INSIDE THE MECHANICS OF NETWORK DEVELOPMENT: HOW COMPETITION AND STRATEGY REORGANIZE EUROPEAN AIR TRAFFIC

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ABSTRACT

Air transport forms complex networks that can be measured in order to understand its structural characteristics and functional properties. Recent models for network growth (i.e., preferential attachment, etc.) remain stochastic and do not seek to understand other network-specific mechanisms that may account for their development in a more microscopic way. Air traffic is made up of many constituent airlines that are either privately or publicly owned and that operate their own networks. They follow more or less similar business policies each. The way these airline networks organize among themselves into distinct traffic distributions reveals complex interaction among them, which in turn can be aggregated into larger (macro-) traffic distributions. Our approach allows for a more deterministic methodology that will assess the impact of airline strategies on the distinct distributions for air traffic, particularly inside Europe. One key question this paper is seeking to answer is whether there are distinct patterns of preferential attachment for given classes of airline networks to distinct types of European airports. Conclusions about the advancing degree of concentration in this industry and the airline operators that accelerate this process can be drawn.

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INTRODUCTION

Hub-and-spoke networks have been discussed in the management and economics literature before.[1] With the growth of low cost carriers, new operational characteristics (i.e., point-to-point route structures) of many networks needed to be taken into account when assessing the overall evolution of traffic and distribution of routes. More practitioner-oriented research into air traffic focused on network development and the effects that it had on airports and route structures (see Burghouwt, 2005; Reynolds-Feighan, 2001). However, the latter covered networks only partially leaving scope for extension from the airline's or the airport's network-wide perspective. Although differences between point-to-point versus hub-and-spoke structures are often highlighted, the way different airlines' networks evolve or interact to change their structure and function, remain untreated. Such network research of air traffic often seems limited in terms of validity, both internally (with regards to the different geographies served by airlines) and externally (with regards to its applicability to other industries, for example). If network development in a (regulated) market context is to be understood better, air traffic may provide valuable lessons *how* these networks develop, and in particular, *how* the different constituent airline networks organize air traffic (European, in our case) between airports.

Through a totally different stream of research, statistical physics suggests regularities through a power law for the ranked order distribution of vertices that form networks. Data from worldwide distributions of air traffic across airports have empirically been tested (see Amaral, Scala, Barthelemy & Stanley, 2000). Methods from statistical physics are of interest in this paper for several reasons: (a) the regularity of traffic distributions for air traffic provides a helpful benchmark against empirically found data; (b) network characteristics of classes of airlines can be compared with the ranked traffic distribution among airports and the locus of certain airline groups on a European (or global) distribution of air traffic can be highlighted; (c) by aggregating distinct classes of airlines and understanding their attachment patterns, distinct mechanisms driving growth in air traffic can be identified; and finally, (d) those network characteristics that influence a more or less desirable evolution of air traffic from a policy perspective can be emphasized.

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[1] A short review of literature covering the European context is presented later in this article.

The topology of European air traffic

The findings derived from *statistical physics* (Amaral et al., 2000; Barabasi & Albert, 1999) can be highly relevant when conducting empirically rooted research in economics or strategy. Its methods allow us to derive the big picture of a networks' topology first, before pinpointing interesting phenomena within it. In fact, statistical physics has been used to look at the topology of world air traffic in previous research (Amaral et al., 2000). The examined connectivity distribution for the world's busiest airports shows that there was no power law regime and that air traffic among them showed exponentially decaying tails, implying that there was a single scale for their connectivity. Amaral et al. infer that physical constraints (at the most connected hub airports) would prevent the formation of scale free networks in traditional transport networks, that is, that of air traffic. Their assessment of the various connectivities of world airports was based on the number of passengers in transit at airports (as well as cargo loads for a second connectivity distribution) rather than data on the number of distinct connections provided through a given airport. In particular, they expect that the number of distinct connections from a major airport was proportional to the number of passengers in transit through that airport. To this end, they made two assumptions. First, there is a typical number of passengers per flight. As the number of seats in airplanes does not follow a power law distribution, the assumption seemed to be reasonable. Second, there is a typical number of flights per day between two cities. In the cases examined, there are a maximum of about 20 flights per day and per airline between any two cities, thus the distribution of number of flights per day between two cities was delimited.

Networks can be planar or non-planar,[2] a feature that can prove crucial in the context of airports. In planar networks, the number of edges that can be connected to a single node is limited by the physical space available to connect them. In airport networks the number of connections is limited by the space available at the airport, "such constraints may be the controlling factor for the emergence of scale-free networks" (Amaral et al., 2000, p. 11149). Would the same assumptions and inferences hold when examining a distribution for European air traffic? Such an analysis would seek to determine whether European air traffic connections present significantly different properties for connectivity distributions.

Summary data on passenger flows and number of movements per airport were obtained through the Airport Council International (ACI) for the years 2001 and 2004. We ranked 330 European airports. This data included

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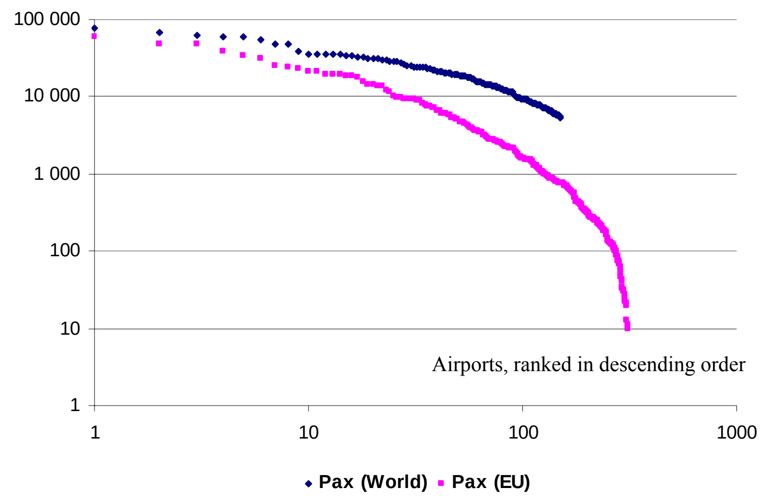
[2] Planar network form vertices whenever two edges cross, where non-planar networks can have edges cross and not form vertices.

domestic, European and intercontinental flights for European airports. These data sets show some major advantages when compared to that used by Amaral et al.: (a) total passengers flows are known; and (b) no extrapolation needs to be made from transit passenger flows. The other assumptions made by them still hold: (a) the number of passengers is supposed to be proportional to the number of city-pair links to that given airport; and (b) the bounded distribution criteria for the number of flights between airports holds as well.

The total number of passenger traffic connecting into a European airport was tabulated in ranked (descending) order. At this point of our analysis, more detailed structural network data was not available and the number of nodes was quite small (less than 330).

In Figure 1, data for 2001 was plotted in ranked order on a log-log plot. The distribution for the worlds' 150 biggest airports (in analogy to Amaral et al.) can thus be compared with the distribution for Europe's 330 biggest ones. For each graph the *y*-axis shows the number of passenger flows for a particular airport (in thousands, on a log scale) and the *x*-axis is the airport ranked in descending order.

Figure 1. Ranked order connectivity distribution for traffic movements of all airports and European Union airports, in thousands of passengers, 2001 and 2004



Pax = total passenger flows, in thousands
Note. Source: Airport Council International

This plot confirms that the traffic distribution for European airports decays much faster than a power law. Whereas the distribution seems more linear for the first 70 or so busiest airports in the world, the decay accelerates significantly thereafter. Among European airports, traffic distribution decays much faster from the 20th biggest airport on. Unfortunately, we are unable to describe a fat-tail end of world airports due to insufficient data from our ACI database. Also, it is impossible to confirm scale freeness between both geographic scopes; their respective slopes of decay are different from each other. At the other end of the graph for European airports, one can observe a flattening of the connectivity distribution at around 100,000 passengers per year. It appears as if above a critical threshold, the incremental cost for adding new links to the network are becoming prohibitive and are thus preventing the addition of new flights to these hubs. Amaral et al. (2000) explicitly cite world airports as such an example and our results conclude the same for European airports, although the critical threshold (of saturation) seems somewhat lower. It is unclear, however, why significant differences in passenger flows remain between the most highly connected airports in both geographies. If constraints of available space at the most highly connected airport hubs were indeed so central for shaping the structure of networks (see Amaral et al., 2000), would this necessarily mean that the slopes for the rest of the traffic distribution of airports would be impacted?

This question may be addressed in the light of the preferential attachment principle, as shown in the Barabasi-Albert model. Preferential attachment stipulates that there is a higher probability for a new or existing node to connect or reconnect to a vertex that already has a large number of links than there is to (re)connect to a low degree vertex (Barabasi & Albert, 1999). As the network grows incrementally it expands following preferential attachment. The probability (Π) that a new vertex will connect with another vertex (i) depends on the connectivity k_i of that vertex so that $\Pi(k_i) = k_i / \Sigma_j k_j$ (Barabasi & Albert, 1999). Because of preferential attachment, a vertex that acquires more connections than another one will increase its connectivity at a higher rate; thus, an initial difference in the connectivity between two vertices will increase further as the network grows. However, our empirical findings, along with Amaral et al., suggest that a preferential attachment mechanism may seem to be compromised in air traffic due to the saturation at hub airports. Other mechanisms that drive the structural evolution of European air traffic may be identified.

Table 1. Ranking of Europe's biggest airports

RANK 2004	RANK 2001	AIRPORT	Passengers in 2004
1	1	LONDON (LHR)	67 344 054
2	3	PARIS (CDG)	51 260 363
3	2	FRANKFURT/MAIN (FRA)	51 098 271
4	4	AMSTERDAM (AMS)	42 541 180
5	5	MADRID (MAD)	38 704 731
6	6	LONDON (LGW)	31 461 454
7	7	ROME (FCO)	28 118 899
8	8	MUNICH (MUC)	26 814 505
9	11	BARCELONA (BCN)	24 550 949
10	9	PARIS (ORY)	24 053 215
11	13	MANCHESTER (MAN)	21 544 199
12	22	LONDON (STN)	20 908 006
13	14	PALMA DE MALLORCA (PMI)	20 411 024
14	17	COPENHAGEN (CPH)	18 965 675
15	15	MILAN (MXP)	18 554 874
16	19	ISTANBUL (IST)	17 375 127
17	10	ZURICH (ZRH)	17 282 106
18	20	DUBLIN (DUB)	17 138 373
19	16	STOCKHOLM (ARN)	16 364 163
20	12	BRUSSELS (BRU)	15 594 508

Note. Source: Airport Council International

The 2001 and 2004 data sets suggest a remarkable stability in the rank order for the 10 most highly connected (busiest) airports in Europe. At this point we cannot say whether this stability is due to preferential attachment, to the fact that the historic operators (airline incumbents) concentrate their traffic at these hubs[3] or due to other causal factors. More striking are the changes in rank order for the other 10 airports. The fall of Sabena and the near bankruptcy of Swissair are most likely the causes for the drop in traffic at Brussels and Zürich airport. The success of London Stanstead can be linked to the concentration of low-cost carriers there. These first findings are noteworthy, because they suggest that beyond these two extreme cases, business policy (or strategy) of airline operators may indeed make a difference when structuring European air traffic. Without foregoing the findings that follow, we expect that changes in rank order will become more important, particularly with medium and small airports. The influence of business policy of airlines on such medium and small airports cannot be underestimated. The way these airline networks are likely to shape connections between airports, particularly medium and small ones, needs to be better understood.

ANALYSIS OF NETWORK ORGANISATION

Competition between airports has frequently been discussed before. Humphreys and Francis (2002) proposed a review on the literature that treats the various measures of airport performances. But many questions remain open, with certain problems not being dealt with. For example, Veldhuis (1997) notes that airport rankings by total number of passengers, cargo or aircraft movements are often used to describe the competitive position of airports. Other measures that enter into the assessment of spatial concentration in air traffic focus on scheduling and capacity related measures by flight stage (Burghouwt & de Wit, 2005); quality and frequency of direct connection (Adler & Berechman, 2001; Adler & Golany, 2001; Button & Reynolds-Feighan, 1999; Lijesen, 2001); quality and frequency of indirect connections (Veldhuis, 1997); and efficiency and performance of airports (Janic, 2003; Oum, Yu & Fu, 2003). These studies have not covered explicitly the fact that linkages between airports are determined by airlines' strategies and that the competitive situation of airports needs to take into account the structural characteristics of the network operators. Also, a clear distinction seems to be necessary when applying such factors to different geographies. According to Burghouwt & de Wit (2005), "Deregulation in the US resulted in reconfiguration of airline networks into hub-and-spoke

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[3] For instance, many hubs maintained or even increased traffic in 2001, despite the important drops in passenger demand that had severely affected their intercontinental routes.

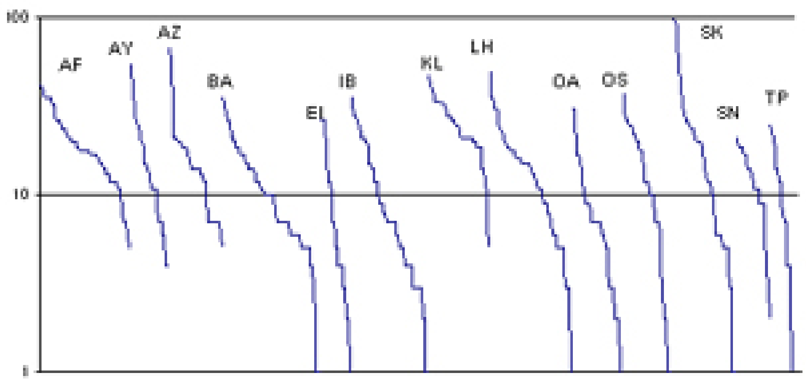
systems. In contrast, airlines in Europe already operated spatially concentrated networks, long before deregulation. This concentration at a national home-base was the outcome of bilateral traffic rights designated to the national carrier" (bilateral air service agreements). Most of the studies of airline network development in Europe and the US considered airline networks that were radially organized in space as equivalent to hub-and-spoke networks (Burghouwt & Hakfoort, 2001; Reynolds-Feighan, 2001). Although spatial measures for concentration may indeed be suitable for tracing hub-and-spoke network structures in the US (Reynolds-Feighan, 2001), the same measures may be regarded more critically if it were to be applied to a European context.

In order to favor a bottom-up (i.e., airline-induced) approach for explaining network structure among airports, we need to find causal factors in the business policies of airline operators and their respective network operations. A method would be to look at all the operators in the industry and compare the ways in which they organize their respective networks. For example, are operations among those that we call incumbents similar or different from other carriers? Will distinct (strategic) groups of airlines form distinctively different network structures among airports over time? Using such microscopic approaches towards network analysis we can explain how airlines contribute to air traffic and its structural evolution in Europe. The following ranked order distributions for flight frequency (number of weekly flights, see Figure 2) shows how much service the constituent incumbent airlines, for example, allocated to given airports in Europe in 2004.

The distribution shows that this sample of incumbent carriers have concentrated their traffic at very few airports, and that this traffic degenerates rapidly once a wider scope of airports are being served within the same airline's network. Such a bottom-up perspective may help illustrate how different business policies shape different networks among airports and these findings can be contrasted with the general statistical assertion of preferential attachment as the driving mechanism for network growth.

Again, the historical bias of European incumbent carriers towards domestic feeder routes cannot be neglected. If one were to consider all European airports as the relevant base for our market, the domestic bias would continue to shape current network structure in the future. On the other hand, the advancing integration (through alliances, code-sharing, etc.) among European carriers will likely trigger more reallocation of routes towards trans-European connections. The definition of a European market in light of a still very recent deregulation is unlikely to show high degrees of concentration for small airlines that have entered the industry only recently, including low-cost carriers. In short, European air traffic is still at an early stage of organizing itself, and current network structures are probably not a permanent configuration.

Figure 2. Weekly intra-European flight frequencies of incumbent carriers of European networks, at selected airports, 2004, ranked order distribution



Note. OAG data, September 2004.
Airline codes definition: Air France (AF), Finnair (AY), Alitalia (AZ), British Airways (BA), Air Ireland (EI), Iberia (IB), Royal Dutch (KL), Lufthansa (LH), Olympic (OA), Austrian (OS), Scandinavian Airline System (SK), Sabena (SN), Portuguese Airlines (TP)

METHODOLOGY AND DATA

In order to determine the influence of airlines' business policies on the evolution of European air traffic under a network perspective, we have to start by classifying the linked airports with regard to their function in the overall hierarchy for air traffic in Europe. Methods used in previous studies for US data use the potential or realized capacity of airports as their single classification variable, for example, passengers departing from a certain airport (used by the US Department of Transportation), from certain airport regions rather than individual airports (used by the Federal Aviation Administration), or including also non-scheduled flights at small airports (Graham, 1998). Although Reynold-Feighan (2001) uses a more comprehensive measure of passengers and/or number of movements per airline across airports in the US, such a measure would not sufficiently account for network characteristics inside Europe. In particular, the rapid growth of some low-cost entrants (as compared to the more established carriers such as Southwest in the US) and the yet unaccomplished consolidation through alliances and/or mergers and acquisitions among incumbents in the future could remain unaccounted for. Burghouwt & Hakfoort (2001) propose an alternative by employing cluster analysis based on Ward's method. "Multi-dimensional scaling is appealing because capacity alone does not capture the hub structure of an airport fully. It only measures the size but not connectivity" (p. 313).

We have collected data from the OAG dataset for the years 2001 through 2004. From this data we constructed variables such as departure airport, destination airport, flight frequency, aircraft type, and seat capacity for each flight. The data was based on a representative week in early November for each year. We decided to use the following three dimensions for cluster analysis to classify hierarchies among airport networks.

1. Total flight frequency deployed (by all scheduled airlines) at the airport: this captures the size and capacity actually used at the airport. We prefer frequency over number of passengers or available capacity since, beyond its direct correlation with airport capacity, the variable also expresses policy choices (that is, the same number of passengers—or capacity—can be made available through different choices in aircraft size and flight frequency).
2. The scope of other airports served by a given airport: it represents the number of destinations and captures what Burghouwt (2001) calls *connectivity* of the airport; and
3. The number of intercontinental destinations: to capture the intercontinental orientation of the airport and helps to distinguish intra-European scope from intercontinental scope.[4]

In the end our clustering methodology is in some aspects similar to Burghouwt's approach, although we shall cluster around observations for the first week of November for the years between 2001 and 2004. Observed data for scope and total frequency were converted into their log-scale, simply because empirical evidence suggests a logarithmic relationship to be more appropriate than a linear one to account for traffic distribution. Values for intercontinental links remained on a nominal scale, because no valid log can be obtained for airports that show zero intercontinental links. A proximity matrix was calculated, based upon Euclidean distance, with observations being subsequently grouped according to increase in sum of squares. A cut-off point was defined at the 6th cluster level for two reasons. For one, our t-statistic showed a 95% confidence interval when the 6th cluster was formed. Also, a clear and succinct interpretation would be facilitated if the number of clusters remained limited.

At this point it shall suffice to present results for the first week of November 2001 (the evolution of these clusters will be discussed at a later stage). The six airport clusters are described below.

Clusters 1 and 2 represent four primary hubs: London Heathrow (LHR), Paris CDG (CDG), Frankfurt (FRA) and Amsterdam (AMS). Both the

[4] The same measure was used by Burghouwt.

number of destinations and flight frequencies are very high. Strikingly, the number of intercontinental links represents a high percentage of overall connections, although Cluster 2 (London Heathrow and Amsterdam) show one third less intercontinental connections compared to Cluster 1 (Paris CDG and Frankfurt).

Clusters 3 and 4 represent 18 secondary hubs in Europe: the nine hubs in Cluster 3 [including Madrid (MAD), London (LGW), Munich (MUC), etc.] are slightly bigger than those in Cluster 4 [Düsseldorf (DUS), Vienna (VIE), Athens (ATH), Copenhagen (CPH), etc.], with more than twice as many intercontinental links per airport, on average. These secondary hubs remain both in scope (i.e., connectivity) and size well below the primary hubs.

Cluster 5 consists of 101 airports that can be considered medium and small. Examples are Lyon (LYS), Basel (BSL), Nürnberg (NUE) or Naples (NAP). A significant level of intra-European connections and medium frequencies per connection contrast with a small number of intercontinental connections.

Cluster 6 consister of 357 very small airports, for example Porto Santo (PXO), Kerry County (KIR), Narvik (NVK), Samos (SMI), Nimes (FNI), etc. There are practically no intercontinental links, and European or domestic connections are few, although the frequency per route served can be compared to that of other airports.

Before we go on to apply a model equation and to interpret the relationships between airline operators, their strategies and the evolution (or variation) of air traffic at airports, it seems appropriate to group airlines according to their networks' descriptive features that reflect route strategies. In the next section, we shall proceed by clustering what will resemble in many respects the method used in the above, but applied to the specifics of airline networks. In the section thereafter, changes in European airports' network structures shall be assessed. Finally, the impact of the various operators' strategic policies on these airport networks' evolution shall be estimated and be interpreted through appropriate (logit) regression analysis.

CLASSES OF AIRLINE NETWORKS IN EUROPE

Again we chose multi-dimensional scaling in order to classify European airline operators' networks. The methodology is analogous to the one applied in the above, except that carriers' strategies can be summarized even more concisely:

By clustering their operational characteristics around three dimensions—(a) the scope of airports served through its European airports; (b) the highest frequency deployed at one airport inside the European network;[5] and (c) the slope of decreasing frequencies across the network—we can group all airlines into strategic groups, as their allocation choices for service are closer to one another inside the same cluster as compared to airlines that are clustered elsewhere (see Table 2).

Table 2. Strategic groups of airports formed around airline networks, 2001

2001	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Members	[16]	[30]	[38]	[53]	[53]	[20]
Scope	4,042	2,935	2,072	1,289	0,927	0
Frequency	8,039	6,591	5,266	3,538	1,681	0,7
Slope (nom.)	1,786	1,882	1,707	1,399	1,134	0

There were 16 airlines that were grouped inside Cluster 1, including Olympic Airways (OA), Finnair (AY), Turkish Airways (TK), Austrian (OS), SAS (SK), British Airways (BA), Alitalia (AZ), KLM (KL), Air France (AF), Iberia (IB), and Lufthansa (LH). It remains instructive to see the structural differences between this Cluster 1, containing the biggest networks of operators, most of them incumbents, and other clusters. Although showing the lowest number of member airlines, the number of airports that each member's network serves, are the highest. This broad scope in serving many airports is, on average, associated with the highest number of flights from the carriers' main airport(s). The difference to the other airline groups is striking. Cluster 4 carriers appear to focus their strategy on high flight frequency on relatively few routes; also, the distribution of frequency across the airports being served is starting to flatten here (with Cluster 5 showing an even flatter slope). This means that frequency is being more evenly spread compared to the more hub-and-spoke like concentration inside Clusters 1, 2 or 3. In fact, the frequency distribution of airlines inside Cluster 2 is the most uneven of all. However, the scope of destinations, or the maximum frequency observed inside the network, remain below that of Cluster 1.

NETWORK TRAFFIC DISTRIBUTIONS

On an airport cluster level of analysis

If we apply the same method used in 2001 (refer to airport clusters) for the years 2002 to 2004, changes in Euclidean distance will form new clusters

[5] This variable will differentiate at a later stage between total frequency and frequency that is deployed at EU routes only.

(see Table 3). The separation of 4 primary hubs into two clusters in 2001 yields a single cluster including these same airports between 2002 and 2004. As November 2001 was still heavily influenced by the events of September 11, 2001 (9/11), the change could be explained by it. Also, a certain physical constraint at such primary hubs may impede growth beyond a critical point. Cluster 2 (2001) may still have had some margin to grow, whereas Cluster 1 was simply saturated. Cluster 3 (2001) leaves most operational characteristics unchanged, but due to the yield of Cluster 2 into Cluster 1, this Cluster 3 moves up in our classification to become Cluster 2 (2002-2004). Only intercontinental links grow significantly by some 17% within this cluster. A similar pattern can be observed for Cluster 4 (2001), which becomes Cluster 3 (2002-2004). Airports within this cluster keep their multiple scales relatively stable over time, but this cluster seems to develop more during 2004, particularly with regards to its intercontinental scope (+27%). What we classify as Cluster 4 (2002-2004) can not really be identified as a distinct cluster in 2001: around 25 airports are contained in it.

Table 3. Evolution of strategic groups of airports, based on weekly averages, 2001-2004

2001*	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**
Members	[2]	[2]	[9]	[9]	[101]	[357]
Scope	5,401	5,126	4,753	4,287	3,112	0,787
Frequency	8,362	8,271	7,649	7,064	5,81	3,219
Intercont.	105	75,5	37,889	17,333	1,505	0,017
2002						
Members	[4]	[11]	[7]	[25]	[260]	[167]
Scope	5,263	4,783	4,192	3,771	1,803	0,249
Frequency	8,33	7,655	6,974	6,38	4,446	2,383
Intercont.	92,25	37,727	16	5,56	0,073	0,006
2003						
Members	[4]	[10]	[8]	[25]	[82]	[352]
Scope	5,29	4,768	4,316	3,686	2,978	0,828
Frequency	8,322	7,656	7,028	6,256	5,666	3,14
Intercont.	95	37	17,25	5,48	0,207	0,02
2004						
Members	[4]	[9]	[10]	[28]	[91]	[332]
Scope	5,315	4,836	4,444	3,904	2,911	0,8
Frequency	8,331	7,727	7,129	6,501	5,421	3,089
Intercont.	98	43,222	21,8	5,036	0,319	0,039

*November each year.
Note. Source: Airport Council International.

It would be interesting to see whether such a cluster had existed before 2001 (due to 9/11), or whether these airports would form for the first time and in a very rapid way. Unfortunately, our database does not allow us to go further back in time. In any case, this classification appears quite durable over the subsequent three year period. Changes in Clusters 5 and 6, which contain over 90% of all European airports are quite noteworthy. The very small airports in Cluster 6 remain remarkably unchanged over time, except for 2002. In 2002, less than half of these 350 some airports maintain very low activity, and even drop further. Similarly, Cluster 5 seems quite comparable in 2001 and 2003-2004. The most significant change is probably due to elimination of the remaining very few intercontinental links at the airports concerned. The changes in 2002 concerning Clusters 5 and 6 may be explained by some 190 airports (normally part of Cluster 6) that were then included in Cluster 5, due to the growing Euclidean distance in intra-European scope and frequency with the residual 167 airports that remained inside Cluster 6.

On an origin-destination level of analysis

In order to trace the evolution of airport networks on a comparable basis, as well as changes in the presence of airlines inside such network structures, the following procedure was chosen. First, airports that were part of a certain cluster in period 1 (i.e., during 2001) stayed within this initial classification during the four-year observation period. This allowed us to pinpoint possible changes in network characteristics for groups of airports whose members did not change. We will see that these airports' intra-European characteristics, on average, remained remarkably stable over time, but changes for individual airports within the same cluster could be quite significant (see Table 4). Other, more significant changes in these networks rather concerned inter-continental scope of air traffic. Secondly, our data also looked at different airlines that served these airports. An origin-destination perspective, discriminating among the different airlines serving distinct routes, allowed for such more detailed examination. Some observations regarding market presence can be made and some inferences about the differential attraction of airport networks relative to airline operators can be drawn.

Table 4. Evolution of strategic group of airports, based an origin-destination perspective and airlines' presence, 2001-2004

		Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		Cluster 6	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2001	# of observations	170		129		433		170		129		433	
	# of airports	2		2		9		2		2		9	
	# of airlines	115		88		156		115		88		156	
	Scope	5,403	0,005	5,131	0,007	4,779	0,005	5,403	0,005	5,131	0,007	4,779	0,005
	Frequency	8,360	0,005	8,265	0,009	7,675	0,016	8,360	0,005	8,265	0,009	7,675	0,016
	Inter-continental	105,071	0,154	75,419	0,132	38,741	0,258	105,071	0,154	75,419	0,132	38,741	0,258
2002	# of observations	167		126		477		167		126		477	
	# of Airports	2		2		9		2		2		9	
	# of airlines	112		83		165		112		83		165	
	Scope	5,370	0,009	5,164	0,004	4,811	0,004	5,370	0,009	5,164	0,004	4,811	0,004
	Frequency	8,375	0,003	8,274	0,010	7,722	0,016	8,375	0,003	8,274	0,010	7,722	0,016
	Inter-continental	101,431	0,620	82,825	0,758	40,757	0,192	101,431	0,620	82,825	0,758	40,757	0,192
2003	# of observations	165		133		487		165		133		487	
	# of airports	2		2		9		2		2		9	
	# of airlines	115		93		171		115		93		171	
	Scope	5,406	0,007	5,191	0,006	4,788	0,005	5,406	0,007	5,191	0,006	4,788	0,005
	Frequency	8,364	0,004	8,261	0,011	7,693	0,016	8,364	0,004	8,261	0,011	7,693	0,016
	Inter-continental	105,776	0,272	83,797	0,475	39,187	0,270	105,776	0,272	83,797	0,475	39,187	0,270
2004	# of observations	169		151		524		169		151		524	
	# of airports	2		2		9		2		2		9	
	# of airlines	114		104		178		114		104		178	
	Scope	5,396	0,003	5,248	0,007	4,856	0,006	5,396	0,003	5,248	0,007	4,856	0,006
	Frequency	8,377	0,002	8,270	0,009	7,762	0,015	8,377	0,002	8,270	0,009	7,762	0,015
	Inter-continental	104,456	0,038	91,331	0,122	43,897	0,292	104,456	0,038	91,331	0,122	43,897	0,292

Airports that were grouped inside Cluster 2 (during 2001) increased their inter-continental scope (connectivity) from some 75 to 91 links (+21%) and the same type of links from airports inside Cluster 3 increased by +13% between 2001 and 2004. For Cluster 4 airports, these increases amounted to +30% over the same period. With the absolute number of inter-continental connectivity differing substantially between the clustered airport groups, growth (or new attachment) of such linkages going outside the European market shows a clear preference for airports inside Cluster 2. That is, primary hubs (London Heathrow, Amsterdam), but also to a lesser extent medium airports (including those of Cluster 4) appear to continue to grow with regards to their intercontinental links.[6] Some kind of critical threshold (cut-off) for growth through intercontinental connectivity seems to separate Clusters 5 and 6 from Cluster 4 or bigger.

As far as the attractiveness of differently sized airport networks for airline operators is concerned, clear preferences for the much larger airports appear. In 2001, 115 airlines serve the largest two European airports, 88 airlines serve the next two biggest airports, 156 airlines serve the nine airports in Cluster 3, and 133 airlines serve the nine airports in Cluster 4. A relatively few (201) airlines serve 101 airports that are grouped in Cluster 5. We cannot easily draw conclusions from such summary descriptions, but it is clear that incumbent operators' market power, though substantial at primary hubs, could be counter-balanced by the sheer number of alternative operators already present there. Also, airline operators seem to be able to exert much higher influence on airport policy at small airports (i.e., Cluster 5). Given the fact that the same airline operators most often operate across airport clusters, differential market power at airports may often better be exploited at medium or small airports rather than at primary hubs.

Another factor relative to the evolution of air traffic networks is the entry of airlines at airports. Between 2001 and 2004 the number of airlines[7] serving Cluster 1 primary hubs remained (almost) unchanged: 115 versus 114. Cluster 2 increased from 88 to 104 airlines. This may signal more and new routes being attached to Cluster 2 rather than Cluster 1. The number of airlines serving Cluster 3 airports increased by 22 (+14%) and for Cluster 4 by 22 as well (+16.5%). Only ten more airlines were present for Cluster 5 airports (+5%) in 2004 compared to 2001. In all these cases, the (intra-European) connectivity of the airports had increased in the process (compare with Tables 4 and 5). However, this increased connectivity was the highest

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[6] Almost all of these additional inter-continental links are operated by incumbent operators, as no agreements with extra-European authorities to liberalise such traffic had been concluded yet (e.g., Open skies, etc.).

[7] Again, only airlines being part of the EU were taken into account.

for airports within Cluster 5 (+21%), followed by Cluster 4 (+19%), Cluster 2 (+13%) and Cluster 3 (+8%). Clearly, the growth at medium airports was dependent on new entrants. There is no indication that preferential attachment mechanisms would drive the development of intra-European air traffic. Rather, we would like to suggest that airlines' strategies determine the structure, shape and development of European air traffic even if that may be in a rather complex manner.

THE IMPACT OF BUSINESS STRATEGY

The model equation

Our model needs to classify different airline networks' and their (business) policy choices and relate them to the different clusters of airports. As these six airport categories reflect increasing scales for the airport networks, we conclude that they are ordinal. We can even determine by how much, the respective scales differ between these clusters. Under circumstances where the dependent variables are ordinal categories (as opposed to continuous variables), and where the independent variables are either continuous or categorical (or both), ordered logit analysis is the appropriate type of analysis. Unlike Ordinary Least Squares regression, logistic regression does not assume linearity of relationship between the independent variables and the dependent, does not require normally distributed variables, does not assume homoscedasticity, and in general has less stringent requirements (Smith, 1997).

Like logistic regression, ordered logit uses maximum likelihood methods, and finds the best set of regression coefficients to predict values of the logit-transformed probability that the dependent variable falls into one category rather than another. Ordered logit fits a set of cut-off points for the fitted probability of the dependent variable. If there are 6 levels (as in our case) of the dependent variable (1 through 6), it will find 5 cut-off values separating Clusters 1 through 6. In our case (see model below), the reference for these cut-offs is Cluster 6 (i.e., the smallest airport networks). If the fitted value of logit(p) is below Cluster 5 intercept, the dependent variable is predicted to take a value corresponding to Cluster 6. If the fitted value of logit(p) is between Clusters 5 and 4, the dependent variable is predicted to take value for Cluster 5, and so on. In that sense, decreasing values for airport cluster intercepts in our model signal that the airline's policy choices for route service are oriented towards the bigger airport networks, if coefficients of the explanatory variable are negative.

As with logistic regression, we get an overall Chi-square for the goodness of fit of the entire fitted model, and we can also use a Chi-square test to assess the improvement due to adding an extra independent variable or group of independent variables. As with logistic regression, a crucial piece of information for evaluating the fit of the model is a table of predicted versus observed category membership.

Interpretation of results from ordered logit analysis

We run the model for our entire four-year sample that includes all European airlines. An additional measure compared the model prediction with the accuracy that could be obtained simply by chance. Under the cumulative chance criteria for ordinal, multinomial cases, one examines whether a prediction by guessing can achieve a correct rate for each group involved equal to the proportion of that group in the training set. Standard test statistics (\le, our dummy variable representing data for 2001 shows that airline networks tended to allocate routes to significantly smaller airports with their respective networks and 9/11 appears to have discouraged further concentration around primary hubs and spokes. This tendency was slightly corrected for data in 2002, but not durably, as the dummy variable for 2003 shows.

As far as airlines' policy choices go, we find that new routes (see connectivity) had significant impact in the sense that they were more likely to attach to bigger airport networks. Although this result may appear self-evident, we have to keep in mind that airlines could also have renounced to routes at the bigger airports and start new routes from smaller airports instead, which is not supported by our findings. Similarly, we see that total flight frequencies deployed by airlines (including frequencies for intercontinental traffic), clearly were more likely to favour bigger airport networks which rendered them denser, which is quite coherent with the hub-and-spoke logic of feeding regional and national traffic into hubs before transiting into intercontinental traffic. Flight frequencies that account for intra-European traffic only, however, follow a pattern that is completely opposite. Intra-European routes show a significant tendency to increase their frequency preferentially on medium or even small airports, rather than primary hubs. One reason may be the growth of low-cost scheduled airlines that prefer to save costs with regards to landing fees at non-hub airports and that prefer direct flights to tourist sites. Interestingly, our slope variable shows a significant explanatory coefficient that is negative: airlines that concentrate their capacity (i.e., frequency) on some airports only, rather than spreading them evenly, tend to increase frequency at bigger airports. That is, the more uneven the distribution of frequency inside such airlines' networks, the higher the probability that the airports concerned will figure among the bigger ones.

With these first results in mind, we seek to go into more detail to understand how particular strategic groups of airlines influence the development and evolution of differently sized airport networks. To this end, we filtered our data base for the selected groups (clusters) of airline networks and conducted the same logit ordinal regression analysis as above in a separate manner for each airline group.

Likely impact of distinctive groups of airlines

The desired multicollinearity of the independent variables and the small number of observations in some of the dependent variable categories raised methodological problems by diminishing the model's predictive power and descriptive potential, and increasing rounding errors for some airline groups. These problems became more salient for the smallest two groups, in particular for Cluster 6 (where the Chi Square for Cluster 6 yields a p = 0.13). We could have chosen to remove those variables that contribute most to the intercorrelation problem in a stepwise process. Since our logit regression analysis is ordinal and the overall results are very coherent and symmetrically structured across all examined airline groups, we decided not to modify our format (the logit equation) for problematic clusters and, rather, maintain comparability across all six clusters. Therefore, the results for Cluster 6 had to be interpreted particularly carefully, that is, regarded in the light of their coherence with other clusters rather than focusing on the resulting values as such (see Table 6).

Table 6. Differential odds for strategic groups of airports (2001 classification)

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
[AP_CLUST = 1]	-3,910*	-6,719*	-1,069*	-1,358*	-1,960*	-1,943*
[AP_CLUST = 2]	-2,679*	-5,486*	0,159	-0,059	-0,586	-0,626
[AP_CLUST = 3]	-2,046*	-4,934*	0,767	0,689*	0,242	0,088
[AP_CLUST = 4]	-1,240*	-4,170*	1,598*	1,647*	1,033*	1,204*
[AP_CLUST = 5]	0,495	-1,790*	3,588*	3,343*	2,754*	3,579*
AL_SCOPE	1,153*	-0,083*	-0,955*	-1,066*	-0,453	0,485
FREQ_T	-13,428*	-4,490*	-1,331*	-0,254*	-1,161*	-0,821*
FREQ_M	13,013*	4,232*	1,965*	1,083*	1,612*	0,649*
AL_SLOPE	-0,885*	-0,948*	0,342*	-0,099	-0,692*	-0,008
[WK_NOV=2001]	0,839*	0,599*	0,809*	0,978*	1,512*	1,356*
[WK_NOV=2002]	-0,327*	-0,281*	-0,154	0,175	0,135	0,212
[WK_NOV=2003]	0,514*	0,146	0,035	-0,005	0,155	0,165

* $p < 0,5$

The Chi Square test indicated that, of the four explanatory variables describing airlines' policy choices, the degree of connectivity (scope) of airline operators showed no significant impact on changes in airport clustering (for airlines grouped in Clusters 5 or 6). The slope variable that represents airlines' concentration of capacity across airports shows no significant impact for Cluster 6, nor does it for Cluster 4 airlines.

As was already shown before, 9/11 had a tendency to fragment the market structure among airport networks—that is, airline networks had a tendency to remove capacity from airports—grouping many then in lower ranked categories (see dummy variable NOV = 2001). Although this trend was pervasive across all different groups of airlines, its effect was more important with the medium and small operators: although larger airlines reduced their presence, smaller airlines did so much more. It was the latter that showed higher likelihood of dropping route service, particularly at larger airports. In 2003, only the most important airline networks (Clusters 1 and 2), corrected this movement in a statistically significant way and added capacity on the bigger airports.

Airline scope

The most important airline networks (Cluster 1) had a tendency to extend their routes into medium and maybe small airports, rather than increasing their concentration around primary and secondary hubs. This is not the case for big airline networks that are grouped inside Cluster 2: although there is a significant relationship to deploying routes more on the primary and secondary hubs, but its importance is much smaller. Medium airline operators show both a significant and strong likelihood that their routes attach on hub airports, maybe also medium airports, but much less on the small ones.

Intercontinental frequency

Measures for flight frequency that include intercontinental frequency show the same pattern across all six groups of airlines, although this pattern appears to diminish for smaller airline networks: intercontinental flight frequencies show a strong tendency (likelihood) to attach to the primary and secondary hubs. Although this finding seems quite intuitive, it is noteworthy that it is only the very biggest airline networks (to a lesser extent Cluster 2) may reap more immediate benefits from such a strategy, given the current state of market liberalisation.

Intra-European frequency

The opposite is true for airline policies that increase frequencies on intra-European routes: here, the likelihood that they occur in small or medium airports is much more important. Interestingly, medium or even small airline operators show a much stronger propensity towards such intra-European service outside of primary or secondary hubs (when comparing the coefficient with total frequency in *Freq_T*).

Concentration of capacity

The slope variable indicates significant relationships for Clusters 1, 2 and, to a lesser extent, for small airline operators grouped in Cluster 5. These airlines, when concentrating their traffic at some airports rather than spreading it evenly across the entire network, show a stronger likelihood to attach to the bigger airports (primary and secondary) hubs. Although its impact may be less important than that for connectivity or frequency, we have to keep in mind that it is correlated with the former and that the distinct slope variable remained significant for the likelihood of attachment. Medium airlines (Cluster 3), however, suggest that increased concentration of traffic may also favour medium or maybe even small airports as a base.

CONCLUSIONS

Starting with general assumptions that came from statistical physics, our analysis allowed us to assess and identify in a more microscopic way drivers of concentration in air traffic. The role of airlines' strategy for the evolution of different structures in air traffic could be emphasized. The general statistical assumption that attempted to model network growth, that is, that of preferential attachment, was put in perspective in an empirically founded analysis for distinct ranges in the distribution of air traffic in Europe.

We found that different (strategic) groups of airlines showed a significant and varying influence on the structure and distribution of air traffic. The most serious qualification for the preferential attachment assumption came from the biggest airline operators (most of them incumbents) with regards to connectivity and for all groups of airlines regarding frequency on intra-European routes: here, clear patterns for decentralizing air traffic emerged. In particular, it was the strategies of medium airlines (i.e., Clusters 3, 4, and also 5) that grew service through frequency in a more decentralized way inside Europe. The way airlines allocate their capacity inside their own networks mattered as well: Cluster 3 type of airlines showed commitment to concentrating routes on few medium airports rather than primary hubs. Also, distinct groups of airlines provided much better resistance to airports in the case of demand shocks: airports that were served by airlines in Cluster 2 suffered much less after 9/11. Despite the apparent complexity in the interaction between groups of airlines regarding the structuring of airline networks, lessons about the progressing degree of concentration in air traffic and about the actors responsible for it can be drawn. It is up to policymakers to draw further conclusions about the optimality of the paths chosen.

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