.0000
Labor	0.444000	0.006218	71.40127	0.0000
WLU * capital	0.004358	0.005120	0.851256	0.3948
WLU * materials	0.079628	0.014703	5.415719	0.0000
WLU * labor	−0.067977	0.005748	−11.82712	0.0000
Materials * capital	0.011691	0.013103	0.892225	0.3725
0.5 * Materials * materials	0.172921	0.040635	4.255468	0.0000
0.5 * Capital * capital	0.032190	0.013078	2.461466	0.0140
Materials * labor	−0.093924	0.015303	−6.137559	0.0000
Capital * labor	2.70E−05	0.014828	0.001819	0.9985
0.5 * Labor * labor	0.094430	0.112414	0.840023	0.4011
0.5 * WLU * WLU	0.086298	0.006936	12.44183	0.0000
Time	−0.008873	0.003430	−2.586549	0.0098
Time * labor	−0.003920	0.003562	−1.100317	0.2715

$R^2 = 0.966662$.

the number of check-in desks (CHK). The original model featured the total warehouse area (WAR), but it was later removed because of the lack of significance. Their marginal productivities were measured in terms of WLU because passengers and freight are the most material-intensive outputs.

Capital costs encompass interest paid and economic depreciation of the airport's fixed capital assets such as landside buildings or the airside movement areas. The proxy variables used as input factors were the total gross floor area of terminal buildings (TER) and total runway length (RUN), excluding general aviation runways where possible. Marginal productivities were calculated against the ATM variable because it is the most capital- intensive output, thus minimizing the aggregation bias related to the use of single-output production frontiers.

All monetary variables were deflated by the consumer price index of the National Statistics Agency (INE). Furthermore, we decided not to account for price differences across regions because many items, including labor, are centrally acquired by AENA. Finally, in order to provide an easy calculation of output cost elasticities (see previous section), the outputs and prices are deviated with respect to the mean of the logged variable, e.g.

$$\mathrm{Atm} = \ln(\mathrm{ATM}) - \overline{\ln(\mathrm{ATM})} \tag{9}$$

These variables have a clear meaning and the fact that the source of the data is AENA, clearly helps in reducing the problems of comparability. This is especially true in regard to the capital cost. Further homogenisation is achieved by excluding some small and specialised airports that cannot be classified as commercial airports. We have tried unsuccessfully to expand our sample period to include more recent years, but AENA is reluctant to release more recent information.

5. Estimation results

In this study, we estimate both mono and multiproduct long-run cost functions, as well as a short-run multiproduct specification.

5.1. The long-run monoproduct model

The long-rung monoproduct cost function features *WLUs* as the only output variable, as well as the prices of *capital*, *materials*, and *labor*. The model is completed with a time trend. The cost system also includes the cost share equations and other common regularity restrictions such as linear homogeneity in prices. The estimation results corresponding to this model are shown in Table 2.

The most important parameters[12] present the correct signs and are significant at the 95% confidence level. The sign of the time coefficient suggests the existence of some degree of technological progress. Additionally, the regularity conditions at the sample mean are satisfied, that is, the cost function is non-decreasing and concave in input prices and increasing in output. Regarding output elasticity, we observe a strong positive relationship between the total cost and the number of WLU served. In other words, 1% increase in WLU, produces 0.69% increase in total cost, *ceteris paribus*.

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[12] Note that the assumption of a Cobb–Douglas production for the Spanish airports is clearly rejected because the majority of the second-order parameters are significant and different from 0.

Table 3
Multiproduct LR cost function. Estimation results.

Variable	Coefficient	Std. error	*t*-Statistic	Prob.
Constant	13.60238	0.006754	2013.960	0.0000
Atm	0.415125	0.017597	23.59120	0.0000
WLU	0.128934	0.021487	6.000526	0.0000
REV	0.204375	0.011559	17.68163	0.0000
Capital	0.338996	0.004220	80.33301	0.0000
Materials	0.215037	0.006988	30.77191	0.0000
Labor	0.457725	0.004195	109.1178	0.0000
Atm * capital	0.020008	0.017060	1.172817	0.2412
Atm * materials	0.000964	0.027504	0.035034	0.9721
Atm * labor	0.003942	0.020905	0.188584	0.8505
WLU * capital	0.078038	0.018050	4.323381	0.0000
WLU * materials	−0.182337	0.029301	−6.222818	0.0000
WLU * labor	−0.156824	0.020323	−7.716678	0.0000
REV * capital	−0.065136	0.010860	−5.997614	0.0000
REV * materials	0.182414	0.012443	14.66020	0.0000
REV * labor	0.067925	0.012200	5.567463	0.0000
Materials * capital	0.012832	0.012587	1.019462	0.3082
Materials * materials	−0.199805	0.035987	−5.552083	0.0000
Capital * capital	0.093878	0.013301	7.058092	0.0000
Materials * labor	−0.144465	0.013937	−10.36552	0.0000
Capital * labor	−0.008466	0.014466	−0.585233	0.5585
Labor * labor	0.060125	0.075206	0.799475	0.4242
Atm * WLU	0.016210	0.002704	5.995646	0.0000
Time	−0.015047	0.002264	−6.645948	0.0000

R^2 = 0.987728.

5.2. The long-run multiproduct model

In the multiproduct model we consider the same functional form as in the previous case, but now the output vector includes both ATMs, WLUs and the commercial revenues (REV) as well. The interaction between ATMs and WLUs was specified. Other interactions (i.e. WLU and REV) were initially specified as well, but later removed because of the lack of significance. The results of this model are shown in Table 3. It can be seen, that this specification again shows a very good performance; correct signs and a high level of significance for most of the parameters; and, as expected, the global adjustment of the model measured by R^2 has been increased.

We also observe that some parameters are not really affected by the inclusion of an additional output, namely, the first-order price parameters and the constant. This result is absolutely consistent, because these parameters are associated with the expenditure shares of each input category and the average cost at the approximation point. In addition, note that the time trend is now fully significant allowing us to conclude that technological progress was present. Again, the model satisfies the regularity conditions at the sample mean. Focusing on the output elasticities, we observe a strong positive relationship between cost and output. Hence, it can be deduced that 1% increase in WLU, ATM and REV produce only 0.41%, 0.12% and 0.20% increase in the total cost, respectively.

Since the cost function describes the technology, the degree of substitutability among the production factors can be analyzed using the Allen's elasticities of substitution (AES). These are related to the cross-price elasticity of input demands according to the following expression (Allen, 1938):

$$\sigma_{AES_{ij}} = \frac{\lambda_{ij}}{s_j} \quad \text{where } \lambda_{ij} = \frac{\partial x_i}{\partial w_j}\frac{w_j}{x_i} \quad \text{and} \quad s_j = \frac{w_j x_j}{C} \tag{10}$$

Higher values of AES indicate greater flexibility in the use of input factors, i.e. airports are able to substitute one factor with another without sacrificing excessive output. Conversely, negative AES implies rigidity in the combination of inputs. The estimated Allen's elasticities (see Table 4) suggest very limited possibilities for substitution among the different pairs of production factors. In fact, labor is a net complement for materials at some airports. All point estimates are numerically small, and cross elasticity between labor and capital is close to unity. Capital and labor are substitutes as automation replaces the use of manual labor in some processes. For instance, aerobridges or self check-in counters are both a form of capital investment in substitution of human labor. This trend started during the period under study but it is more noticeable nowadays.

The same patterns hold for the cross elasticity between capital and materials but with higher possibilities of substitution. Looking at the own price elasticities, it can be seen that the expected signs are present, and that demand for labor is by far the most elastic.

Table 4
Allen elasticities of substitution. Mean (std. dev.).

Variable	Mean	Std. dev.	Min	Max.
Labor	−23.76302	7.529695	−84.97264	−13.96
Capital	−2.361224	0.6385081	−4.576755	−0.2342691
Materials	−4.387117	2.22154	−14.5813	−1.143015
Lab_Cap	1.029956	0.0066035	1.019939	1.05904
Lab_Mat	−0.1055313	1.075937	−16.01041	0.3810188
Cap_Mat	1.972723	0.6339378	1.315005	7.030015

5.3. The short-run multiproduct model

In the short-run model the airport's capital assets are assumed to be fixed, that is, they cannot be easily adjusted to meet capacity requirements in the short run. In this case, we use the sum of materials and labor costs as the dependent variable and the price of capital is substituted by the runway length as the fixed production factor. The estimated coefficients are presented in Table 5.

Many second-order interactions between the fixed factor and other variables were non-significant and therefore removed from the final specification. However, it is worth noting that the significance of the two remaining fixed factor parameters could imply some degree of short-run disequilibrium. Additionally, the first-order ATM parameter is less significant than in the previous model, reinforcing the idea that this output is more capital intensive and, therefore, is not a good regressor to explain the short-run cost variability. In spite of that, correct signs of the estimated parameters, significant output cost elasticities and technological progress still remain in this short-run version.

5.4. Returns to scale and marginal costs

Returns to scale are obtained through expression (3). Marginal cost estimates are easily calculated from the expression:

$$\frac{\partial C}{\partial y_i} = \frac{\partial \ln C}{\partial \ln y_i}\frac{C}{y_i} = \left(\alpha_i + \sum_{j=1}^{s}\rho_{ij}(\ln y_j - \overline{\ln} y_j) + \sum_{j=1}^{m}\gamma_{ij}\ln(w_j - \overline{\ln} w_j)\right)\frac{C(\omega, Y)}{y_i} \tag{11}$$

where the term in brackets represents the output-specific cost elasticity. Table 6 shows the airports' marginal costs estimates obtained from the different model specifications and Fig. 1 presents the corresponding kernel density graphs.

The long-run monoproduct cost function exhibits important IRS (1.47 for the average airport) which cannot be rejected (using the Wald test) at a reasonable level of significance. Keeping everything else constant, this result implies that the average cost will fall as more WLU are served. This result is similar to those obtained in other previous studies, however the IRS figure seem to be a bit overestimated, which could be explained by the small size of the average Spanish airport. This result justifies the extension of the model considering the multi-output airport activity. The marginal cost estimation for the average airport is 7.10 Euros per WLU. Although some outliers are present in the sample, this figure is lower than 3 Euros per WLU in the airports with highest levels of traffic.

Table 5
Short-run variable cost function. Estimation results.

Variable	Coefficient	Std. error	*t*-Statistic	Prob.
Constant	13.21860	0.009338	1415.638	0.0000
Atm	0.061218	0.026851	2.279914	0.0229
WLU	0.260004	0.033486	7.764530	0.0000
REV	0.270204	0.019118	14.13334	0.0000
Run	0.171408	0.032096	5.340397	0.0000
Materials	0.332894	0.008881	37.48490	0.0000
Labor	0.682707	0.006532	104.5096	0.0000
Atm * materials	−0.024595	0.035354	−0.695681	0.4868
Atm * labor	−0.021291	0.022066	−0.964885	0.3349
WLU * materials	−0.226774	0.040426	−5.609642	0.0000
WLU * labor	−0.175101	0.030268	−5.784945	0.0000
REV * materials	0.244568	0.019459	12.56806	0.0000
REV * labor	0.083011	0.017499	4.743785	0.0000
Materials * materials	−0.263900	0.052292	−5.046709	0.0000
Materials * labor	−0.186339	0.018620	−10.00724	0.0000
Labor * labor	0.232261	0.114385	2.030520	0.0427
Atm * run	0.055780	0.013139	4.245433	0.0000
Time	−0.020776	0.003503	−5.930424	0.0000

$R^2 = 0.971340$.

Table 6
Returns to scale, economies of capacity utilization and marginal costs. Individual estimates.

Airports	Pax (10^3)	ECU SR	RTS mono LR	RTS multi LR	Marginal costs (EUR)						
					Mono LR	Multi LR			Multi SR		
					WLU	ATM	WLU	REV	ATM	WLU	REV
Alicante	4398	1.57	1.21	1.12	3.45	166.03	0.81	1.42	18.87	0.62	1.15
Almeria	714	1.78	1.44	1.18	8.64	254.85	1.42	6.22	27.90	0.99	3.85
Asturias	595	2.13	1.41	1.19	8.24	200.05	0.94	7.54	14.38	0.77	4.78
Badajoz	18	7.66	1.88	1.31	39.32	299.17	–	–	10.80	–	–
Barcelona	14,561	1.48	1.06	1.08	2.50	84.46	0.62	1.73	13.20	0.46	1.01
Bilbao	1970	1.73	1.29	1.16	4.24	109.62	0.71	4.13	9.89	0.56	1.13
Cordoba	1	–	2.03	1.28	699.85	1828.83	–	–	–	–	–
Fuerteventura	2440	1.60	1.29	1.15	3.32	128.75	0.68	2.69	11.91	0.53	1.29
Girona	507	2.07	1.46	1.15	14.75	628.82	2.85	6.79	36.30	1.07	4.17
Gran Canaria	7927	1.59	1.13	1.10	3.10	135.95	0.77	2.43	14.47	0.55	1.99
Granada	447	2.04	1.45	1.18	10.70	265.33	1.46	9.46	24.04	0.93	7.89
Hierro	97	2.63	1.72	1.24	21.12	246.27	1.67	17.55	2.09	1.06	11.86
Ibiza	3528	1.42	1.27	1.14	3.13	113.46	0.77	1.31	12.85	0.60	0.75
Jerez	453	2.79	1.38	1.19	10.22	259.48	0.64	9.19	15.59	0.46	6.10
La Coruña	398	2.13	1.48	1.21	9.45	203.95	1.04	9.34	12.40	0.85	6.45
La Palma	696	1.78	1.45	1.19	7.08	151.82	1.05	8.81	12.36	0.86	5.98
Lanzarote	4005	1.19	1.34	1.16	2.10	78.87	0.60	0.72	9.97	0.53	0.47
Madrid	23,122	1.54	1.01	1.06	2.64	123.19	0.72	1.44	18.92	0.45	0.78
Malaga	7190	1.72	1.12	1.10	3.58	172.33	0.80	1.81	18.27	0.57	1.45
Melilla	352	1.50	1.70	1.25	7.98	82.79	1.21	16.14	4.91	1.19	10.82
Menorca	2232	1.47	1.33	1.15	3.97	122.31	0.90	1.86	12.14	0.71	1.47
Murcia/San Javier	108	2.57	1.67	1.25	22.89	258.95	1.30	13.85	17.96	1.13	8.57
Palma de Mallorca	16,449	1.56	1.04	1.08	2.40	130.95	0.57	2.26	22.21	0.46	1.20
Pamplona	288	1.86	1.56	1.23	9.76	107.46	1.03	16.01	9.45	1.08	11.21
Reus	518	1.78	1.51	1.21	6.06	214.45	0.88	5.32	20.01	0.72	3.08
San Sebastian	173	1.97	1.68	1.23	15.32	204.24	1.86	16.80	11.47	1.37	12.05
Santander	204	2.04	1.60	1.20	18.07	241.48	2.34	17.94	17.05	1.41	13.80
Santiago	1283	1.68	1.34	1.15	6.96	178.15	1.34	4.14	19.92	0.96	2.25
Sevilla	1543	2.41	1.22	1.12	8.95	278.60	1.23	6.70	21.55	0.51	3.86
Tenerife Norte	2042	1.44	1.33	1.16	4.10	101.13	0.89	3.59	13.32	0.73	2.15
Tenerife Sur	7438	1.37	1.18	1.11	2.55	144.64	0.74	1.26	18.27	0.56	0.98
Valencia	1912	1.88	1.26	1.15	5.78	130.01	0.89	4.39	11.63	0.69	2.83
Valladolid	191	1.42	1.82	1.26	8.30	106.57	1.17	9.23	16.62	1.28	7.64
Vigo	556	1.71	1.50	1.19	7.85	174.50	1.32	6.22	15.03	0.93	4.91
Vitoria	145	6.29	1.34	1.19	31.10	194.63	–	–	11.67	–	–
Zaragoza	244	2.75	1.45	1.22	14.89	144.01	0.30	12.30	13.12	0.54	6.27
Mean	**2940**	**1.70**	**1.47**	**1.18**	**7.10**	**272.95**	**1.08**	**6.56**	**15.44**	**0.79**	**4.07**

The long-run multiproduct cost function also exhibits IRS (1.18 for the average airport).[13] This result again implies that the incremental average cost will fall as more traffic is served. Of course, the important IRS observed in the average airport is again related to its small size. In Table 6, we can also compare the magnitude of airports' returns to scale for the two models. In general, we observe that RTS are overestimated in the monoproduct specification except for some of the biggest airports. However, IRS does not seem to be exhausted at any output level in the sample, as even Madrid Barajas and Barcelona present significant RTS in the multiproduct specification, even though the RTS estimates decrease with airport size as shown in Fig. 2.

We can extract some very important conclusions regarding policy analysis from the existence of important economies of scale exist in each airport. First, the airport industry's minimum efficient scale is shown to be located well beyond the maximum observed level of production, approx. 25.6 million annual WLUs, which is ten times larger than the figures reported by past literature. Secondly, it is clear that first-best prices are not enough to cover all the costs. There are different strategies to determine airport charges which can be based on cross subsidies from non aeronautical activities or some sort of Ramsey prices when cost recovery is a requirement. Bel and Fageda (2009), using data for 100 large airports in Europe, found that they charge higher prices when they move more passengers, and that competition from other transport modes and nearby airports imposes some kind of discipline on the pricing behaviour of airports. There is a general consensus in the literature that the pricing policy at each airport should be undertaken on an individual basis (Starkie, 2004). However, AENA's pricing policy is based on a system of cross subsidies between airports which implicitly imposes that several airports with markedly distinct characteristics charge airlines the same prices.

Long-run marginal costs for the average airport are 1.08, 272.95 and 6.56 Euros per additional WLU, ATM and REV, respectively. However, we can find some outliers for very small airports like Cordoba, in which the marginal cost is extremely high. It can also be seen that, as expected, marginal costs for an additional WLU are clearly lower in the multiproduct model.

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[13] As in the monoproduct case, the existence of IRS cannot be rejected according to the Wald test.

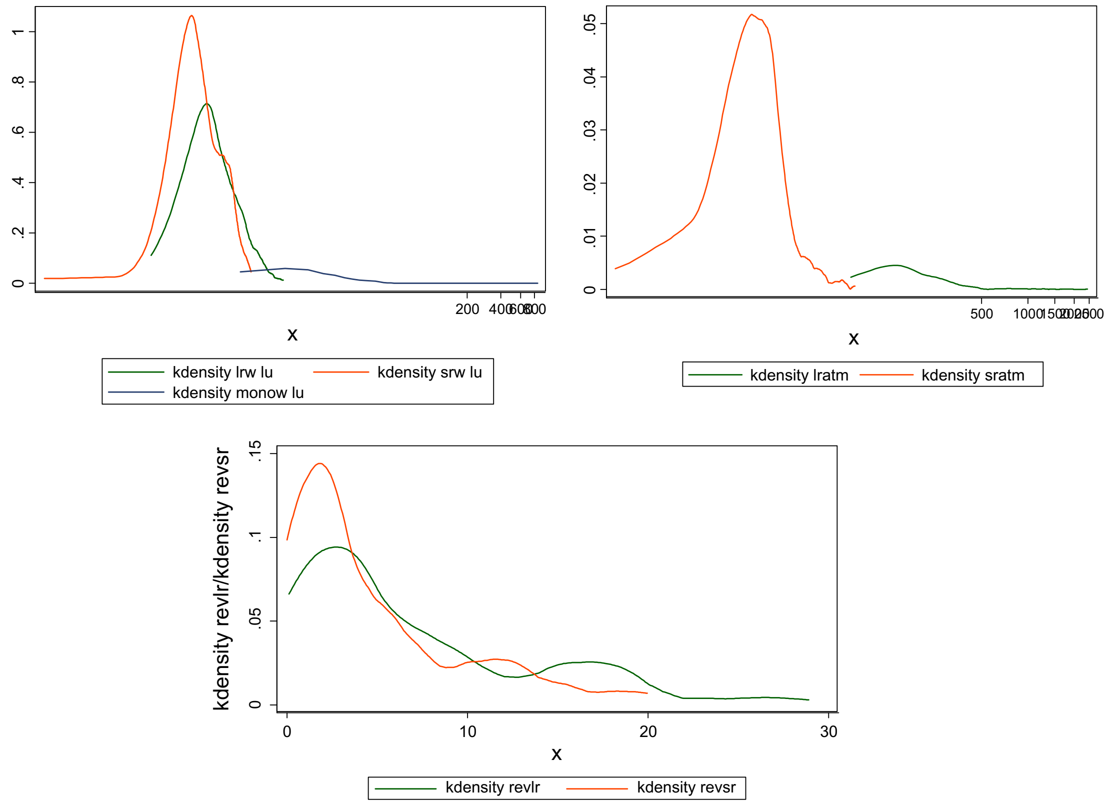

Fig. 1. Kernel density graphs of airports' marginal costs.

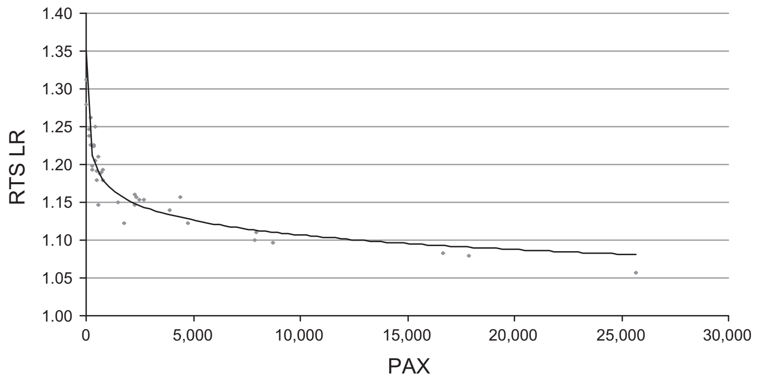

Fig. 2. LR multiproduct economies of scale (thousand passengers).

Another interesting result is that, for the average Spanish airport, the marginal cost of producing 6 Euros of commercial revenues is higher than this figure. This shows the lack of profitability of commercial operations at these small airports during that period, where concession revenues were not so important in the efficient management of airports. If fact, it is well known that retail activities in Spanish airports had not evolved because airports were only considered as mere infrastructure providers with the main focus on the safety of air transport. However, this vision has changed dramatically in the last decade, as revenues generated from non-aircraft related commercial activities in the terminals are considered as a core activity in the airport business.

In the short-run model, the marginal costs for the average airport are 15.44, 0.8 and 4.07 Euros for each additional ATM, WLU and REV, respectively. In this case, all the figures are significantly lower than the long-run model as we are not including capital costs. As expected, this difference is especially significant for the capital-intensive ATMs, also implying that airports are capable of adjusting more easily their landside facilities than the airside ones.

An interesting interpretation of these results is related to the issue of optimal charge decomposition, i.e., how much capital cost should bear any hypothetical landing charge? Evaluating the difference between long-run and short-run marginal costs for the average airport, we observe that 94% of long-run optimal landing charges are accrued to capital costs. Whether short-run or long-run marginal costs are reasonable figures that should be applied by airport regulators is out of the scope of this paper; but it is clear that the financial implications of one policy over the other are dramatically different, especially in regard to possible cross subsidisation or the need for public investments.

The short-run cost function also exhibits significant ECU (1.70 for the average airport). This result implies that the incremental average variable cost will fall as more traffic is served because of the excess capacity. Note that both Madrid Barajas and Barcelona present significant ECUs, Lanzarote being closest to full capacity utilization (1.19).

6. Summary and conclusions

In this paper, we have estimated three alternative cost function models which are based on the well known and extensively used translog functional form. Several interesting managerial insights can be derived from this study. In particular, we have showed evidence of the existence of economies of scale which are not exhausted at any output level (up to 23 million passengers), as well as slightly significant technological progress. We also found very limited possibilities for input substitution and elastic production factor demands. These are important contributions of the paper to the existing literature in the airport industry because the evidence so far suggests that economies of scale are exhausted for very small airports (5–8 million passengers) and our results contradict this standard view.

The existence of returns to scale cast some doubts about the convenience of multi-airport systems located in the same catchment area, unless the individual airports were really congested and could not be expanded. For example, in the Basque country, Navarra and the north of Spain, there are six airports which are accessible by driving less than 80 min and our results suggest that the traffic of these airports could more efficiently serviced (in terms of operating costs) by one single airport in the region.

Economies of scale and marginal costs are overestimated for most of the airports when the monoproduct model is considered. Marginal cost estimates were significantly different depending on whether fixed factors were considered or not, showing that the application of first-best pricing policies based on short- or long-run incentives would have implied different financial scenarios for airports.

There are some possible extensions to this paper. First, the calculation of capital and material prices should be more related to production factors. Second, hedonic cost functions or second-stage analysis could be applied to understand some systematic cost differences among airports. Third, the model can be expanded with the consideration of technical inefficiency in a Stochastic Frontier framework.

Finally, note that the database is mostly composed by financial information directly collected from the AENA. No external effects derived from airport operations have been included in the database and hence the effect of the service quality is not addressed by the present methodology. Therefore, policy implications can only be interpreted from a financial point of view, but they can hardly be taken in terms of social benefits. Nevertheless, the proposed methodology can be easily adapted to the analysis of external costs, such as noise or congestion, if adequate data are provided to researchers.

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