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(Article begins on next page)

SCALE AND (QUASI) SCOPE ECONOMIES IN AIRPORT TECHNOLOGY. AN APPLICATION TO UK AIRPORTS

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Abstract

In this study we consider a sample of the largest UK airports in order to estimate, for the first time for this sector, a multiproduct cost function using a flexible technology that nests most of the specifications commonly employed in the empirical literature. Another novelty of this work is that we provide estimates of *quasi- scope economies* for the airport industry, defined as the cost advantage for a diversified firm of jointly providing a set of outputs/services with respect to the costs of their provision through a set of firms quasi-specialized in a single production. Our main results suggest the existence of quasi-scope economies that tend to decline with the size of the airport. This finding, coupled with the results of a set of cost complementarity tests, suggest that cost savings mainly arise from the joint provision of services for national and international passengers and, to a lesser extent, to the addition of cargo transport activities. In turn, pairs of outputs that include (a proxy of) commercial revenues seem to be characterized by anti-cost complementarities. Finally, global economies of scale seem to be exhausted at about five million passengers.

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1. Introduction

Recent studies in urban and regional economics have highlighted the positive effects that the aviation sector might play on the performance of local economies.[1] Within the aviation industry, airports provide key essential facilities to airlines, such as runways for landing and take-offs, parking space for aircrafts, check-in-desks and commercial services for passengers, logistic services for the movements of cargo, among others. The inefficient provision of airport services might be transferred, through higher airport charges, to the downstream airline market and therefore to final customers, possibly jeopardising the abovementioned positive effects on local economic performance.

In the past few years, a rich empirical literature[2] has sought to better understand and critically evaluate the main drivers of airports' efficiency and productivity dynamics, such as the type of ownership, the existence of economic regulation, the levels of corruption, the intensity of competition among airports and the role played by Low Cost Carriers. While this literature has enriched our knowledge of the determinants of efficiency and productivity differentials in the airport industry, our understanding of the cost structure of the sector, in terms of degree of scale economies, optimal output mix and economies of scope is still limited. This is unfortunate, because the optimal dimension of an airport, in terms of both scale and output mix, can have important implications on the overall minimization of the industry production costs. This is particularly true for an industry where public ownership is still widespread and where the opening of new airports is often justified on place-based policy arguments. Sometimes, virtual no consideration is paid to the possibility that demand might not allow the new airport to reach the minimum efficient scale, so that the global industry costs might even increase as a result of the entry of the new operator.

If one looks at the empirical literature on the cost structure of the airport industry, recently surveyed by Bottasso and Conti (2017), it emerges that scale economies are clearly important for small-to-medium sized airports, while there is still debate on whether or not the largest airport operators are enjoying economies of scale.

[1] See, among others, Bloningen and Cristea (2015), Bilotkach (2015), Fageda (2017), and Gibbons and Wu (2017).

Moreover, modern airports are multi-product firms, serving different types of passengers (i.e., domestic versus international) and providing cargo and non-aeronautical services: a better understanding of the cost structure of the airport industry cannot avoid the evaluation of economies of scope; unfortunately, the evidence in this case is almost non-existent.

In this study we consider a sample of the 24 largest UK airport operators observed over the 1994-2008 period[3] and we estimate a multiproduct cost function using the Pulley and Braunstein (1992) flexible functional form, that nests most of the specifications commonly employed in the empirical literature. Our main findings are that global scale economies are exhausted for airports serving approximately 5 million passengers and that quasi- scope economies - the relevant concept to consider when there are very few specialized airports in the sample – do exist and decline with the size of the airport. Quasi-scope economies might be as large as 60-70% in the case of airports serving 0.5 million passengers per year and 10-13% for airports serving about 9 million passengers. Interestingly, we also find that scope economies mainly arise from the combination of international and domestic passengers.

The remainder of this study is organized as follows. Section 2 surveys the relevant empirical literature while Section 3 describes the econometric cost function model. Section 4 describes the data while Section 5 contains the estimation and model selection procedure. Finally, Section 6 describes the empirical results and Section 7 concludes.

2. Literature review

As highlighted in the recent survey conducted by Bottasso and Conti (2017), the available evidence on the presence of scope economies for airports is very scant. While very few papers tried to study *cost complementarities* between output pairs (which are a sufficient but not a necessary condition for the presence of scope economies), to the best of our knowledge, no one has attempted to undertake a

[2] See Bottasso et al. (2013), Bottasso and Conti (2017), Martini et al. (2013), Yan and Oum (2014) and the literature review in Liebert and Niemeier (2013).

[3] For a short summary of the main institutional and regulatory features of the UK airport industry, see Bottasso et al. (2017).

direct estimation of aggregate scope economies, as well as scope economies for different output combinations and at different airport sizes.

Chow and Fung (2009), working on a sample of 46 Chinese airports observed in 2000, estimate an input distance function using air passenger movements and air cargo movements as outputs and find some evidence of cost complementarities between them. McCarthy (2016) estimates a three output (number of departures (*atm*), commercial revenues and work load units (*wlu*), which include both the number of passengers and the amount of cargo transported) cost function for a sample of 50 US airports observed over the period 1996-2008. He finds some evidence of anti-cost complementarities between non-aeronautical revenues and *wlu* and between non-aeronautical revenues and *atm*, while estimates suggest the presence of cost complementarities between aviation activities (i.e., the couple *wlu-atm*), albeit the relation is not statistically significant. While these results could be consistent with the presence of diseconomies of scope, the author recognizes that **"***generalizing the model's variables through Box-Cox specifications which admit 0 outputs would enable the calculation of product-specific economies and economies of scope***"** (McCarthy, 2016, p. 272), a task which is left for future research. Abrate and Erbetta (2010) estimate a three output (number of passengers, handling revenues and commercial revenues) input distance function for a sample of 26 Italian airports observed over the 2000-2005 period, and find evidence of anticomplementarities between passengers and handling revenues, especially when handling is outsourced. Finally, Martin and Voltes-Dorta (2011) estimate a cost function[4] for a sample of 161 worldwide airports observed over the period 1991-1997, using five output categories (domestic and international passengers, an adjusted measure of *atm*, cargo and commercial revenues) and find evidence of cost complementarities only between domestic and international passengers.[5]

The inclusion of outputs such as *atm* and *wlu* is not appropriate if the goal is to investigate the presence of scope economies. In fact, since *atm* accounts for the

[4] It is worth noting that some studies adopted a cost function approach, while others relied on stochastic cost frontier analysis or on non-parametric methods, such as data envelopment analysis, or on the estimation of input distance functions. As will be argued in section 3, we believe that, for our purposes, the estimation of a cost function seems to be the most appropriate method.

number of flights, and *wlu* includes the number of national and international passengers as well as freight transportation, they cannot be interpreted as distinct (but potentially interdependent) activities, as required for a correct investigation of scope economies. For that reason, in this paper we consider four categories of outputs that, at least in principle, could be present or not in an airport: domestic passengers, international passengers, commercial revenues and cargo transport. Our dataset reveals that there are very few instances of "zero outputs", because all UK airports are offering domestic and international flights, and at the same time, they all provide cargo transport and undertake commercial activities. Therefore, while it is possible to compute *cost complementarities*, the computation of scope economies would not be appropriate, as it would involve out of the sample evaluations with output mixes that are very different from what it is actually observed in UK airports (an issue known as extrapolations bias)[6]. As an alternative, we will rely on the concept of "*quasi*"-scope economies. Instead of setting zero values for some outputs, airports are assumed to produce a small positive amount of each output and the costs of quasi-specialized airports (i.e. focusing mostly, but not completely, in cargo transport, or in international flights, or in national flights, or in commercial activities) are compared with those of diversified airports.

Abrate and Erbetta (2010), Martin and Voltes-Dorta (2011) and McCarthy (2016) rely on datasets that include a precise measure of commercial revenues[7]. However, the information on revenues not associated to airport charges (fares from air carriers, rights from the boarding of passengers, fees for the freight) is often aggregated and includes both non aeronautical revenues (retail, food and beverage, parking, rental cars) and revenues from ground handling activities (baggage handling, catering, check in, apron, hangar). This is the case of Adler and Liebert (2014) for European and Australian airports, and of Bottasso and Conti (2012), and Voltes-Dorta and Lei (2013), who both rely on the same source of data on UK airports we use in the present paper. Our proxy for commercial

[5] Different types of passengers are usually aggregated. When distinct categories of passengers are considered, it is not surprising that empirical results point towards the presence of cost complementarities between domestic and international passengers.
[6] For a detailed discussion, see Bottasso and Conti (2017).
[7] See Kramer (2010), for a detailed categorization of revenues of an airport.

revenues is therefore a measure of both non-aviation activities and non-core aeronautical activities[8].

It is worth mentioning the existence of a related literature on the estimation of multioutput cost functions for the analysis of scale and scope economies in other types of transport terminals. For example, Nunez-Sanchez et al. (2011) estimate a five-output quadratic cost function for 26 Spanish ports observed over the period 1986-2005[9], underlining the somewhat neglected importance of passengers in port infrastructure costs. In a similar vein, Jara-Diaz et al. (2005) focus on cargo handling activities of three firms operating in a large Spanish port. The estimation of a three-output (general cargo, containers and roll-on/roll-off trucks) quadratic cost function points to the presence of both global scale and scope economies.

There is also a related literature on the estimation of scale and scope economies for airline companies. Similar to airports, airlines can be multi-output firms that serve domestic and international passengers and organize cargo transport as well as a range of other services (apron, catering, hotel services, payment services such as credit cards etc.). Beyond the traditional measures of scale and scope economies, in the case of airlines, the concepts of *density economies* (that can be exploited, keeping fixed the size of the network, by increasing the size of aircrafts or the frequency of flights) and *spatial scope* economies (which occur when airlines jointly serve markets that generate larger networks) are relevant, too.[10]

While in this paper we focus on cost complementarity, an important and related issue is also that of demand complementarity between different output categories (Zhang and Czerny, 2012). In our context, the most important interrelationship is between traditional aeronautical operation and commercial activities (concessions). As shown by Morrison (2009), the presence of a complementary link may lead to strategic reduction of aviation prices in order to attract more passengers and extract profits from the non-aviation business. Bracaglia et al. (2014) and D'Alfonso and Bracaglia (2017) have explored the two sidedness of such a complementarity, arguing that by reducing the price of concessions (for

[8] Ground handling services have been liberalized in the late nineties, so that airports can manage them in-house or outsource them to independent contractors. Indeed, often airlines are in charge of the management of some non-core aeronautical activities, and offer their services to competing airlines, too.

[9] The five outputs are containerized cargo, non-containerized cargo, passengers, solid bulk, liquid bulk.

example, the price of car rental) an airport can be successful in attracting more passengers.[11] D'Alfonso et al. (2013) have argued that, as long as non-aviation revenues increase in importance, airports can have incentives to create delays and congestion that transform travellers into consumers that spend more time and more money to the benefit of the airport.

3. The econometric cost function model

The availability of data on costs, outputs and inputs for UK airports allows us to undertake a detailed study of the cost function in order to detect the presence of economies of scale and scope.

We consider a total cost function. Alternatively, one might estimate a variable cost function, as in Bottasso and Conti (2012), which requires the assumption that firms minimize variable costs only. While this assumption is likely to be more defendable with respect to the assumption of total cost minimization, scope economies are usually estimated in a total cost function framework.[12] As a further alternative, one might estimate a total cost frontier, allowing for inefficiency. However, this approach implies additional problems: first, firms are still assumed to minimize total costs, even if one allows them to do so inefficiently. Moreover, the estimation of a cost function system allows us to model the cost function together with the cost shares, thereby increasing the degrees of freedom and the precision of the estimates, while such analysis is not feasible in the cost frontier framework.[13]

As far as the functional form is concerned, it is well known that the Translog specification (TL) suffers from the well-known inability to evaluate cost behavior when any output is zero, due to its log-additive output structure. This has been proved to yield unreasonable and/or very unstable estimates for scope economies

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[10] The interested reader may refer to the recent survey conducted by Jara-Diaz et al. (2013).

[11] Indeed, by using websites, mobile apps, and e-commerce, a traveler can plan the entire trip on advance and buy at the same time concession services together with the air ticket. Airports can get more customers also by implementing fidelity programs for non-aeronautical services (car rental, food and beverage, car parking).

[12] Moreover, the results on scale economies in this study are very much in line with those obtained by Bottasso and Conti (2012) who estimate a variable cost function for essentially the same sample and period.

[13] Airports are also assumed to minimize private rather than social (i.e., including delays, congestion, etc.) costs.

and product-specific scale economies (i.e., Pulley and Braunstein, 1992; McKillop et al., 1996).

To overcome the above problems, Pulley and Braunstein (1992) proposed a novel functional form - the *Composite* cost function - that is well suited for examining cost properties of multi-product firms. Such a model, as well as other widely used alternative cost functions (i.e., quadratic forms), are nested into the following *General* specification (PB_G):

$$C^{(\phi)} = \left\{ \exp\left[\left(\alpha_0 + \sum_i \alpha_i Y_i^{(\theta)} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} Y_i^{(\theta)} Y_j^{(\theta)} + \sum_i \sum_r \delta_{ir} Y_i^{(\theta)} \ln P_r \right)^{(\tau)} \right] \cdot \exp\left[\sum_r \beta_r \ln P_r + \frac{1}{2} \sum_r \sum_l \beta_{rl} \ln P_r \ln P_l \right] \right\}^{(\phi)} + \psi_C \qquad [1]$$

where the superscripts in parentheses represent the Box-Cox transformation of outputs ($Y_i^{(\theta)} = (Y_i^{\theta} - 1)/\theta$ for $\theta \neq 0$ and $Y_i^{(\theta)} \to \ln Y_i$ for $\theta \to 0$). C refers to the total cost of production, Y_i refers to outputs, P_r indicates factor prices, and ψ_C is a random noise having appropriate distributional properties to reflect the stochastic structure of the cost model.[14]

The associated input cost-share equations are obtained by applying the *Shephard's Lemma* to expression [1][15]

$$S_r = \left(\sum_i \delta_{ir} Y_i^{(\pi)} \right) \cdot \left[\alpha_0 + \sum_i \alpha_i Y_i^{(\theta)} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} Y_i^{(\theta)} Y_j^{(\theta)} + \sum_i \sum_r \delta_{ir} Y_i^{(\theta)} \ln P_r \right]^{\tau-1} + \beta_r + \sum_l \beta_{rl} \ln P_l + \psi_r \qquad [2]$$

where ψ_r is the error term relating to the cost-share r (S_r).

A less general composite specification (PB_C) is obtained by setting $\theta = 1$ and $\tau = 0$. In a similar vein, the well-known *Generalized Translog* (GT) and *Standard Translog* (ST) models (Caves et al., 1980), as well as a *Separable Quadratic* (SQ) functional form can be estimated by imposing simple restrictions on the system (1)-(2): The GT model is obtained by setting $\phi = 0$ and $\tau = 1$, while the ST model

[14] For ease of exposition, we omit the subscripts identifying the different airports and the different years.

[15] Cost-shares are computed as $S_r = (X_r P_r)/C$. By Shephard's Lemma $X_r = \partial C/\partial P_r$, where X_r is the input demand for the rth input, so that $S_r = \partial \ln C / \partial \ln P_r$.

requires the further restriction $\theta = 0$. [16] The SQ model is obtained from the PB_C specification by adding the restrictions $\delta_{ir} = 0$ for all *i* and *r*.

The PB_G and PB_C cost functions originate from the combination of the log-quadratic input price structure of the ST and GT specifications with a quadratic structure for outputs. The latter is appropriate to model cost behaviour in the range of zero output levels and gives PB-type specifications an advantage over ST and GT forms[17] as far as the measurement of economies of scope is concerned. In addition, the log-quadratic input price structure can be easily constrained to be linearly homogeneous.[18]

The studies that made use of PB specifications in order to study economies of scale and scope are still few. After the first applications to the banking industry (Pulley and Braunstein, 1992; Pulley and Humphrey, 1993; McKillop et al., 1996) and telecommunications (Braunstein and Pulley, 1998; Bloch et al., 2001; McKenzie and Small, 1997), the Composite specification has been used to study the cost function of local public utilities providing services such as water, electricity, and gas distribution (Piacenza and Vannoni, 2004; Bottasso et al., 2011), garbage collection (Abrate et al., 2014), as well as public transportation (Di Giacomo and Ottoz, 2010; Ottoz and Di Giacomo, 2012; Abrate et al., 2016). Overall, the composite models proved to be successful in obtaining more stable and reliable estimates than the alternative functional forms. To the best of our knowledge, this is the first application to the airport technology.

3.1. Measures of scale and scope economies

Assume that an airport multi-product cost function can be represented by $C = C(Y;P)$, where the output vector $Y = (Y_{PNAT}, Y_{PINT}, Y_{CARGO}, Y_{REV})$ includes the

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[16] Setting $\theta \to 0$ in [1] and [2] yields the nested *Standard Translog* (ST) *Specification*, with all output terms in the cost function and in the corresponding cost-share equations assuming the usual logarithmic (ln Yi) form. In this case, zero values for any of the four outputs are substituted by 0.000001.

[17] For small values of θ, the estimated GT function is a close approximation to the ST functional form.

[18] To be consistent with cost minimization, (1) must satisfy symmetry ($\alpha_{ij} = \alpha_{ji}$ and $\beta_{rl} = \beta_{lr}$ for all couples *i, j* and *r, l*) as well as the following properties: *a*) non-negative fitted costs; *b*) non-negative fitted marginal costs with respect to outputs; *c*) homogeneity of degree one of the cost function in input prices ($\Sigma_r\beta_r = 1$ and $\Sigma_l\beta_{rl} = 0$ for all *r*, and $\Sigma_r\delta_{ir} = 0$ for all *i*); *d*) non-decreasing fitted costs in input prices; *e*) concavity of the cost function in input prices.

four output categories used in our analysis: yearly number of national passengers (Y_{PNAT}), yearly number of international passengers (Y_{PINT}), tons of cargo&mail (Y_{CARGO}), and our proxy for commercial revenues (Y_{REV}). Following Baumol et al. (1982), measures of global scale and scope economies can be easily defined. *Global* or *aggregate scale economies* are computed via

$$SL(Y;P) = \frac{C(Y;P)}{\sum_i Y_i MC_i} = \frac{1}{\sum_i \varepsilon_{CY_i}} \qquad [3]$$

Where $MC_i = \partial C(Y;P)/\partial Y_i$ is the marginal cost of the *i*th output and $\varepsilon_{CY_i} = \partial \ln C(Y;P)/\partial \ln Y_i$ is the cost elasticity with respect to the *i*th output.

The above measure describes the behavior of costs as all outputs increase by strictly the same proportion.

The second relevant measure for the comprehension of the cost structure of multi-product firms is that of *scope economies*. The latter appear when the cost of joint production of a given output set is lower than the sum of the "stand-alone" production costs of subsets of outputs. In other words, scope economies (diseconomies) are reflected into cost savings (cost disadvantages) associated with the joint production of many outputs.[19]

The measure of *global* or *aggregate scope economies* for our airports could be computed as:

$$SC(Y;P) = \frac{\left[C(Y_{PNAT},0,0,0;P) + C(0,Y_{PINT},0,0;P) + C(0,0,Y_{CARGO},0;P) + C(0,0,0,Y_{REV};P) - C(Y;P)\right]}{C(Y;P)}$$

[4]

with $SC(Y;P) > 0$ (< 0) denoting global economies (diseconomies) of scope.

A partial indication of the synergies that could be enjoyed by combining the production of several goods (or the provision of different services) comes from the related concept of *cost complementarity*. Cost complementarities exist in a multi-product cost function when the marginal cost of producing one product (Y_i) decreases as the quantity of another output (Y_j) is increased. More formally, for a

[19] When there are neither economies nor diseconomies of scope the production process is said to be non-joint, so that productive inputs are completely specialized by product and there are no strong interdependencies among the costs of different outputs.

twice continuously differentiable cost function, cost complementarities are present at Y' if

$$CC_{ij}(Y';P) = \frac{\partial^2 C(Y';P)}{\partial Y_i \partial Y_j} < 0, \qquad i \neq j \qquad [5]$$

for all $Y' \in [0,Y]$.

Cost complementarity tests can be applied only to *pairs of outputs*. While they are informative, they do not offer conclusive information about the presence of scope economies. In fact, scope economies can be due to the sharing of fixed costs among different activities, even in the presence of cost anti-complementarities.[20]

It is not surprising that in the empirical literature on the airport technology, while one can find some sporadic estimates of cost complementarities between pair of outputs/services, the issue of scope economies has been virtually unexplored. Indeed, multi-utilities jointly provide services (gas, water, electricity) that could be offered also by specialized firms, diversified bus companies provide intercity and urban passenger transport services that coexist together with specialized urban or intercity operators, waste management companies can be diversified into recycling activities or not. Instead, all airports are expected to offer international and domestic flights together with cargo transport services and are supposed to manage other activities that generate commercial revenues.

In fact, in our dataset, we have only few "zeros" for cargo activities (two observations) and for international flights (two observations). In such a context, it is not appropriate to estimate scope economies using equation [4], and this difficulty might explain why the literature has been practically silent with respect to the issue of scope economies.

A concept that can be conveniently used in this case is that of "*quasi*"-scope economies where, instead of setting $Y_i = 0$ for some i, firms are assumed to produce a positive share of each output. Quasi-specialized firms are producing a high quantity of one output and small quantities of the other (nonspecialized) outputs. Defining ε to be the proportion of the nonspecialized outputs produced,

[20] In other terms, the concept of scope economies is related to the firm's total costs and not to the marginal cost of each single output. Baumol et al. (1982) have shown that a multi-product cost function characterized by weak cost complementarities over the full set of outputs up to the observed level of output exhibits scope economies.

the general formula for "*quasi*"-scope economies ($QSC(\varepsilon)$) in our four-outputs case is:

$$QSC(\varepsilon) = [C(\varepsilon Y_{PNAT}, \varepsilon Y_{PINT}, \varepsilon Y_{CARGO}, (1\text{-}3\varepsilon)Y_{REV}) + C(\varepsilon Y_{PNAT}, \varepsilon Y_{PINT}, (1\text{-}3\varepsilon)Y_{CARGO}, \varepsilon Y_{REV}) + C(\varepsilon Y_{PNAT}, (1\text{-}3\varepsilon)Y_{PINT}, \varepsilon Y_{CARGO}, \varepsilon Y_{REV}) + C((1\text{-}3\varepsilon)Y_{PNAT}, \varepsilon Y_{PINT}, \varepsilon Y_{CARGO}, \varepsilon Y_{REV}) - C(Y_{PNAT}, Y_{PINT}, Y_{CARGO}, Y_{REV})] / C(Y_{PNAT}, Y_{PINT}, Y_{CARGO}, Y_{REV}) \quad [6]$$

Such a measure allows the evaluation of the benefits of diversification as an alternative to quasi-specialized production. Production of the specialized output is adjusted so that the total amount produced by quasi-specialized firms equals the amount of joint production (i.e., $\varepsilon+\varepsilon+\varepsilon+(1\text{-}3\varepsilon)$ equals one for all four outputs).

Surprisingly enough, despite the computation of $QSC(\varepsilon)$ is appealing in circumstances in which firms are expected to manufacture several outputs (or to provide several services) at different combinations, but specialized units are not plausible, only few papers investigated them (Pulley and Humphrey, 1993; Di Giacomo and Ottoz, 2010, Delgado et al., 2015).

4. Data description

Our dataset refers to a balanced panel of 24 UK airports observed over the period 1994-2008, for a total of 360 *pooled* observations. In principle, we would like to extend the dataset to cover the most recent periods; unfortunately, the main source of data (the Centre of the Study of Regulated Industries at the University of Bath), has ceased to report the relevant data for the UK airport industry and the recovery of recent data, especially the financial ones, was not feasible. Nevertheless, we believe the data are still interesting enough for the purpose of this study, namely the estimation of economies of scale and scope in the airport sector. Indeed, the UK airport industry, observed over the time span considered in this study, is broadly representative of the situation of this industry in most western countries and empirical findings on scale and scope economies should still provide interesting insights for policymakers.

Total cost (C) is the sum of labor cost, other operating costs (including energy, materials and services), taken from data published by the Centre for the Study of

Regulated Industry at the University of Bath, and capital costs.[21] The four output categories are yearly number of national passengers (Y_{PNAT}), yearly number of international passengers (Y_{PINT}), yearly tons of cargo&mail (Y_{CARGO}), and our proxy of yearly commercial revenues (Y_{REV}). As discussed in section 2, the latter captures operating revenues different from charges to airlines. The bulk of revenues come from retail, property, and car parking, but *REV* includes also non-core aviation activities such as baggage handling, apron services, hangar, etc.[22]

Productive factors are labor, capital and other factors. The price of labor (P_L) is given by yearly average of the weekly average salary in the area where the airport is located.[23] The price of capital (P_K) is a proxy of the user cost of capital, measured by the opportunity cost of capital and a depreciation rate of 0.045, common for all airports.[24] Finally, the price of other factors (P_O) is obtained as a weighted average of the Construction Output Price Index (COPI), i.e. a proxy for material prices, a price index for water, gas and electricity and the Retail Price Index (RPI), a proxy for other services purchased by airports, where the weights are taken from various years of BAA's statutory accounts.[25]

Summary statistics for the full sample and for three sub-periods are provided in Table 1. As can be noted, on average, costs more than doubled between 1994-1998 and 2004-2008. Among the four output categories, the number of

[21] Capital costs are obtained by multiplying the price of capital (the sum of the depreciation rate and the opportunity cost of capital) and the capital stock. The latter is derived by applying the perpetual inventory method and exploiting asset revaluations that occurred over the sample period. See Bottasso and Conti (2012) and the references therein.

[22] In order to further clarify this issue we have been able to collect information from the British Airports Authority (BAA)'s statutory accounts for a few selected years over the period 2001-2006. In those years, the share of revenues different from charges to airlines (i.e., the share of REV) associated to concessions (retail, property and car parking) was well above two thirds.

[23] The data are taken from the Annual Survey of Hours and Earnings as the average gross wage that is paid to employees that work in the local authority where the airport is located. Bottasso and Conti (2012) compare this approach with the more conventional one of computing the price of labour as the ratio between labour costs and the number of employees and they find similar results. See also Bottasso and Conti (2017) for a more in depth discussion.

[24] The opportunity cost of capital was proxied by the weighted average cost of capital using information on the assumptions made by the airport regulator Civil Aviation Authority (CAA) in the relevant price reviews. In particular, for public-owned airports we used the CAA assumption for Manchester Airport, while for private and mixed-ownership ones we used the assumptions for BAA owned airports.

[25] In order to better capture the regional differentials in the price of materials and utility bills, it would be ideal to have airport specific weights. However, for lack of data we have been forced to use the BAA's weights. Nevertheless, we believe it to be a reasonably good first approximation, given the lack, to the best of our knowledge, of systematic regional differences in material and utility costs in the UK.

international passengers increased sharply (from an average of 3.2 million passengers in the first sub-period to 6.1 million passengers in the last sub-period), followed by cargo (from 82252 to 104473 tons) and by national passengers (from 2.5 to 3.0 millions).

Y_{REV}, which is computed in real terms, has not changed very much in the period, but the corresponding nominal (i.e., not deflated) revenues increased from an average of 43.5 million GBP in the period 1994-1998 to an average of 64.6 million GBP in the period 2004-2008.[26]

Table 2 show the pairwise correlations of the variables used in the cost function estimation. It is not surprising that correlation coefficients among outputs are high, especially for the couple P_{INT}-REV and, to a lesser extent, for the pairs CARGO-REV and P_{INT}-CARGO. However, the distinction between national and international passengers allows reducing significantly the issue of correlated outputs.[27]

Figure 1 shows the distribution of the four outputs for the 24 UK airports, classified in four size groups according to the average level of total costs over the period 1994-2008. The height of each bar represents the size of an airport's output with respect to the average amount of that output in the total sample. For example, Heathrow, the largest airport in our dataset, serves a number of national passengers twice as large as the number of national passengers served by the average airport in the sample. The figure shows that there are airports which are relatively specialized in cargo activities (Nottingham East Midlands), in national flights (Cardiff, Exeter, Newcastle, Glasgow, Aberdeen, Edinburgh) or in international flights (London City), while other airports are diversified in national and international flights as well as in cargo activities (Liverpool, Leeds, Gatwick, Stanstead). Most importantly, the figure shows that there are not fully specialized airports. In fact, few "zeros" are recorded for cargo activities and for international passengers in some years, while for the large majority of observations all the 24

[26] The share of non-core revenues over total revenues increased from 47% to 51%. The cost shares were very similar across sub-periods, while the price of labor increased from a yearly average salary of 15487 GBP in the first sub-period to 22211 GBP in the period 2004-2008.

[27] Notice that none of the above-cited papers reports the full correlation matrix. An exception is Scotti et al. (2012), who show the correlations between input pairs and between outputs and inputs, but omit to report the portion of the matrix relative to three output pairs they use.

airports simultaneously offer international and national flights, provide cargo services and produce other sources of revenues.

5. Estimation procedure and model selection

All the specifications of the multi-product cost function are estimated jointly with their associated input cost-share equations. Because the three share equations sum to unity, to avoid singularity of the covariance matrix only the labor (S_L) and the capital share (S_K) equations have been included in the systems. Before the estimation, all variables were normalized with respect to their respective sample medians.[28] Parameter estimates were obtained via a Non-Linear Seemingly Unrelated Regression (NLSUR), which is the non-linear counterpart of the Zellner's iterated seemingly unrelated regression technique. This procedure ensures estimated coefficients to be invariant with respect to the omitted share equation (Zellner, 1962). Assuming the error terms in the above models are normally distributed, the concentrated *log-likelihood* for the estimated *cost function* and related *labor-share and capital-share equations* can be respectively computed via[29]

$$\ln L_C = -\sum_{t=1}^{T} \ln C_t - \frac{T}{2}[1+\ln(2\pi)] - \frac{T}{2}\ln\left[\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{Ct}^2\right] \quad [7]$$

$$\ln L_{S_L} = -\frac{T}{2}[1+\ln(2\pi)] - \frac{T}{2}\ln\left[\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{Lt}^2\right] \quad [8]$$

$$\ln L_{S_K} = -\frac{T}{2}[1+\ln(2\pi)] - \frac{T}{2}\ln\left[\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{Kt}^2\right] \quad [9]$$

where t is the single observation (t = 1, …, 360), $\hat{\psi}_C$, $\hat{\psi}_L$ and $\hat{\psi}_K$ are the estimated residuals of the three regressions, and ($-\Sigma_t \ln C_t$) is the logarithm of the Jacobian of the transformation of the dependent variable from C_t to $\ln C_t$ ($J = \prod_{t=1}^{T} J_t$ with

[28] As a point of approximation, we prefer the median to the average, because of the presence of two large airports, such as Heathrow and Gatwick. However, results of estimations do not change if one standardizes using the mean values of variables.
[29] See Greene (1997), Chapters 10 and 15.

$J_t = |\partial \psi_{C_t} / \partial C_t| = 1/C_t$). Similarly, the concentrated *system log-likelihood* is defined by:

$$\ln L_{(C,S_L,S_K)} = \ln J - \frac{T}{2}\left[3(1+\ln(2\pi)) + \ln|\Omega|\right] \qquad [10]$$

where J is the Jacobian of the transformation of (C_t, S_{Lt}, S_{Kt}) to $(\ln C_t, S_{Lt}, S_{Kt})$, and Ω is the (3×3) matrix of residual sum of squares and cross products for the system, with the pq^{th} element of Ω, Ω_{pq}, equal to $\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{p_t}\hat{\psi}_{q_t}$ and $p, q = C, S_L, S_K$.

The summary results of the NLSUR estimations for the ST, GT, SQ, and PB models are presented in Table 3. In the first three rows, one can observe that the values of the Box-Cox parameters ϕ and θ are significant, while the coefficient associated to τ is not statistically different from zero. This gives a preliminary indication that Composite and quadratic models (which both assume τ =0) describe our data better than GT or Standard Translog functional forms. The subsequent five rows present the estimates of cost elasticities with respect to outputs and factor prices for the 'median' firm.[30]

While the five estimated cost function models seem to perform similarly with respect to labor price elasticity (S_L ranges from 0.21 to 0.26 and S_K ranges from 0.39 to 0.41), the estimates for the output elasticities show a greater variability, with the PB_G model attributing more weight to domestic passengers and less weight to Y_{REV} .

By looking at the diagnostic statistics, one can observe that the R^2 for the cost functions is very similar across models, while the R^2 for the labor-share equation ranges from 0.14 (SQ model) to 0.38 (PB_G model).[31] The lower ability of the SQ specification to fit the observed factor-shares is not surprising given that it assumes a strong separability between inputs and outputs. McElroy's (1977) R^2 (R_*^2) can be used as a measure of the goodness of fit for the NLSUR system. The results suggest that the fit is high for all five models.

[30] The *median* firm (the point of normalization) corresponds to a hypothetical firm operating at a median level of production for each output and facing median values of the input price variables.

[31] The relatively low fit of the cost share equations can be partially attributed to the fact that we are forced to use rather aggregated proxies for the prices of inputs.

Standard likelihood ratio (LR) hypothesis testing based on system log-likelihoods can be applied to see which model fits the observed data better. The LR statistics are in favor of the PB_G model, since all the alternative specifications are rejected (for example, comparing PB_G with PB_C, the critical ${}_{0.01}\chi^2_{(2)}$ = 9.21, while the computed $\chi^2_{(2)}$ = 76.54). Similarly, the null hypothesis that PB_C and SQ (or GT and ST) models are equally close to the true data generating process is rejected in favor of the PB_C (GT).

Table 3 shows also the estimates of global economies of scale calculated for the median firm ($SL = 1/\sum \varepsilon_{CY_i}$). The results, which are not dramatically different across models (*SL* ranges from 1.05 to 1.18 and is always statistically different from 1), are clearly in favor of the presence of scale economies.

On the base of statistical fit, and as a result of LR based statistics, we focus on the PB_G specification[32] for carrying out the empirical tests concerning quasi-scope and scale economies.[33]

Turning to the issue of correlation among output pairs, we cannot rule out the possibility that multicollinearity might have an impact on the estimates of the coefficients associated to the outputs (parameters α_i and α_{ij} in Equation 1). However, we are rather comforted by the fact that standard errors of all first-order output coefficients are very small and that results are robust to changes in model specification and to slight permutations of the dataset (obtained, for example, by dropping one airport at a time from the sample and by re-running the regression to check if results are robust).[34]

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[32] The assumption that errors have a normal distribution is confirmed by a Jarque-Bera (JB) test. The JB chi squared statistic is equal to 5.2 (critical value equal to ${}_{0.05}\chi^2_{(2)}$ =5.99), which means that the normality assumption is not rejected at 95% significance level.

[33] The estimated PB_G cost function also satisfies *each* of the output and price regularity conditions at 90 percent of the sample data points. More precisely, fitted costs are always non-negative and non-decreasing in input prices (fitted factor-shares are positive at each observation). Concavity of the cost function in input prices is satisfied everywhere in the sample (the Hessian matrix based on the fitted factor-shares is negative semi-definite). Fitted marginal costs with respect to each output are non-negative for 341 observations on 360.

[34] Moreover, normalizing the variables and estimating systems of equations that include cost shares should reduce multicollinearity problems. Finally, while multicollinearity has an impact on the precision of the estimate of a single coefficient, it does not affect the estimates of scale and scope economies, which rely upon combinations of several coefficients. See Woolridge (2002) and Maddala (2005) for more details.

Table 3 presents estimates of the rather parsimonious specification of the cost function (Equation 1). Our results are robust to the inclusion of a time trend and its squared term, and other additional control variables,[35] such as a dummy for regulated airports (Heathrow, Gatwick, Stanstead, Manchester), ownership dummies (private, public, mixed), proxies for the role of low-cost carriers (the share of passengers or the share of flights managed by low-cost carriers) and HHI, a proxy for competition among airports.[36] The only variable that turns out to be significant and robust across different specifications is HHI, whose positive coefficient suggests that a strong competitive pressure pushes airports to reduce their costs, a result consistent with those of Bottasso et al (2017) who find, for the same sample, that more competition is associated to lower aeronautical charges.[37]

6. Scale and "quasi" scope economies

Table 4 reports in the last row the estimates of global scale economies (*SL*) evaluated at the output sample medians, $Y^*=(Y^*_{PNAT}, Y^*_{PINT}, Y^*_{CARGO}, Y^*_{REV})$, and at ray expansions and contractions of Y^*.[38] More precisely, we consider the following output scaling: $\lambda Y^* = (\lambda Y^*_{PNAT}, \lambda Y^*_{PINT}, \lambda Y^*_{CARGO}, \lambda Y^*_{REV})$, with outputs ranging from one fourth ($\lambda = 0.25$) to four times ($\lambda = 4$) the values

[35] However, following Ottoz and Di Giacomo (2012), we do not include airport fixed effects. As shown by Cameron and Trivedi (2005) and by Lancaster (2000), when dealing with nonlinear functional forms, the estimation of fixed effects or random effects models may lead to inconsistent estimates of all the parameters (incidental parameter problem). Therefore, we rely on the results of the pooled model presented in Table 3.

[36] HHI is a specific Herfindahl Index built for each airport. In order to obtain this variable, we first derive a measure of the market power of airport *i* in its catchment area over a single *superoute r*. Following Bottasso et al. (2017), to whom we refer for further details, a *superoute* refers to airline services that depart from a given UK airport and whose destination is one of the airports that, according to the CAA, operate in the same geographic market (and vice versa). For instance, while Milan Linate-London Heathrow and Milan Malpensa-London Heathrow are two distinct routes, they belong to the same *superoute*. Next, we aggregate such measures over all *superoutes* after weighting them for the relative importance of each *superoute* for each airport. This approach is justified by noting that even in the case of an airport with big market power over a certain *superoute*, the latter might contribute very little to an airport *i*'s overall market power if that *superoute* accounts for only a very small share of total passengers for that airport. Finally, we aggregate market power for every airport across all *superoutes*. This procedure generates an airport level Herfindahl measure ranging from 0 to 1, where 0 indicates that an airport faces many competitors, while 1 indicates that the airport is a local monopolist.

[37] The role of competition on the efficiency of airports has been studied using frontier techniques and Data Envelopment Analysis, and results are still mixed. While both D'Alfonso et al. (2015) and Scotti et al. (2012) point towards a negative impact of competition on technical efficiency, Pavlyuk (2009 and 2010) suggests a positive relationship. See also Adler and Liebert (2014) and Ha et al. (2013).

[38] Using equation [3], $SL(Y^*,P) = 1.177$, while $SL(2Y^*,P) = 1.098$, and so on.

observed for the 'median' firm. All estimates are larger than one and significantly different from one (except for the case in which $\lambda = 4$), and reveal the presence of *increasing returns to scale* for airports that serve up to about 5 million passengers. Economies of scale are quite large (*SL*=1.5) for airports with a number of passengers below 500.000[39], than they reduce progressively and appear to be exhausted for big airports, such as Heathrow, Gatwick, Stanstead, Manchester, Glasgow, Edinburgh, Birmingham and London Luton (which are all well above the threshold of 5 million passengers per year). Indeed, *SL* becomes even lower than one, but the lack of statistical significance suggests caution in pointing towards the presence of diseconomies of scale for the largest UK airports. Such results are broadly in line with Bottasso and Conti (2012), even if they used a different methodology and estimated a cost function that included a different set of outputs (*atm*, *wlu*, and the same proxy for commercial revenues we are using here).[40]

Table 4 reports also the estimates of *quasi*-scope economies. In the central column, which focuses on the results for the "median airport", $QSC(\varepsilon)$ is computed according to the formula in equation [6]. For example, in the fourth row ($\varepsilon = 0.10$):

$$QSC(\varepsilon) = [C(0.1*Y_{PNAT},0.1*Y_{PINT},0.1*Y_{CARGO},0.7*Y_{REV})+C(0.1*Y_{PNAT},0.1*Y_{PINT},0.7*Y_{CARGO},0.1*Y_{REV})+C(0.1*Y_{PNAT},0.7*Y_{PINT},0.1*Y_{CARGO},0.1*Y_{REV})+C(0.7*Y_{PNAT},0.1*Y_{PINT},0.1*Y_{CARGO},0.1*Y_{REV})-C(Y_{PNAT},Y_{PINT},Y_{CARGO},Y_{REV})]/C(Y_{PNAT},Y_{PINT},Y_{CARGO},Y_{REV})$$

The positive estimate for $QSC(\varepsilon)$ suggests that, by combining the production of four quasi-specialized airports into a single airport (that would reach a size comparable to the median airport in our sample), costs would fall by about 18 percent. The other columns report the estimates of $QSC(\lambda\varepsilon)$ for airports larger and lower than the sample median.[41]

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[39] Southend, Blackpool, Humberside, Norwich.

[40] International passengers may flight from UK to other European countries or take intercontinental flights. In order to account for the fact that big aircrafts and long-distance flights require bigger and costlier runways and terminals, we have added as controls a measure of the length of runways as well as the ratio between passengers and *atm*, which proxies for the aircraft size. Results, which are available upon request, are robust to the inclusion of the above controls.

[41] Taking always the fourth row ($\varepsilon = 0.10$, $\lambda=2$) as an example:

$$QSC(\lambda\varepsilon) = [C(0.2*Y_{PNAT},0.2*Y_{PINT},0.2*Y_{CARGO},1.4*Y_{REV})+C(0.2*Y_{PNAT},0.2*Y_{PINT},1.4*Y_{CARGO},0.2*Y_{REV})+C(0.2*Y_{PNAT},1.4*Y_{PINT},0.2*Y_{CARGO},0.2*Y_{REV})+C(1.4*Y_{PNAT},0.2*Y_{PINT},0.2*Y_{CARGO},0.2*Y_{REV})-$$

The first row ($\varepsilon = 0$) reports the estimates of *SC* according to the formula in equation [4], while the last row ($\varepsilon = 0.25$) *de facto* considers diversified airports that experience an increase in the size of all four activities. Therefore, as far as ε gets closer to 0.25, the *quasi* scope index approaches a measure of global scale economies.[42] In such a case, as shown by Bailey and Friedlaender (1982), both product specific economies of scale and product specific scope economies contribute to determine *SL*.[43]

Overall, the results are in favour of the presence of global (quasi) scope economies, which are very high for small airports (around 70%) and reduce progressively as far as the size of the airport increases (when the passengers are close to 9 million per year, quasi scope economies are around 12%). When ε is very low (i.e, below 0.1) the figures are of a lower magnitude and lose statistical significance.

6.1. Cost complementarities and marginal costs

The analysis of cost complementarities (CC_{ij}; i, j = P_{NAT}, P_{INT}, *CARGO*, *REV*, with $i \neq j$) provides further evidence on the cost advantage (or disadvantage) enjoyed by an airport which decides to diversify into different services. Under this empirical test, we investigate pairwise how an increase in the level of one out of

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$C(2{*}Y_{PNAT}, 2{*}Y_{PINT}, 2{*}Y_{CARGO}, 2{*}Y_{REV})]/C(2{*}Y_{PNAT},2{*}Y_{PINT},2{*}Y_{CARGO},2{*}Y_{REV})$. The value of 0.11 suggests that, combining the production of four relatively specialized airports into a diversified airport (that would be twice as big as the median airport in the sample), costs would fall by 11 percent.

[42] Indeed, when ε=0.25 and λ=1, we compare the costs of four equally diversified airports (of a size equal to one fourth that of the median firm) with the costs of a single diversified airport of a size equal to the median firm. That is clearly a measure much more similar to *SL*: in fact, after having subtracted one from the first three *SL* figures (highlighted in italics and underlined) in the last row of Table 4, we get estimates which are not (and should not be) very different from the last three figures (highlighted in bold characters) in the seventh row (i.e., 1.349-1=0.349, which is similar to 0.319, and so on).

[43] *Product specific economies of scale* reflect changes in costs as one of the outputs changes, while the quantities of the other outputs are held constant. For example, scale economies specific to the product *i* are $SL_i(Y;P) = IC_i \big/ Y_i MC_i$ where $IC_i = C(Y;P) - C(Y_{-i};P)$ is the incremental cost relating to the *i*th product and $C(Y_{-i};P)$ is the cost of producing all outputs except the *i*th. Similarly, *product specific economies of scope* for output *i* are computed as $SC_i(Y;P) = \frac{[C(Y_i;P) + C(Y_{-i};P) - C(Y;P)]}{C(Y;P)}$, where $C(Y_i; P)$ is the cost of producing only output *i*, and $SC_i(Y; P) > 0$ (< 0) indicates a cost disadvantage (advantage) in the "stand-alone" production of output *i*. Both SL_i and SC_i contribute to the determination of the global measure *SL*. See Bailey and Friedlaender (1982) and Fraquelli et al. (2004) for further details.

four services will affect the marginal cost of producing the other ones. Unlike scope economies, cost complementarities are 'local' properties because they describe how the cost function behaves in the neighborhood of an observation or set of observations. Given the functional form of PB models, CC_{ij} mostly depend on the second order cross-outputs coefficients, α_{ij}, and on the input price levels. Table 5 reports the estimates of cost complementarities evaluated at the sample medians. The results show the presence of cost complementarities for the couples P_{NAT}-P_{INT} and P_{INT}-*CARGO*, and anti-complementarities in all the couples involving *REV*, while $CC_{PNAT,\ CARGO}$ is not significantly different from zero. These findings suggest that offering flights for both international and national passengers would reduce the marginal costs of both services, while increasing non-core activities would result in an increase in the marginal cost of aviation activities (cargo, national and international flights).[44]

As to the level of marginal costs, our estimates show that, for the median airport, the marginal costs of increasing by one unit the number of national and international passengers are equal to 3.1 GBP and 4.0 GBP, respectively.

The marginal cost of generating an additional real GBP of REV (our proxy for commercial revenues) is 0.65 GBP, while the marginal cost of transporting an additional ton of cargo is 178 GBP. In spite of the fact that we use different output categories as well as a different methodology, such figures are broadly in line with the ones reported by Martin and Voltes-Dorta (2011) for worldwide airports, by McCarthy (2016) for the US and by Voltes-Dorta and Lei (2013) for the UK.

In order to link marginal costs associated to passengers to the aeronautical charges per passenger[45], we derive estimates of marginal costs from a three output cost function specification, where the three outputs are Y_{CARGO}, Y_{REV} and $Y_{PTOT}=Y_{PNAT}+Y_{PINT}$.[46] The marginal cost of increasing by one unit the number of total passengers is equal to 3.3 GBP for the median airport. We have also

[44] As highlighted in section 2, Martin and Voltes-Dorta (2011) found cost complementarities between domestic and international passengers, while McCarthy (2016) found anti-complementarities between commercial revenues (measured with precision and not through a proxy) and aviation activities.

[45] We thank an anonymous referee for having suggested us to develop this angle of investigation.

[46] The estimates are in line with the results presented in Table 3. For example, for the median airport, $\varepsilon_{CY_{REV}}$ = 0.42, $\varepsilon_{CY_{CARGO}}$ =0.18, $\varepsilon_{CY_{PTOT}}$ =0.27, and the resulting global scale economies are estimated at SL = 1.149.

computed the marginal costs associated to an expansion in passengers for airports of different sizes, as in Figure 1: marginal costs vary between about 2.8 GBP for medium-large airports and 8.4 GBP for small ones, with large and medium-small airports somewhere in between. Marginal costs fell over time, from an average of 5.58 GBP in 1994 to an average of 4.53 GBP in 2008. With very few exceptions, marginal costs are lower than aeronautical charges per passenger[47]; interestingly, if we exclude the four regulated airports (for which marginal costs closely match aeronautical charges per passenger), we find a weakly positive correlation between the level of concentration in an airport catchment area (which acts as an inverse proxy for the intensity of competition) and the level of the price–cost margin; moreover, price-cost margins tend to be weakly negatively correlated with the share of airport passengers served by low costs carriers. This result, associated with a reduction of price-cost margins across time, seems to be consistent with the fact that UK airports experienced an increasing competitive pressure, that pushed them to reduce revenues per passengers as well as price-cost margins in the period 1994-2008.

6.2. Different combinations of outputs

In order to shed more light on the contribution of each of the four services in explaining the cost advantages of diversification, we compute quasi scope economies for different combinations of couples or "*triplets*" of outputs.

In fact, the *quasi*-scope economies estimates reported above refer to airports that, being quasi-specialized in one activity, diversify *symmetrically* in the other three services, and end up being fully diversified firms. We now analyze, more realistically, asymmetrical situations, such as airports that are mostly active in two services (for example, P_{NAT} and P_{INT}), or in three services, and furtherly diversify into the remaining activities/activity. The results would be of help for airports that, being already diversified in an output pair (or in a "*triplet*" of services) are evaluating further diversification strategies.

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[47] For the median airport, aeronautical charges per passenger are equal to 6.5 GBP. They monotonically decrease with the size of the airport, ranging from 5.7 GBP (large airports) to 10.4 GBP (small airports), and fall over time (from an average across all airports of 7.83 GBP in 1994 to an average of 6.16 GBP in 2008).

Table 6 shows the estimates of $QSC\ (\lambda=1,\varepsilon=0.1)$ for all the six output pairs and the four output *triplets*. The results show that the average value of *quasi*-scope economies (0.177) reported in Table 4 is essentially due to the synergies that can be exploited between P_{NAT} and $P_{INT.}$ Airports already diversified in national and international flights do not seem to obtain remarkable cost savings by increasing the activities in cargo transport and/or in Y_{REV},[48] while for airports with limited involvement in international (national) flights, an increase of Y_{PNAT} (Y_{PINT}) would bring large cost benefits. Results shown in Table 6 also suggest that the only combination yielding negative scope economies, although not statistically significant, is when output is portioned into total passengers, on the one hand, and cargo and Y_{REV}, on the other hand: this suggests that airports specialized in passengers only (e.g. not providing cargo services) seem to be economically justified.

The above synthesis relies on the results (reported in Tables 4-6) based on the PB_G model. If we replicate the analysis based on the PB_C or the quadratic model SQ we get a quite similar picture. The only remarkable difference is that the results of scale and quasi-scope economies are of a lower magnitude (given the higher cost-elasticity of REV).

7. Conclusions

In this study, we have estimated a total cost function for the UK airport industry using the Pulley and Braunstein (1992) flexible functional form. Our main findings are that scale economies are important only for airports up to about 5 million passengers, while larger airports tend to operate at approximately constant returns to scale. More interestingly, ours is the first paper to provide estimates for (quasi) scope economies in the airport industry, which we find to be large, although declining with size. Moreover, we find that (quasi) scope economies are largely associated to the synergies arising from the combination of international and domestic passengers; in turn, the expansion of non-core activities tends to

[48] While the effect of expanding cargo activities is small, but positive ($QSC_{PNAT\text{-}PINT\text{-}REV}$ =0.031), the negative values reported for $QSC_{PNAT\text{-}PINT}$ and $QSC_{PNAT\text{-}PINT\text{-}CARGO}$, albeit not significantly different from zero, are due to the presence of anti-complementarities for the couples P_{NAT}-*REV*, P_{INT} -*REV* and *CARGO-REV*.

increase the marginal costs of producing passengers and cargo services. Bottasso and Conti (2017) interpret this finding as an indication that some airports might have devoted too much space to shops, at the expense of check-ins and gates, thereby creating congestion problems that negatively affect aviation activities[49].

However, it should be borne in mind that the anti-cost complementarity result for (our proxy of) commercial activities should be traded-off with possible increases in revenues associated to the exploitation of airports spaces.

The results of this study might be of interest to policymakers who a) need to undertake a cost benefit analysis to inform a decision on whether to open a small airport and b) need to decide whether to close an airport and concentrate the activity in a neighboring one (which might be producing different outputs). Moreover, our findings on quasi-scope economies might be important also for competition authorities that might evaluate whether or not to allow the merger between airport operators sharing the same catchment areas as well as for airport managers who might be planning to expand and/or diversify their airport's activities. Indeed, further refinements of this analysis would imply to obtain more accurate measures of revenues associated to non-aeronautical services.

Overall, it is important to remind that understanding the cost structure of the airport industry is a necessary step in order to advise policy decisions. However, it needs to be complemented by a wider analysis of the economic context where a single airport, or a group of airports, is located or is planned to be located. Indeed, place based policies require an extensive set of considerations, stemming from competition policy issues to welfare analysis. By way of example, the positive correlation that we find between airports' costs on one side and the level of concentration in each airport's catchment area on the other side, suggests that a larger number of airports competing with each other might put pressure on managers to cut costs. Therefore, synergies deriving from economies of scale and scope that could be exploited by concentrating the activity of nearby (possibly specialized) airports into a single one should be traded off with the reduction in competition, and the associated lower incentives to cut costs, that the concentration of activity into a single airport would entail. Needless to say, a

[49] For example, congestion can generate passenger delays. This might require extra services and more employees might be involved in managing queues associated to delays.

partial equilibrium approach is not able to fully inform an economic policy decision, but it provides crucial information that needs to be taken into account when evaluating economic policy projects from a wider perspective.

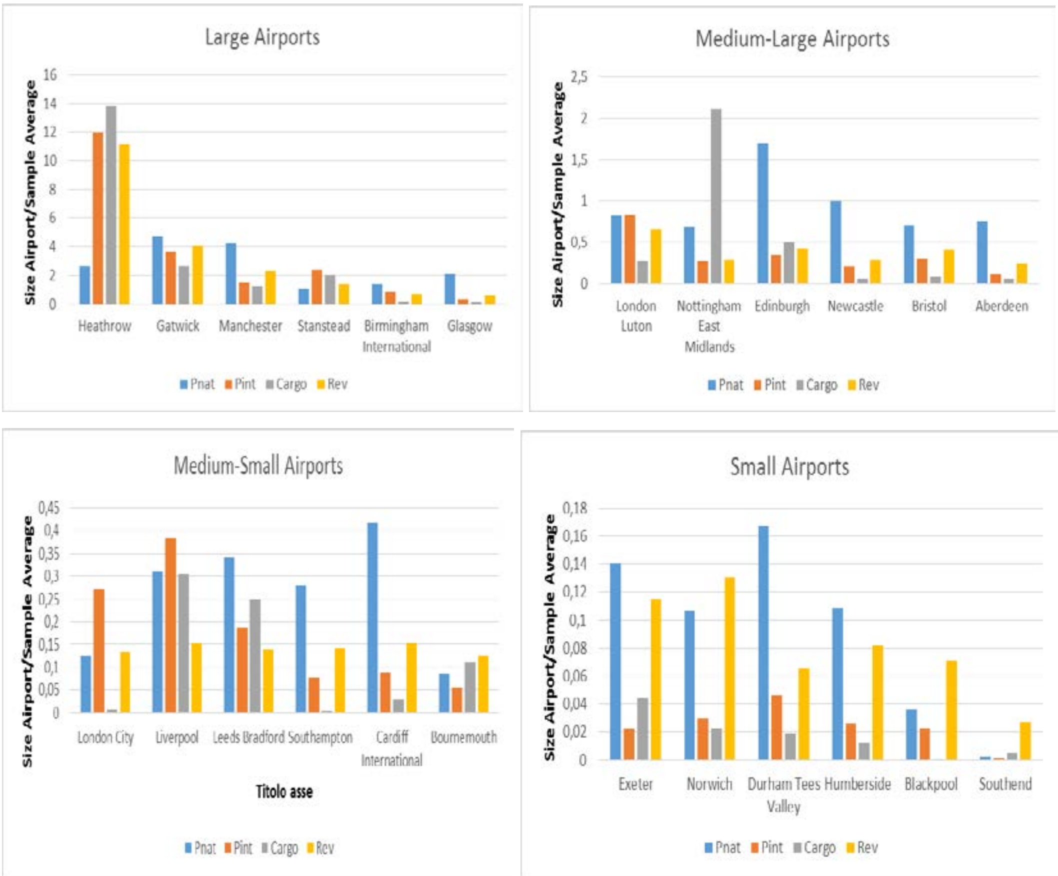
Table 1. Summary Statistics

	Mean	Std. dev.	Min	Median	Max
Total Cost (000£)	98654	230314	2501	27468	2070315
Output					
P_{NAT} (yearly number of nat. pass.)	2822911	3600181	3457	1348300	14861000
P_{INT} (yearly number of intern. pass.)	4602617	11473984	0	667480	63253333
CARGO (yearly tons of cargo-mail)	94564	265561	0	7189	1486300
REV (yearly 000£)	63230	145993	929	13632	750280
Input prices					
P_L : Price of labor (£)	18808	3641	11526	18385	32374
P_K : Price of capital (percentage)	0.122	0.002	0.119	0.123	0.125
P_O : Price of other inputs (index)	163	21	133	159	202
Cost shares					
S_L : Labor share	0.263	0.095	0.016	0.249	0.550
S_K : Capital share	0.358	0.142	0.052	0.382	0.702
S_O : Other inputs share	0.379	0.116	0.053	0.366	0.683
Sub-period 1994-1998	Mean	Std. dev.	Min	Median	Max
Total Cost (000£)	65845	120422	2501	18997	625717
P_{NAT}	2468535	3498628	4589	1081847	13825000
P_{INT}	3196262	9800650	0	324538	53698000
CARGO	82252	240973	49	7720	1293700
REV	60403	147840	940	11176	735611
Sub-period 1999-2003	**Mean**	**Std. dev.**	**Min**	**Median**	**Max**
Total Cost (000£)	89394	170694	3478	27888	1049452
P_{NAT}	2962949	3779481	3457	1304711	14861000
P_{INT}	4467956	11446879	0	621136	57470500
CARGO	96969	269654	0	6949	1385297
REV	60747	141928	929	12787	704562
Sub-period 2004-2008	Mean	Std. dev.	Min	Median	Max
Total Cost (000£)	140724	336796	4527	35798	2070315
P_{NAT}	3037250	3519109	3724	1692416	14311200
P_{INT}	6143634	12871610	0	1835038	63253333
CARGO	104473	285857	0	6052	1486300
REV	68540	149187	1663	17917	750280

Table 2. Correlation Matrix

	Cost	P_{NAT}	P_{INT}	CARGO	REV	P_L	P_K	P_O	S_L	S_K	S_O
Cost	1	0.501	0.917	0.883	0.892	0.455	-0.13	0.146	-0.33	0.257	-0.04
P_{NAT}		1	0.475	0.305	0.519	0.236	-0.08	0.056	-0.30	0.208	-0.01
P_{INT}			1	0.736	0.806	0.454	-0.14	0.109	-0.33	0.196	0.032
CARGO				1	0.761	0.379	-0.10	0.033	-0.34	0.219	0.006
REV					1	0.340	-0.08	0.026	-0.32	0.154	0.071
P_L						1	-0.59	0.790	-0.32	0.139	0.092
P_K							1	-0.64	0.310	-0.14	-0.08
P_O								1	-0.14	0.044	0.058
S_L									1	-0.59	-0.09
S_K										1	-0.75
S_O											1

Figure 1. Distribution of Outputs among UK Airports



Legend. Each bar represents an output category (Y_{PNAT} = national passengers; Y_{INT} = international passengers; Y_{CARGO} = tons of cargo, Y_{REV} = proxy for commercial revenues). In the horizontal axes are shown the different airports. The height of each bar represents the size of an airport's output with respect to the average amount of that output in the total sample.

Table 3. NLSUR estimation: General (PB_G), Composite (PB_C), Separable Quadratic (SQ), Generalized Translog (GT) and Standard Translog (ST) models [a]

	PB_G MODEL	PB_C MODEL	SQ MODEL	GT MODEL	ST MODEL
Box-Cox Parameters					
ϕ	-0.0922*** (0.029)	-0.0366 (0.032)	-0.0319 (0.0288)	0	0
θ	0.7290*** (0.045)	1	1	0.3377*** (0.0226)	0
τ	-0.0211 (0.058)	0	0	1	1
Output and factor prices elasticities [b]					
$\varepsilon_{CY_{PNAT}}$	0.0878** (0.0415)	0.0451*** (0.0188)	0.0511* (0.0299)	0.0478* (0.0277)	0.0564** (0.0226)
$\varepsilon_{CY_{PINT}}$	0.1716*** (0.0538)	0.1898*** (0.0447)	0.1797*** (0.0423)	0.1754*** (0.0396)	0.1383*** (0.0329)
$\varepsilon_{CY_{CARGO}}$	0.1712*** (0.0438)	0.1356*** (0.0383)	0.1278*** (0.0360)	0.1537*** (0.0340)	0.1449*** (0.0304)
$\varepsilon_{CY_{REV}}$	0.4188*** (0.0851)	0.5568*** (0.0644)	0.5697*** (0.6189)	0.5741*** (0.0758)	0.5539*** (0.0505)
S_L	0.2071*** (0.0101)	0.2119*** (0.0104)	0.2638** (0.1185)	0.2288*** (0.0096)	0.2230*** (0.0107)
S_K	0.4015*** (0.0101)	0.4017*** (0.0106)	0.3879*** (0.1246)	0.4098*** (0.0114)	0.4022*** (0.0115)
Scale Economies: $1/(\sum \varepsilon_{CY_i})$	1.1773*** (0.0036)	1.0785*** (0.0267)	1.0772*** (0.0229)	1.0513*** (0.0035)	1.1193*** (0.0228)
System log-likelihood	1248.31	1210.04	1106.10	1213.34	1169.72
Goodness of fit [c]	0.9979	0.9976	0.9974	0.9979	0.9974
Cost Function R^2	0.9991	0.9990	0.9989	0.9991	0.9987
Labor share R^2	0.3841	0.3667	0.1414	0.2956	0.2754
Capital share R^2	0.3303	0.3312	0.0183	0.3256	0.2726
LR test statistics					
PB_G versus other models	--	76.54 [d]	284.42 [d]	69.94 [d]	157.18 [d]
PB_C versus SQ	--	--	207.88 [d]	--	--
GT versus ST	--	--	--	--	87.24 [d]

[a] Estimated asymptotic standard errors in parentheses computed using the 'delta' method (Greene, 1997). *** Significant at 1%, ** Significant at 5%, * Significant at 10%.
[b] The values are computed at the median firm.
[c] The goodness-of-fit measure for the NLSUR systems is McElroy's (1977) R_*^2.
[d] The null hypothesis that the two models fit equally well the data is rejected at the 1% level of significance.

Table 4. Estimates of quasi-scope economies for the PB_G model at different output levels (and at the medians of input price variables)[a]

	$\lambda = 0.25$ (550,000 passengers)	$\lambda = 0.5$ (1.1 million passengers)	$\lambda = 1$ (2.2 million passengers)	$\lambda = 2$ (4.4 million passengers)	$\lambda = 4$ (8.8 million passengers)
QSC (ε, λ) **: Quasi-scope economies** [b]					
ε =0 (**SC: Global scope economies**)	0.391	0.146	0.010	-0.004	-0.033
	(0.924)	(1.202)	(1.664)	(2.232)	(2.823)
ε = 0.01	0.459	0.215	0.133	0.022	0.013
	(0.844)	(1.075)	(1.206)	(1.944)	(2.443)
ε = 0.05	0.566	0.319	0.151	0.104	0.122
	(0.652)	(0.764)	(0.818)	(0.813)	(0.815)
ε = 0.10	0.641	0.392	0.177**	0.110*	0.107**
	(0.489)	(0.496)	(0.091)	(0.062)	(0.051)
ε = 0.15	0.689*	0.438**	0.145***	0.131***	0.118***
	(0.387)	(0.222)	(0.059)	(0.049)	(0.036)
ε = 0.20	0.719**	0.467**	0.249***	0.221***	0.112***
	(0.333)	(0.236)	(0.046)	(0.056)	(0.035)
ε = 0.25	0.768*	0.477**	**0.319*** **	**0.229*** **	**0.129** **
	(0.465)	(0.214)	(0.048)	(0.045)	(0.067)
SL: Global scale economies	*1.349****	*1.252****	*1.177****	1.098*	0.945
	(0.049)	(0.036)	(0.004)	(0.050)	(0.106)

[a] Estimated asymptotic standard errors in parentheses. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

[b] Coefficient $\varepsilon \in [0, 0.25]$ has been used to split the production of the four outputs among firms, so as to generate configurations ranging from four specialized firms (ε = 0.0) up to four diversified firms (ε = 0.25). Parameter λ refers to the coefficient used to scale down (λ = 0.25, 0.5) and up (λ = 2, 4) the median values of the four outputs.

Table 5. Estimates of cost complementarities for the PB_G model evaluated at the sample median outputs (at the median input prices)*

$CC_{PNAT,PINT}$	$CC_{PNAT,CARGO}$	$CC_{PINT,CARGO}$	$CC_{PINT,REV}$	$CC_{CARGO,REV}$	$CC_{PNAT,REV}$
-0.340***	-0.001	-0.178**	0.620***	0.264**	0.388***
(0.084)	(0.064)	(0.092)	(0.154)	(0.119)	(0.125)

* Estimated asymptotic standard errors in parentheses. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table 6. Estimates of quasi-scope economies for airports quasi-specialized in "couples" of activities or diversified in "triplets" of activities for the PB_G model evaluated at the sample median outputs (at the median input prices)*

	QSC_{COUPLE} $(\varepsilon = 0.1, \lambda = 1)$					
COUPLES	P_{NAT}-CARGO → P_{INT}, REV	P_{NAT}-P_{INT} → CARGO, REV	P_{NAT}-REV → P_{INT}, CARGO	P_{INT}-CARGO → P_{NAT}, REV	CARGO-REV → P_{NAT}, P_{INT}	P_{INT} - REV → P_{NAT}, CARGO
	0.079*	-0.101	0.191**	0.042**	0.262***	0.321***
	(0.045)	(0.062)	(0.092)	(0.026)	(0.114)	(0.119)
	$QSC_{TRIPLET}$ $(\varepsilon = 0.1, \lambda = 1)$					
TRIPLETS	P_{NAT}-P_{INT}-CARGO → REV	P_{NAT}-P_{INT}-REV → CARGO	P_{NAT}-CARGO-REV → P_{INT}	P_{INT}-CARGO-REV → P_{NAT}		
	-0.077	0.031*	0.217***	0.331***		
	(0.061)	(0.019)	(0.093)	(0.041)		

* Estimated asymptotic standard errors in parentheses. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

QSC_{COUPLE} (ε=0.1), for a firm quasi-specialized in a generic pair of outputs (Y_1,Y_2), is computed as $[C(0.8*Y_1,0.8*Y_2,0.1*Y_3,0.1*Y_4)+C(0.1*Y_1,0.1*Y_2,0.8*Y_3,0.1*Y_4)+C(0.1*Y_1,0.1*Y_2,0.1*Y_3,0.8*Y_4)-C(Y_1,Y_2,Y_3,Y_4)]/ C(Y_1,Y_2,Y_3,Y_4)$.

$QSC_{TRIPLET}$ (ε=0.1), for a firm diversified in a generic triplet of outputs (Y_1,Y_2,Y_3), is computed as $[C(0.9*Y_1,0.9*Y_2,0.9*Y_3,0.1*Y_4)+C(0.1*Y_1,0.1*Y_2,0.1*Y_3,0.9*Y_4)-C(Y_1,Y_2,Y_3,Y_4)]/ C(Y_1,Y_2,Y_3,Y_4)$.

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