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The dilemma between capacity expansions and multi-airport systems: Empirical evidence from the industry's cost function

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ABSTRACT

This paper explores the problematic of airport capacity expansions from the perspective of the airport financial management, using the operating costs as the variable of interest. The objective is to provide empirical evidence on the financial advantages of expanding capacity against the operation of multi-airport systems (MAS) under the presence of significant returns to scale in airport operations. This is done by comparing the actual operating costs of the MAS with the predicted costs that correspond to the aggregated level of output and input prices. Predictions are obtained from a multi-output specification of the industry's cost function, estimated with a broad database of international airports. The results indicate the presence of non-exhausted scale economies at the current levels of production. Hence, the atomization of air traffic always increases operating costs at a system level. In the last section, the degree of economic inefficiency of five European MAS is calculated. These results also provide revealing conclusions about the size of the industry's minimum efficient scale. Furthermore, the use of data on American MAS allows us to separate the inefficiency costs derived from the atomization of air traffic from those related to the individual airports' inefficient behavior.

1. Introduction

Airports are designed as infrastructure providers for air transportation, and this industry is regarded as one of the fastest-growing sectors in the world economy. As a result of the increase in passenger and cargo traffic, the world's fleet will be almost doubled by 2025 and aircraft size will increase by 20% (Airbus, 2006). This explosive growth presents a continued challenge to the airports in terms of capacity development. The expansion of existing infrastructures is the most common alternative to accommodate the increasing demand. This involves the construction or lengthening of existing runways and apron areas, the improvement of ground transport facilities, new passenger and cargo terminals, and especially the development of new boarding piers. A second alternative to provide additional capacity is the construction of a new airport in the vicinity of the area. Nevertheless, in some cases, the multi-airport system (MAS)[1] would stand as the only alternative because land restrictions do not allow further expansions at the original location.

MAS are present in many world-class cities, such as London, New York, Paris or Tokyo, which are capable of attracting and generating huge amounts of traffic. The typical MAS features a major international airport (e.g. LHR, JFK, CDG) that serves as an established hub for major international (full-service) carriers and then one (or more) secondary airports which are focused on domestic, regional and commuter traffic. In Europe, it is typical that these secondary airports (e.g. BGY, ORY,

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[1] All the acronyms used in the paper can be easily consulted in Appendix A.

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Table 1
Cost function studies in the airport industry.

Study	Functional form	Data (panel or cross section)	Output	Conclusions
Keeler (1970)	Cobb-Douglas	P 13 US 65–66	Air traffic movements (ATMs)	No increasing returns to scale (IRS) exist in ATMs
Doganis and Thompson (1974)	Cobb-Douglas	CS 18 UK 1969	Work load units (WLUs)	IRS between 1 and 3 million WLUs
Tolofari et al. (1990)	Translog	P 7 UK 79–87	WLUs	IRS by 20.3 million WLUs
Main et al. (2003)	Cobb-Douglas	CS 27 UK 1988 P 44 world 98–00	Passengers (pax)/WLUs	IRS by 4 million pax or 3 million WLUs
Jeong (2005)	Translog	CS 94 US 03	Pax/WLUs/output index	IRS by 2.5 million pax or 3 million WLUs
Low and Tang (2006)	Translog	P 9 Asia 99–03	WLUs	Constant returns to scale (CRS) were imposed
Martín and Voltes-Dorta (2008)	Translog	P 41 world 91–05	WLUs and ATMs	Unexhausted IRS
Oum et al. (2008)	Translog (short-run)	P 109 world 01–04	Pax, ATMs and revenues (REV)	–
Martín and Voltes-Dorta (present study)	Translog (long-run)	P 161 world 91–08	Domestic (Dom)/ international (Int), hedonic ATM, cargo (CGO) and REV	Unexhausted IRS

HHN) serve as technical bases primarily for low-cost carriers that run point-to-point networks. In other cases, the MAS may remain as the result of a failed (i.e. rushed) transfer of traffic from the old to the new airport, as in the Montreal case.

The decision on whether expand capacity or build a second airport depends upon many factors, and it is clear that different stakeholders have their own interests. From the passengers' perspective, a secondary airport may be attractive for the local communities of its hinterland because it provides better accessibility even at the cost of reduced frequencies and less connectivity. Thus, MAS is appropriate to serve areas with a higher share of originating than connecting traffic (De Neufville, 1995). In this environment, a parallel network of secondary airports serving low-cost traffic (De Neufville, 2005) can grow around niche markets that serve different passenger needs. However, De Neufville (2000) also admits that "market forces impelling concentration almost always prevail decisively". Besides the evident advantages for transfer passengers in terms of connectivity, the airlines also prefer to concentrate their frequencies in hub airports because they obtain higher yields and greater profits. Taking into account all these different perspectives, the mentioned study recommends expanding capacity as the primary option.

This paper explores the MAS problematic from a different perspective that cannot be ignored, which is the perspective of the airport operator. Besides all passenger and airline considerations mentioned above, there is also the very important issue of how much is going to cost the operator to run the system, especially since all airports in a MAS are typically managed by single companies. The key technological feature associated with the MAS dilemma is the presence of scale economies in the provision of infrastructure for air transportation. If the technology exhibits increasing returns to scale (IRS) at the relevant output level, it will be cheaper to run an expanded airport rather than operate a MAS. Under hypothetical decreasing returns to scale (DRS), the operation of MAS should provide lower average costs per traffic unit as long as the new infrastructure is not operating with a significant excess of capacity.

In order to perform this analysis, the estimation of the airport industry's cost function is the suitable methodology. However, in the past literature, only a few studies have dealt with the costs of airport infrastructure services, and the use of very different data and methodologies provides inconsistent findings. Table 1 summarizes all the previous literature concerning the estimation of cost functions in the airport industry. This work uses an approach based on a multi-output long-run stochastic cost frontier that describes airport technology, featuring a much broader database than previous studies.

The rest of the paper is organized as follows. Section 2 presents the cost function and briefly introduces the analysis of both efficiency and industry structure, paying special attention to the calculation of the scale elasticities. Section 3 tests the results presented in the previous section against the cost performance of seven MAS from both Europe and US, providing monetary estimations of the inefficiency losses related to the atomization of air traffic. These results also provide revealing conclusions about the size of the industry's minimum efficient scale (MES).[2] Finally, Section 4 concludes.

2. The airport industry's cost function

The estimated long-run cost model features five outputs air traffic movements (ATMs), domestic (dom) and international passengers (int), cargo (CGO) and commercial revenues (REV). Aircraft operations were hedonically adjusted using the average aircraft weight (maximum take-off weight – MTOW) as a quality variable (see Eq. (1)). The model also features three input prices (capital/wc, materials/wm, and personnel/wp). These prices were calculated by dividing the respective costs by input quantity indexes constructed using marginal productivity ratios obtained from the equivalent ray production

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

Table 2
Long-run cost function parameter estimates.

Node	Mean	SD	Node	Mean	SD
Constant	10.76696	0.01591	rev*wp	−0.02363	0.00397
ATMmtow	0.12228	0.02060	0.5*wc^2	0.10550	0.00446
dom	0.13116	0.01095	wc*wm	−0.09310	0.00248
int	0.04314	0.00680	wc*wp	−0.02381	0.00359
cgo	0.06838	0.00787	0.5*wm^2	0.09293	0.00291
rev	0.13475	0.01479	wm*wp	−0.00667	0.00305
wc	0.37069	0.00288	0.5*wp^2	0.02983	0.00454
wm	0.31785	0.00214	0.5*ATMmtow^2 ^2*atm	0.01050	0.00923
wp	0.31072	0.00319	0.5*dom^2	0.01653	0.00149
ATMmtow*wc	−0.00999	0.00512	0.5*int^2	0.00520	0.00114
ATMmotw*wm	0.02457	0.00362	dom*int	−0.00945	0.00206
ATMmtow*wp	−0.00913	0.00469	0.5*cgo*cgo	0.00754	0.00223
dom*wc	0.00034	0.00108	0.5*rev*rev	0.03715	0.00513
dom*wm	0.00398	0.00074	t	−0.02639	0.00220
dom*wp	−0.00312	0.00101	t*ATMmtow	0.01211	0.00363
int*wc	−0.00773	0.00120	t*dom	0.00146	0.00092
int*wm	0.00478	0.00086	t*int t*ATMmtow	−0.00143	0.00094
int*wp	0.00330	0.00118	t*cgo	0.00343	0.00172
cgo*wc	−0.00053	0.00213	t*rev	−0.00920	0.00304
cgo*wm	−0.00830	0.00164	t*wc	−0.00588	0.00073
cgo*wp	0.00763	0.00220	t*wm	0.01061	0.00052
rev*wc	0.00442	0.00443	t*wp	−0.00403	0.00071
rev*wm	0.01676	0.00297	psi (hedonic)	1.11147	0.11219

frontier estimated with the same data. The capital input was represented by the total runway length and terminal surface. The "materials" input was represented by the number of check-in desks, boarding gates and total warehouse area. The time variable was added to the specification in order to account for technical change. The explanatory variables were deviated from their average values. For homogeneity reasons, the monetary variables were converted into purchasing power parity (PPP) USD using the OECD indicators.

$$\ln \mathrm{ATM}_i^{\mathrm{MTOW}} = \ln \mathrm{ATM}_i + \psi(\ln \mathrm{MTOW}_i). \tag{1}$$

The translog function was estimated jointly with its cost minimizing factor share equations (Zellner, 1962). Apart of that, the model features a separate specification of technical and allocative inefficiencies (AI) in a stochastic cost frontier framework (Kumbhakar, 1997). The cost function was restricted to be homogeneous of degree one in input prices. Bayesian inference and Markov chain Monte Carlo methods were used to deal with the non-linear complexities of the cost system (Griffin and Steel, 2007).

The model is thus estimated using an unbalanced pool of financial data on 161 airports from all over the world between 1991 and 2008, with a grand total of 1294 observations. The geographical breakdown is as follows: 94 airports from Europe, 45 from North America, 11 from Asia to Pacific, 9 from Oceania, 1 from Africa and 1 from Central America. It comprises airports of all sizes, featuring many of the world busiest ones in terms of passengers/ATMs or cargo tonnage. Though most financial reports consulted follow the international financial reporting standards (IFRS), many airports were dropped from the database because of heterogeneity. For example, at the three New York metro airports, policemen are considered airport staff, thus resulting in a much higher labor price than the rest of the sample. On the contrary, the quality of the financial reports in certain cases (e.g. Amsterdam, Frankfurt) allowed us to allocate the airport-related figures within a broad scope of activities, thus improving the comparability of the observations. The same applies to the few cases in which the airports charge depreciation on the land (e.g. man-made islands) or when they pay a rent for the land (Canada). Finally, another source of heterogeneity is the presence of dedicated terminals (typical of the US airports). In these cases, most operating expenditures are not directly recorded by the airport authority (AA) but by the concessionaire. Once the information on the total dedicated terminal area at each airport was obtained, the operating costs collected from the AAs' financial statements were proportionally adjusted to meet the declared airport capacity.

The estimated coefficients of the long-run model are shown in Table 2, which reports the posterior mean and standard deviation. Note that most coefficients are significantly different from zero and that the model is significant in overall (the *F*-test is clearly rejected). *R*-squared coefficient is 0.967. Since the hedonic ATM coefficient (psi) is, on average, greater than 1, we can conclude that aircraft costs increase more than proportionally with aircraft weight. The negative sign of the time parameter indicates some degree of technological development in the airport industry. There is also a hint to the existence of scale and input bias in the interactions between time and the other explanatory variables. Finally, note that, in order to be of any use, the estimated coefficients must be considered only in conjunction with their original approximation point.[3]

[3] Because of the logarithmic transformation, the approximation point is the geometric average of the estimating sample. These values are provided in Table 2.

Regarding the efficiency estimates, the results indicate that technical inefficiency ranges between 15% and 18% for the mean airport. The excess capacity, generated by either recent or failed expansions, was found to be the main explanation in most cases. In addition, the costs associated with allocative distortions may deviate up to 16% from the efficient expenditures, yet the average AI level was estimated to be 6.3%. The lack of outsourcing and flexibility in labor markets in some countries was shown to increase AI. Taking into account both effects, the average economic efficiency level of the airport industry is slightly above 79%. Individual estimations related to each airport's potential savings can be easily calculated from their technical and allocative inefficiency estimates. For the year 2008, small-size airports may be losing up to USD 4.5 million each year. The typical middle-size international airport in Europe is expected to accumulate losses of between USD 44 and USD 83 million. Finally, major hubs may be spending, on average, up to USD 143 million per year over the cost frontier.

The analysis of the economies of scale is based on the first- and second-order output parameters of the estimated cost frontier. Assuming a multi-output specification, the scale elasticity (S) is defined as the inverse of the sum of the n-outputs cost elasticities (Baumol et al., 1982). The logarithmic transformation allows us to obtain the expression of each output's cost elasticity directly from their partial derivatives. The calculation of the degree of scale economies gives a lot of practical information about investments, regulation and pricing in the airport industry. They measure the increase of output achieved by expanding all inputs in the same proportion. An important consequence of the existence of economies of scale is that producing the total output with two or more firms (MAS) generates higher operating costs than producing it with one single firm (expanded airport). Thus, the existence of IRS in airport operations would support the expansion alternative against the development of MAS in terms of operating cost efficiency.

The scale elasticity at the average airport is directly obtained as the inverse of the sum of the first-order output parameters. It yields 1.99, a very significant value, indicating that a 1% increase in costs leads to a 1.99% increase in output.[4] However, this result is of little interest as it is clearly related to the smallness of the average airport (6 million annual passengers and 68,000 annual ATMs) with respect to the relevant major hubs that make up the core of most MAS in the world. Hence, there is need to assess the evolution of the output cost elasticity as the scale of production departs from the sample mean.

This information is provided by the second-order output interactions. Since ATMs, passengers and cargo are considered cost-separable outputs (note that they do not typically share any infrastructure), only the squared coefficients and the interaction between passenger outputs are specified. In addition, the interactions between dom/int passengers and non-aviation revenues were not significant enough to draw any conclusions about possible cost complementarities and economies of scope.

The positive sign of the squared output coefficients indicates that the aforementioned scale economies tend to decrease with airport size and are going to be exhausted at a certain, yet unknown, level of production. The negative sign of the dom*int interaction can be clearly interpreted as a cost complementarity between domestic and international traffic at major commercial airports. However, due to the complexity of the multi-output setting, it is not easy to establish whether the industry's MES is reached within the current levels of production. Further empirical evidence is required.

Using the same estimating database, the individual scale elasticities of the nine sample airports over 40 million annual passengers were calculated.[5] The estimations range between 1.52 (Atlanta) and 1.28 (Beijing) for an average value of 1.46. Therefore, it is clear that, within the current technological frontier, even the biggest airports in the world are enjoying IRS. Thus, these results provide strong financial justification for the current expansive trend observed in the industry against the development of MAS. Nevertheless, in the next section, additional evidence in support of this conclusion will be obtained by confronting the cost performance of seven MAS against the industry's technological frontier.

As a final note, a consequence of the existence of such significant IRS at the current traffic levels is the impossibility to obtain a direct estimation of the industry's MES in terms of an observed vector of outputs,[6] as no existing airport is currently operating somewhere close to constant or decreasing returns to scale. In spite of that, this issue will be addressed again in the next section, because the use of consolidated traffic and price data on MAS will allow us to consider much bigger (though artificial) scales of production into the analysis of efficiency and industry structure.

3. Multi-airport systems

This section has three main objectives: (i) to test the results presented before, regarding the presence of IRS, in terms of cost efficiency. (ii) To provide a reliable monetary quantification of the total inefficiency losses associated with some well-known European MAS, as well as those related exclusively to the atomization of air traffic. Finally, (iii) to provide an approximation to the lower limit of the industry's MES by considering the aggregated production of a MAS into the analysis.[7] These objectives are consistent with the intention to validate the proposed methodology as a tool for policy and investment decisions, especially in regard to the management and operation of MAS by a single airport authority.

The hypothesis is that the actual aggregated costs of a MAS are significantly higher than the predicted frontier costs for the aggregated production level, thus leading to an abnormally high level of cost inefficiency. This is a direct consequence of

[4] The hypothesis of constant returns to scale is clearly rejected using a Wald Test.

[5] This includes ATL, DFW, ORD, PEK, AMS, FRA, DEN, LAX, and HKG.

[6] Note that the biggest observed scale is ATL, with 90 mppa and near a million annual aircraft operations.

[7] As seen in Table 1, the existing literature does not provide a reliable estimation of this technological feature. None of the estimated MES is consistent with the observed trend of airport expansions during the last decades.

the existence of such significant IRS in airport operations, i.e. an output increase requires less-than-proportional increase in inputs. However, as the size of the industry's MES remains unknown, the opposite might also be possible for those MAS handling more aggregate traffic than the current busiest hubs in the world, e.g. London.

In this experiment, the MAS will be considered as single decision making units, which is consistent with the fact that most of these MAS are operated under a single airport authority (AA). Therefore, the consolidated financial and operational data for the year 2008 of the five most important European MAS was collected. This includes London, Paris, Rome, Milan and Berlin. For homogeneity reasons, airports serving general and business aviation (LeBourget and London City) were excluded from the respective MAS, since the cost frontier does not include these outputs.

The financial data on costs (disaggregated in capital, materials/outsourcing, and labor/personnel) comes directly from each AA's published annual reports or financial statements. In most cases, airports' web sites include enough detailed information of traffic activity, such as ATMs, passenger enplanements, landed MTOW, and cargo. Regarding this last variable, some official statistics of governmental offices were also consulted, especially foreign trade records. In other cases, the AAs have been directly contacted to request additional information in order to complete the database. Finally, in order to calculate the aggregate input prices, additional information on some fixed factors was collected, i.e. the total runway length (run), the total surface of terminal buildings (ter), and the total number of boarding gates, check-in desks and warehouse space. This is summarized in Table 3.

The estimation of efficiency follows a very straightforward methodology. The explanatory variables are logged and deviated from the same approximation point featured in the estimated cost frontier (Table 3). Then the efficient cost that would correspond to each MAS's scale of production and its aggregated price vector is obtained using the provided coefficients. Finally, an approximate measure of the MAS's cost efficiency is obtained by dividing the predicted expenditure by the observed total costs. The lack of non-consolidated information does not allow us to estimate the efficiency of the individual airports that make up the MAS. Therefore, these inefficiencies are lumped with the extra costs derived from the atomization of air traffic. As a consequence, the results will only be of any relevance as they show that the cost inefficiency of a MAS is significantly higher than the average level of a wide range of comparable airports in terms of traffic, which will be considered a "normal" operating inefficiency in the industry.

The results for the European sample are shown in Tables 4 and 5. As expected, all European MAS present very high levels of economic inefficiency, well above the industry's average. The individual airports in each MAS will be assumed to operate with "normal" efficiency levels for their traffic range. These values are calculated as traffic-weighted averages of the efficiency estimations in a set of comparable airports (in terms of traffic) from the estimating sample. This comparison allows us to allocate any excess inefficiency to the MAS, and thus to provide, in the last column, two separate monetary quantifications: one for the potential savings related to the increase of operating efficiency at each individual airport, and a second related to the consolidation of air traffic into a single location, according to the current technological frontier. In the cases of

Table 3
Sample approximation point (monetary variables expressed in 000's PPP USD).

Domestic passengers	International passengers	ATM	MTOW	Cargo metric tons	Non-aviation revenues	Capital price	Materials price	Labor price
4597,770	1581,905	68,430	54.13	32,935	19,865	1.77	387.38	52.06

Table 4
Multi-airport systems in Europe (2008).

City	Authority	Airports	Pax	CGO (t)	TER (m^2)	RUN (m)
Berlin	Berliner Flughäfen	TXL THF SXF	21,405,505	42,818	98,168	15,095
London	BAA/Luton	LHR LGW STN LTN	116,158,774	1611,553	1603,425	16,015
Milan	SEA/SACBO	MXP LIN BGY	35,357,643	553,568	423,500	13,177
Paris	Aéroports de Paris (AdP)	CGD ORY	87,100,000	2400,000	913,800	23,185
Rome	Aeroporti di Roma (ADR)	FCO CIA	40,018,165	157,062	302,284	16,902

Table 5
Efficiency estimates at European MAS (2008).

City	Airports	PAX	Efficiency	Comparable airports	Estimated savings (PPP USD)	
					Consolidation	Individual
Berlin	TXL THF SXF	21,405,505	0.32	0.76	167,834,000	91,546,000
London	LHR LGW STN LTN	116,158,774	0.67	0.87	517,462,000	336,348,000
Milan	MXP LIN BGY	35,357,643	0.44	0.78	189,298,000	122,487,000
Paris	CGD ORY	87,100,000	0.63	0.87	316,869,000	167,346,000
Rome	FCO CIA	40,018,165	0.51	0.78	163,843,000	133,502,000

Milan, Rome and Berlin, a direct comparison was possible because their aggregated traffic volumes (21–40 mppa) are served by many other individual airports in the database. The cost performance of both Paris and London systems was compared with a broad range of world leading airports such as AMS, FRA or ATL.

The interpretation of these results is very clear; in all cases the aggregate output level could have been produced more efficiently by a single airport, thus saving from 20% up to 44% of the total operating costs, simply because the current technology guarantees the presence of IRS at these levels of production. In addition, the aggregate savings of a hypothetical traffic consolidation at the five most important MAS in Europe are estimated to be a figure around 1.4 billion PPP USD for the year 2008. The overinvestment in redundant airfield infrastructures at a system level can be identified as the main reason, as even the MAS with smaller aggregated traffic provides more than 10 km of runways. Apart of that, an additional 750 million could be saved by improving efficiency at the individual airports.

Regarding the individual case studies, the results of Paris are quite revealing. Its aggregate passenger and aircraft throughput do not differ substantially from those at the busiest single airport in the world, ATL. However, Paris' MAS provides over 9 km more than ATL of total runway length, featuring the longest commercial runway system in Europe and one of the longest in the world. In addition, the total floor area of all passenger terminal buildings at CDG and ORY is 40% more than the aggregate surface offered at the American hub. On the other hand, the French airports handle significantly more cargo traffic and operate with heavier aircraft. In spite of that, and according to the technological frontier, all domestic and international passenger and cargo traffic flying to/from Paris could be accommodated in a single airport on two thirds of the current expenditures. Even without taking into account the individual airports' inefficiency, the annual losses related to the evident overinvestment in redundant air- and landside infrastructures are valued in roughly 300 million PPP USD.

In the Italian MAS, the inefficiency is explained by the moderated numbers of passenger traffic, which face the strong competition of the rail mode. In both cases, the major airports in each MAS are operating with excess capacity. The current traffic levels could perfectly be accommodated in a single middle-size facility. The total savings of airport consolidation range from 160 to 190 million USD.

However, the ultimate example of inefficiency was found in Berlin, where a very high amount of idle capacity remained unused at the three airports serving the metropolitan area and its surroundings. As in the previous case, air transportation to/from Berlin faces the great competition of the rail mode. Output figures are very poor in comparison with the infrastructure offered, e.g. 15,000 m of runways. As an example, CPH is able to handle more than 20 mppa with only 9700 m. The central location of THF and its considerable amount of capacity would make it ideal to serve as Berlin first airport. In spite of that, it was almost abandoned[8] and was finally closed in October 2008. This situation generated annual losses for the AA of about 68% of the total operating costs, which equals to 168 million USD. For that reason, *Berliner Flughäfen* is currently expanding SXF under the new name of Berlin Brandenburg International (BER), which will remain as the only major airport serving the area. The objective is clearly the reduction of costs derived from the traffic consolidation under the presence of strong scale economies in the current level of air traffic to/from Berlin.

Finally, the results are also especially relevant for the London case. The MAS under study is composed by the three BAA airports (LHR, LGW and STN) plus Luton (LTN). They serve an aggregate of 116 mppa, representing the biggest scale of production subject to analysis. The total inefficiency losses are estimated to represent the 33% of the actual expenditure i.e. 850 million PPP USD. Assuming that these airports operate with "normal" efficiency levels, the losses associated to the split of production in four different locations are around 20%, i.e. 517 million.

In spite of that, London presents the most financially efficient MAS in Europe. There are two main explanations for that, the first being the successful running of all kind of commercial activities in the terminal buildings operated by BAA.[9] In the aviation side, however, the high efficiency is most probably related to the evident underinvestment in airside infrastructures. LHR, LGW and STN are best known by their very constrained and congested runway capacity. As of 2009, LHR is the world's busiest airport by number of international passengers. This huge amount of traffic is served by two extremely congested runways and their respective overcrowded terminals. The same applies to LGW, which serves roughly 35 mppa with a single runway.[10] Taking into account only the quantity of traffic served against the total operating expenditures (especially the depreciation of fixed assets), both airports should theoretically score very high in overall operating efficiency. Unfortunately, the effect of these capacity shortages in terms of congestion, delays and overall passenger service quality has not been taken into account[11] in the cost frontier estimation. This methodological shortcoming may explain, in the end, the moderated inefficiency level.

Furthermore, a major consequence of the existence of such significant cost savings related to air traffic consolidation at the London's MAS is that the industry's MES has to be necessarily located beyond its aggregated traffic level. Otherwise, the existence of DRS would have pushed the cost efficiency of the system above the industry's average for a single airport. Therefore, even though no direct evidence can be obtained by means of calculating a scale elasticity, it can be affirmed that the current technology still exhibits IRS at the non-observed output level of 116 mppa. This is also one of the most important conclusions of the present study, and there exists some real evidence that sustains this empirical result as major airports

[8] During the Nazi period, THF was Berlin's primary airport and one of the world's busiest airports.

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

[10] In fact, LGW is the world's busiest single runway airport.

[11] Note that the estimating database is mostly composed by financial information. No external effects derived from airport operations have been included.

Table 6
Efficiency estimates at American MAS (2008).

City	Airports	PAX	Efficiency	Individual airports	Estimated savings (PPP USD)	
					Consolidation	Individual
Washington, DC	IAD DCA BWI	62,393,948	0.56	0.84; 0.79; 0.78	221,824,000	167,823,000
Chicago	ORD MDW	88,732,431	0.70	0.76; 0.86	83,021,000	245,042,000

are currently being expanded to accommodate these very same traffic figures. For example, the new DWC airport at Dubai has been planned to serve up to 120 mppa, and even the busiest ATL and ORD (OMP, 2005) are being expanded with the same passenger throughput in mind. Therefore, it can be concluded that not only the current but also the upcoming generation of major hubs will still be enjoying IRS in the combined provision of infrastructure for air traffic and commercial activities in the long-run.

These results support, from the point of view of the operating costs, the expansion alternative against the operation of MAS, because there is no evidence that IRS are going to be exhausted in the near future. The financial convenience of the current development of a massive MAS in Dubai, which is expected to become one of the world's busiest transportation hubs, is thus brought into serious question. The maintenance of a rail link between the two airports is just one of the extra costs which could be avoided if the (forecast) increasing traffic is shifted entirely into the new hub, until reaching the industry's MES and thus entering into the area of DRS. In the recent times, there have been many examples of airport substitution, such as the recently inaugurated international hub in Bangkok or the mentioned case of Berlin. Also the new Hong Kong airport, built on a land-reclamated island, replaced entirely the congested and constrained old facility. The steady increase in passenger and cargo traffic experienced at this airport makes it the best example of exploitation of scale economies in the industry, and despite its short history, HKG has been consistently ranked among the top performer airports in the world by many international surveys.[12]

In the final part of this section, two additional MAS from the US will be analyzed. The objective is double: (i) provide more reliable estimations of both inefficiencies and (ii) extend the analysis of traffic consolidation to the public airports, where the extra costs are paid by taxpayers and not by shareholders. In order to do that, the financial data of two MAS will be aggregated from the available data on five airports included in the estimating sample. Note that, in this case, the individual airports' own efficiency can be directly estimated, and hence, it is possible to separate and quantify the exact savings related to the traffic consolidation, instead of using industry averages. The featured MAS are the mentioned Chicago system, which includes both ORD and MDW, and the Washington, DC system featuring IAD and DCA and BWI. The US airport industry features a MAS in practically every major city and they are most commonly managed by the own municipalities. Many other MAS were considered for inclusion in this experiment such as San Francisco or New York but they were finally discarded because of the lack of data.

The results for US MAS are presented in Table 6. As expected, the economic inefficiency derived from the splitting of air traffic is added to the individual effects for an overall lower efficiency at a system level. These individual effects are separately quantified and deducted from the total losses. The main conclusion is that the operation of a MAS is costing these municipalities between 6% and 28% of the total operating costs. In the Washington, DC area the losses related to the splitting of air traffic are quantified at 221 million USD, being only 83 million in Chicago. This last value is clearly explained by the smaller influence of MDW with respect to ORD in the MAS, being the benefits of traffic consolidation less evident than in the case of more similar airports.

4. Conclusions

This paper explores the problematic of airport capacity expansions from the perspective of the airport financial management, using the operating costs as the variable of interest. The financial assessment of each expansion alternative is completed by adding the operational costs/savings reported in this paper to the costs of construction and land purchased. Moreover, the results presented in this paper represent just one piece of MAS puzzle. Other important considerations not directly addressed by this paper (but widely covered in other studies) are accessibility, connectivity, congestion or airport and airline competition. All these factors need to be properly weighted in the final decision.

It should be also clear that this methodology does not account for land restrictions, because is of little interest for the validation of results. The fact that, for example, the London, Chicago or New York airport systems may be totally justified because LHR or MDW could not be further expanded, does not change the fact that, at the current output levels, the atomization of aeronautical infrastructure provision always brings an inadequate level of economies of scale exploitation.

Also note that the cost function does not explicitly recognize the fact that secondary airports dominated by low-cost airlines actually serve different markets. This introduces some output heterogeneity that may compromise the aggregations performed in the analysis of MAS, because of a misfit of business models.[13] The explicit recognition of low-cost traffic as

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

[13] We thank an anonymous referee for this observation. It is true that there are airports that do not want to cater to low-cost airlines, preferring to maintain an image as a full-service airport. De Neufville (2005) points out the case of Hamburg airport, which chose not to offer Ryanair low-cost facilities.

a separate output in the airports' cost function has not yet been reported in the literature. However, this area could be analyzed in a future research where scope economies can also play an important role.

In order to summarize, the most relevant results linked to the cost efficiency of MAS make no surprise at all. As expected, airport technology exhibits IRS at the current levels of production. Therefore, the cost efficiency at a system level is significantly lower than the observed at the individual airports due to the extra costs related to the atomization of air traffic, which may amount up to 36% of the annual expenditure for the AA. This provides financial justification for the current expanding trend observed in the industry against the operation and development of MAS. In addition, this paper provides empirical evidence that the industry's MES is located beyond 116 million annual passengers. Therefore, the upcoming generation of major airports will also enjoy IRS in the combined provision of infrastructure for aviation and commercial activities in the long-run. The financial convenience of some current airport developments is thus brought into question.

Appendix A

List of acronyms used in the paper.

AA	Airport authority	DWC	Dubai world central airport	ORD	Chicago O'hare airport
AI	Allocative inefficiency	FRA	Frankfurt airport	ORY	Paris-Orly airport
AMS	Amsterdam airport	HHN	Frankfurt Hahn airport	PAX	Annual passenger traffic
ATL	Atlanta airport	HKG	Hong Kong airport	PEK	Beijing capital airport
ATM	Air transport movement	IAD	Washington Dulles airport	PPP	Purchasing power parity
BER	Berlin Brandenburg airport	IRS	Increasing returns to scale	REV	Non-aviation revenues
BGY	Bergamo-Orio al Serio airport	JFK	New York JFK airport	RUN	Total runway length
CDG	Paris-Charles de Gaulle airport	LAX	Los Angeles intl. airport	STN	London Stansted airport
CGO	Total cargo tonnage	LCY	London city airport	SXF	Berlin Schoenefeld airport
CPH	Copenhagen airport	LGW	London Gatwick airport	TER	Total terminal area
DCA	Washington national airport	LHR	London Heathrow airport	THF	Berlin Tempelhof airport
DEN	Denver airport	LTN	London Luton airport	WC	Capital price
DFW	Dallas Fort Worth airport	MAS	Multi-airport system	WM	Materials price
DRS	Dresden airport	MDW	Chicago midway airport	WP	Personnel price

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