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Assessment of New Hub-and-Spoke and Point-to-Point Airline Network Configurations

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ABSTRACT *This paper aims to provide new measures of airline network configuration with a view to analyse effectively the complexity of modern carriers' network design. It studies network configurations in the airline sector by taking into account both spatial and temporal dimensions. The spatial dimension is measured by using both the Gini index and the Freeman index, which originate from social science research. The temporal dimension is measured by the connectivity ratio, i.e. the share of indirect connections over the total number of connections. According to these indicators, the configuration of the largest full-service carriers and the largest low-cost carriers in Europe is investigated. The results show that the temporal dimension provides a clear distinction between full-service carriers and low-cost carriers; while the spatial dimension appears useful when identifying the peculiarities within groups.*

Introduction

The deregulation of the aviation market in the USA in 1978 has intensely affected the network configuration of airlines. In that period a number of 'trunk-line' carriers rapidly reorganized their network structures from a point-to-point (PP) system into a hub-and-spoke (HS) system.[1] Following the lead of the US, European deregulation began about a decade later. Three policy 'packages' were agreed in 1988, 1990 and 1993, and full deregulation came into force in 1997. European Union (EU) deregulation produced a slow and rather small effect on routes and fares (Brueckner and Pels, 2003) in the initial stage, but during the late 1990s the changes gradually became bigger. Three main effects were identified by Brueckner and Pels: the rise of international airlines alliances; the further development of the HS strategy by the former flag carriers; and the impressive growth of low-cost carriers (LCCs) such as Ryanair and easyJet.

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After the deregulation process and the flag airlines privatization, new airline business models have emerged. Cento (2006) distinguished three types of business models that are the most dominant and emerging in the European arena: the full-service carrier (FSC), the LCC and the charter carrier (CC) models. However, the fastest growing and most interesting model is without doubt that of the LCCs as they are designed to have a strong competitive advantage over the FSCs in terms of operational costs. The LCCs benefited from lower operational costs thanks to a simplified business model which is characterized by a different network configuration (Franke, 2004). The FSC model developed from the former state-owned flag carrier model, through the market deregulation process, into a new airline company with a HS network, or, through international alliances, with multi-HS systems. Sophisticated yield management techniques were adopted in order to control aircraft availability and to provide an even more differentiated product. The LCC business model has experienced fast growth in Europe after the deregulation. LCCs have successfully designed a focused, simple operating model around a PP, no-frills product. This paper does not deal directly with the business practices of FSCs and LCCs, but it analyses one of the key differences in their model, i.e. the network structure.

Traditional analyses of airline networks attempted to measure the network configuration by means of variables such as traffic distribution or flight frequency concentration (Caves *et al.*, 1984; Toh and Higgins, 1985; McShan, 1986; Reynolds-Feighan, 1994, 1998, 2001; Bowen, 2002). These methodologies have mainly addressed the issue of describing and classifying a network in terms of measures of geographical concentration, but they have only indirectly addressed this issue as a comparison of real network configurations with ideal HS and PP structures.

Although geographical concentration and network configuration are related concepts, they are not coincident. Geographical concentration indexes, such as the Gini or Theil indexes, provide a measure of how strong the frequency concentration is in the main airports. HS and PP measures of network configuration do indeed depend upon the shape of the network and its centrality. One of the most popular indexes of centrality is the Freeman index which was developed in social science research.

This paper does not claim that one index is superior to the others. A general comparison of measures will require a more detailed analysis, which falls outside the scope of this paper.[2] It will try to introduce new measures of spatial centrality that can help clarify the current evolution of the network organization.

In empirical analysis, airport spatial concentration in PP and HS networks might be quite similar, although there are strong differences in the role of large airports in these structures. In the PP system, large airports are 'technical bases', while in the HS system they are hubs. A *base* is mainly designed to offer direct flights; while a *hub* plays the role of connecting node.

The PP and HS network structures have received a set of similar and acceptable definitions in the transport literature. Reynolds-Feighan (2001) identified the HS configuration of a carrier when there is a high concentration level of air traffic in both space and time. Although a substantial number of studies on airline network configurations have focused on the spatial dimension, only a small number of empirical studies have attempted to measure the temporal dimension of the airline networks.[3]

In this respect the present paper aims to provide new measures for assessing airline network configurations in order to investigate effectively the complexity of modern carriers' network design and, if possible, to account for differences between LCC and FSC networks in Europe. This is a relatively new research attempt with a few notable earlier exceptions. First, the problem of measuring the network configuration is addressed in terms of the HS versus the PP network and not only the hub concentration. Second, both the spatial and the temporal dimensions are assessed and combined in one picture in order to reach a broader and more complete description of the network configuration. Third, the paper applies empirical methods originating from social network analysis, i.e. the Freeman index and what is called the Bonacich approach.

The paper is organized as follows. The second section provides some basic definitions of airline networks. The third section explores the network configurations of European FSCs and LCCs over the last 8 years. It reviews different measures of spatial configuration, i.e. the traditional measures used by the transport literature, such as the Gini concentration index, and those developed by social network analysis (the Freeman and the Bonacich centrality indexes). Finally, an operational measure is provided to capture time-based centrality that is called the 'connectivity ratio'. The fourth section presents the overall results of the analysis. The fifth section concludes the paper.

Network Definitions: A Review

There is no unique or even widely used definition of what exactly constitutes an HS or a PP network. Instead, a number of definitions coexist. From a network design perspective the HS or PP network can be described by using a simple network of four nodes. Figure 1 depicts two ways of connecting the nodes. On the left the nodes are fully connected through PP relations; on the right there is an HS relation. Airport H is the hub through which the other airports are connected. Note from Figure 1 that it takes three routes to connect all the nodes in the HS system, whereas this takes six routes in the PP network. Generalizing the example, given n airports, the possible number of city-pair combinations is: $n(n-1)/2$. Hence, the pure PP system requires $n(n-1)/2$ routes to cover all combinations, whereas the HS system allows carriers to cover the same airport combinations with only $n-1$ routes.

From an air traffic management perspective, HS and PP structures are related not only to spatial concentration, but also to temporal concentration.

Burghouwt and De Wit (2003) explained the spatial configuration by the levels of concentration of an airline network around one or a few central hubs. This

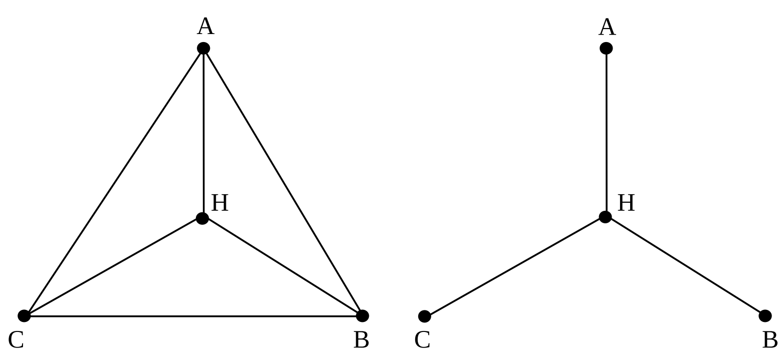

Figure 1. Point-to-point network versus a hub-and-spoke network

definition has been adopted by many geographical network analyses and measured by the Herfindal index (McShan, 1986), or by Gini or Theil's entropy indexes (Reynolds-Feighan, 1998). Temporal configuration is related to the airlines' flight schedule. Bootsma (1997) defined the temporal configuration as the number or quality of indirect connections offered by an airlines or alliance by adopting a wave-system structure in the flight schedule:

> A wave-system structure consists of a number of connection waves, which are a complex of incoming and outgoing flights, structured such that all incoming flights connect to all outgoing flights ….
>
> (Bootsma, 1997, p. 53)

Reynolds-Feighan (2001) identified the HS configuration of a carrier when its network has a high concentration level of air traffic in both space and time.

In contrast, a network is PP-structured when traffic flows are temporally and spatially dispersed. However, the development of a PP network originates from one or a few airports, called bases, from which the carrier starts operating routes to the main destinations. The number of routes may increase but hardly ever reaches the ideal PP configuration where all the airports are connected to each other. The reasons for this strategy are economic and political. Not all the city-pairs have enough demand volume to justify the operation of profitable flights, or there may be difficulties for carriers to obtain slots at all airports, and finally, the logistic costs of fleet rotation may make it convenient for the airlines to develop operational bases. Therefore, from an empirical point of view, it is expected that a PP network will show low levels of temporal concentration (i.e. flights are not organized to establish connections), but not necessarily low levels of spatial concentration (due to the organization in bases). However, an HS structure is a network spatially and temporally concentrated in one/a few airports, called hubs, where the flights schedule is organized in wave systems in order to have the maximal number of flight connections.

Empirical Findings on Network Measures

This section attempts to assess the network configuration of four large European FSCs and four European LCCs over the past eight years. Data on flight schedules, such as departure and destination airport, flight frequency, and seat capacity, are extracted from the Official Airline Guide (OAG) database. Data cover 1996–2004 for the summer season schedule (a representative week in August) and for intra-European flights only.[4] The analysis is carried out for the routes operated under the International Air Transport Association (IATA) carrier codes of the airlines considered, i.e. LH for Lufthansa, BA for British Airways, AF for Air France, and IB for Iberia. This means that the routes operated by other carriers in code-sharing or franchising with the considered carriers are included in the sample. For example, City Jet, Regional Air and Brit Air are franchised carriers of Air France operating under the code AF; Air Dolomiti is a franchised carrier of Lufthansa; and AirOne network is partially code-shared with Lufthansa; and all are included in the analysis. However, other partners or smaller subsidiaries of the four FSCs operating with their own IATA codes are excluded from the sample. The reason for this choice is that code-shared or franchised routes are part of the network optimization process of the HS system. Intercontinental flights have been excluded since they fall outside the scope of this paper.[5] On the basis of total weekly frequencies in 2004, the four largest national carriers were selected: Lufthansa German Airlines, Air France, British Airways, and Iberia; and the four largest LCCs: Ryanair, easyJet, Air Berlin, and Virgin Express.[6]

Burghouwt *et al.* (2003) measured air traffic at an airport by the number of seats supplied per week. The authors believe this variable can be somewhat misleading if applied to intra-European flows. Although it provides a good indicator of the size of the network nodes, in the specific analysis of the intra-European network it can be a biased measure of the spatial configuration measure for at least two reasons. First, the number of seats supplied is the result of the whole network optimization including intra-European and intercontinental flows. In the HS network design, the size of the aircraft is decided on the basis of the sum of local and connecting traffic to both European and intercontinental destinations. If the analysis is restricted to intra-Europe, then the intercontinental seats supply will be erroneously included in the data. The second reason lies in the dynamics of demand over time, which is taken into account in order to determine the optimal levels of seat supply, i.e. the aircraft size is enlarged for some limited period during the year, but the weekly frequency remains fixed. In order to reduce the effect of these factors, it is proposed to use the number of flights per week at the airport instead of the number of seats per week. The paper will now present the results of the Gini, Freeman and Bonacich indexes, as well as the results of the temporal concentration analysis.

Gini Concentration Index

The Gini index of concentration is defined as follows:

$$G = \frac{1}{2n^2}\,\bar{y}\sum_i\sum_j \left|y_i - y_j\right|,$$

where the y_i and y_j (air traffic at i or j) are ranked in increasing order; $\bar{y} = \sum_i y_i$ is the mean of the weekly frequency; and n the is the number of airports in the airline network. According to Burghouwt *et al.* (2003), the Gini index increases with the number of airports in an airline network, n. The maximum value of the index is as follows:

$$\hat{G} = 1 - \frac{2}{n}$$

This maximum Gini index can therefore be observed for an HS network with all traffic concentrated on one HS route. Burghouwt *et al.* corrected the Gini index for the size of the airline network (number of airports) by dividing G by its maximum value. With the normalized Gini, it is possible to compare the spatial structure of airline networks independent of network size.

Figure 2 presents the normalized Gini index for the selected carriers in 1996, 2000 and 2004. FSCs appear to have a higher concentration index than LCCs. This indicates a more unequal spread of air frequencies over the network. This may be the consequence of having single- or multiple-hub networks where many legs are connected.

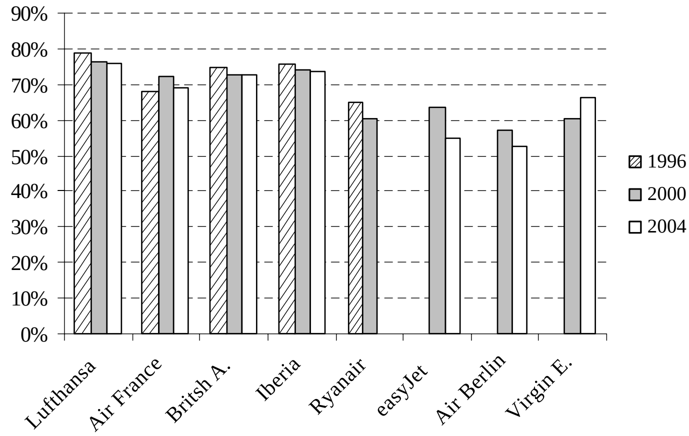

Figure 2. Normalized Gini concentration index for European airlines

The difference between the four FSCs, in terms of concentration indexes for intra-EU traffic, appears to be small. The values range between 0.69 (Air France in 2004 before the merger with KLM) and 0.78 (Lufthansa in 1996). Lufthansa has the highest concentration index level in each period. The index levels of FSCs were quite stable between 1996 and 2004.

The LCCs have a lower concentration than the FSCs, which decreases over the three periods. The indexes vary between 0.66 (Virgin Express in 2004) and 0.53 (Air Berlin in 2004).

The Gini concentration index is a measure of inequality of air frequencies between all pairs of airports in a given airline network. In general, the Gini index increases if the carrier reduces the frequency between spoke airports in order to concentrate its network on one primary airport, the hub (an HS strategy), or grows by the creation of a second hub (a multi-HS strategy). However, it also increases if one or a few routes gain importance in terms of relative frequency to the other routes, regardless of whether those are PP or HS legs.

Freeman Network Centrality Index

This section describes the Freeman (1979) centrality index as a measure of network morphology. To the best of the present authors' knowledge, previous applications of this centrality index to measure airline network configurations have not been recorded in the transport literature. The Freeman index has been developed in the context of social network analysis and measures the network shape by its inequality—or variance as a percentage—with respect to a perfect star network. The authors consider the star network as the pure HS network, and thus the Freeman centrality index is a measure of similarity to an HS configuration.

The literature on social network analysis proposes an operational set of methodologies to describe network complexity. The concept of network centrality is one of the fundamental properties of social structures that can be applied to airline network analysis. The centrality of a node in a network is a measure of the structural importance of the node. Describing the multiplicity of centrality measures is beyond the scope of this paper (for a detailed review, see Wasserman and Faust, 1994; and Hanneman, 2001).

The centrality concept used in the present paper is what is called *betweenness centrality*. Consider the star network presented in Figure 3. Node H has an advantage in the star network as it falls *between* all pairs of nodes, while no other nodes fall between H and the other nodes. If a passenger located in H wants to reach F, he/she may simply do it via a direct link. If a passenger in F wants to reach B, he/she needs to travel via H. This is also the basic concept of an HS network where H is the hub and the other nodes are the spokes. H has a structurally advantageous position because it falls between other nodes.

The measures of betweenness are based on the assumption that information is passed from one point to another only along the shortest paths linking them (as usually also happens for travellers).[7] A path is an alternating sequence of points and lines, beginning at a point and ending at a point, and which does not visit any point more than once. Usually, there is more than one path connecting the initial and the final point, and those paths can have the same or different lengths. In graph theory, the geodesic distance between two points is defined as the length of the shortest path between them. The betweenness $C_B(x_i)$ of a point x_i therefore requires an examination of the geodesics linking pairs of other points. If g_{gk} is the number of geodesics linking points x_j and x_k in a network, and $g_{jk}(x_i)$ is the number of such paths that contain point x_i, then:

$$b_{jk}(x_i) = \frac{g_{jk}(x_i)}{g_{jk}}$$

is the proportion of geodesics linking x_j and x_k that contain x_i.

To determine the centrality of point x_i, sum all these values for all unordered pairs of points where $j < k$ and $i \neq j \neq k$:

$$C_B(x_i) = \sum_{i<k}^{n} \sum_{i<k}^{n} b_{jk}(x_i).$$

This provides a measure of the overall centrality of point x_i in the network. $C_B(x_i)$ is dependent on the size of the network over which it is calculated. What is needed is a measure that is relative to its maximum value in terms of the number of points in its network.

Freeman demonstrated that the maximum value taken by $C_B(x_i)$ is achieved only by the central point in a star:

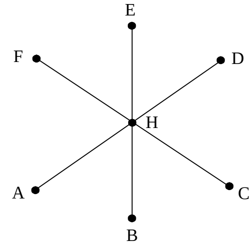

Figure 3. Star network

$$\frac{n^2 - 3n + 2}{2}.$$

Therefore, the relative centrality of any point in a graph may be expressed as the ratio:

$$C'_B(x_i) = \frac{2C_B(x_i)}{n^2 - 3n + 2}$$

which is a normalized measure that varies between zero and 1 and may be compared between networks. A star or wheel, for example, of any size will have a centre point with $C'_B(x_i) = 1$; all other points will yield $C'_B(x_i) = 0$. Both $C_B(x_i)$, $C'_B(x_i)$ are measures of point centrality based on the structural attribute of the betweenness of point x. Let x^* be the node with highest centrality, then the Freeman centrality index of the network is as follows:

$$C_B = \frac{\sum_{i=1}^{n}\left[C'_B(x^*) - C'_B(x_i)\right]}{n-1} = \frac{\sum_{i}^{n}\left[C_B(x^*) - C_B(x_i)\right]}{\left(n^3 - 4n^2 + 5n - 2\right)},$$

where the last equality emerges after substituting $C'_B(x_i)$ in the original definition.

The Freeman network centralization expresses the degree of inequality or variance in the network as a percentage of a perfect star network of the same size. This measure takes 1 for a star (pure HS configuration) and zero for a complete graph (pure PP configuration). These characteristics suggest that this measure can be used to detect HS versus PP configurations.

It is important to note that the Freeman index is particularly suitable when measuring network centrality as it captures the spatial economic behaviour of passengers. In fact, it assigns a high centrality to those nodes that are more often visited by geodesic paths. From a market efficiency perspective, the geodesic paths minimize the network costs and hence individually maximize the social welfare.

Figure 4 presents the Freeman centrality index calculated for the eight selected carriers.[8] The Freeman index shows, like the Gini index, that there is a substantially higher amount of centralization in FSC networks than in the LCC configuration. That is, the centrality of a few nodes varies quite considerably, and this means that, overall, spatial centralization is usually stronger in an FSC network than in the LCC network.

A few differences are also remarkable. The Freeman index detects Lufthansa as having the least centralized network among the FSCs. This means that there is less inequality in the nodes' centrality compared with, for example, Iberia. This suggests that, overall, Iberia's network is more similar to a 'star' network. The fact that the Lufthansa network is separated into two hubs, i.e. Frankfurt and Munich, may explain this. In general, the Freeman index does not present relevant variations over time for both FSCs and LCCs. The only exception is the big decrease of Ryanair's centrality from 1996 to 2000. In 1996 this carrier operated only ten airports linked to Dublin and London-Stansted. The rapid development of the

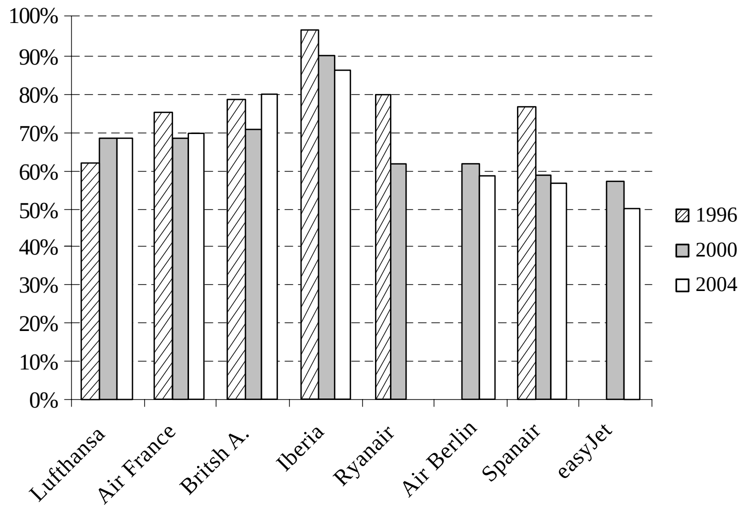

Figure 4. Freeman centrality index

network during the late 1990s obtained by adding new PP connections explains the decrease in the Freeman index for Ryanair.

Freeman Index Versus the Gini Index

Finally, some aspects of the Gini index and the Freeman index are briefly discussed. The normalized Gini index ranges between zero and 1. In the case of a pure PP network, it takes value zero, but with a pure HS it assumes the value 0.5. In several forms of multi-HS the Gini index assumes the value 0.5, failing to detect the spatial morphology. Figure 5 presents some examples of network configuration. These examples are only illustrative and they do not provide any proof that one index is over the other in the real context.

From the diagrams it appears that there is a relation between the frequency concentration and the Gini index value (panel A versus C; and E versus F and G), but it is obvious that there is no unique relation between the spatial morphology and the index value. Panels E and G have the same index value = 0.63. Another similar example is panels D, H and I that have $G = 0.5$, even though their spatial configurations are different (linear versus perfect HS). On the other hand, the Freeman index measures the network shape as the degree of inequality in a network with respect to a perfect star network, i.e. the pure HS. Indeed, in both panels A or C, the Freeman index is equal to 1, while in the perfect PP network (panel B) it is equal to zero. Moreover, the Freeman index seems to be affected not by the concentration of the frequencies (panel E versus F), but by the network morphology (panel D versus E; or H versus I). Finally, the Freeman index is particularly suitable to measure network centrality as it captures the spatial-economic behaviour of passengers. In fact, it assigns a high centrality to those nodes that are more often visited by 'geodesic paths'. Geodesic paths are the shortest paths that link two nodes and also those paths which passengers would like to choose when they travel, in order to minimize their total travel time or the number of connections.

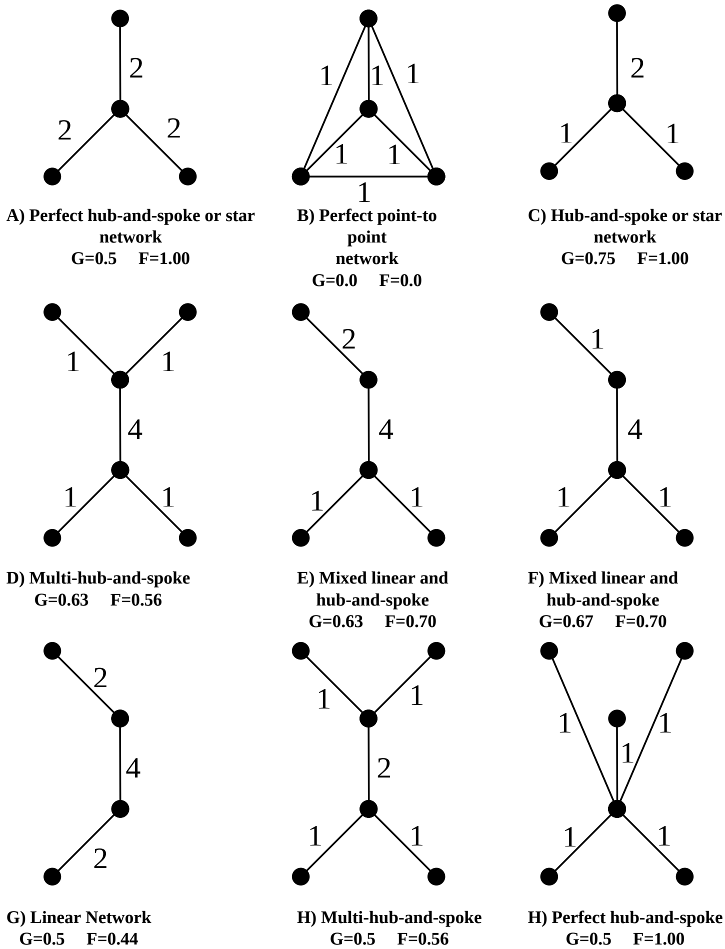

Figure 5. Examples of a normalized Gini concentration index (G) and a Freeman betweenness centrality index (F) for different spatial network configurations

Given the previous caveats, the Freeman index seems to be preferred to the Gini for two reasons. First, it can detect the network morphology in terms of the reference structures, i.e. it takes a value 1 for a pure HS and zero for a pure PP. The Gini index, on the other hand, seems to be more appropriate to measure the flight frequency concentration than the spatial configuration (although the two concepts are strongly related). In this respect the Gini assumes value zero for a pure PP, but 0.5 for a pure HS or even for a different spatial configuration such as multi-HS. Second, the Freeman index captures the economic behaviour of passengers. Freeman centrality assigns high centrality to those nodes that passengers would like to use in order to minimize their total travel time or the number of connections.

Bonacich 'Global' and 'Local' Centrality

Bonacich (1972, 1987) proposed what is called the 'eigenvector measure of centrality'. Let A be a value matrix,[9] where a_{ij} is the intensity of the connection between i and j, and let v be a vector of centrality scores (to be computed). Assume that the centrality of a node is a weighted sum of the centrality of nodes to which it is connected, written as:

$$\lambda v_i = a_{1i}v_1 + a_{2i}v_2 + \ldots + a_{ni}v_n.$$

Such an equation is easily interpretable. In the airline network, the centrality of an airport increases as more important airports are connected to it. The previous equation can be represented in matrix form:

$$\lambda v = A' v.$$

In this form, notice that λ, a scalar, is the eigenvalue, and v is the corresponding eigenvector. This matrix equation presents n possible eigenvalues and n possible corresponding eigenvectors. The eigenvalues can be interpreted as the 'size' or 'extension' of the matrix with respect to the direction provided by the eigenvector. The larger eigenvalues thus provide the main dimensions of the matrix, and hence they are useful to identify the main structures of the value matrix. Usually, the first factor or dimension captures the 'overall' structure of the network; the second and the subsequent dimensions capture more specific and local substructures. In order to select the main eigenvalues, a factor analysis is applied.

In the present study, the Bonacich index seems to be more meaningful in identifying the structure and substructure of the network than in providing a comparable measure of centrality among different networks. Hence, this index will be used primarily for representing the network structure.

The factor analysis is carried out for the eight carriers under consideration.[10] The factors explaining cumulatively about 70% of the overall variation are reported in Table 1 (Hanneman, 2001).

The first factor indicates how much of the overall pattern of distances among airports can be seen as reflecting the global network (the first eigenvalue). Other factors state more about local or additional patterns such as the domestic network or PP local structure.

Global centrality is distributed on the network nodes and is measured with the value of each node of the first eigenvector. Higher values indicate that the nodes are 'more central' to the main pattern of distances among all of the nodes; lower values indicate that nodes are more peripheral. The values of the first eigenvector (first factor) are presented in Table 2. Lufthansa and Air France present no

Table 1. Factor analysis results: cumulative variance percentage

Year:	1996	2000	2004	1996	2000	2004	1996	2000	2004	1996	2000	2004
Flag carriers		Lufthansa			Iberia			British Airways			Air France	
Factor1	58	56	63	81	74	68	38	41	34	62	47	42
Factor2	66	66	72				52	55	46	69	73	68
Factor3	72	73					60	64	54			
Factor4							66	71	60			
LCC		easyJet			Air Berlin			Virgin Express			Ryanair	
Factor1		100	39		54	40		100	86	86	70	n.a.
Factor2			54		65	55			100			
Factor3			65		72	64						
Factor4			74			71						

Table 2. Airports' 'global' centrality

1996		2000		2004	
Lufthansa					
Frankfurt	63.3	Frankfurt	68.7	Munich	68.7
Munich	52.6	Munich	57.1	Frankfurt	66.0
Berlin-Tegel	51.3	Berlin-Tegel	42.3	Berlin-Tegel	41.3
Hamburg	48.0	Hamburg	45.3	Hamburg	38.9
Dusseldorf	42.8	Dusseldorf	40.9	Dusseldorf	38.7
Air France					
Paris-Charles De Gaulle	98.2	Paris-Orly Field	69.3	Paris-Charles De Gaulle	71.9
Nice-Côte d'Azur	31.7	Paris-Charles De Gaulle	61.5	Paris-Orly Field	57.7
London-Heathrow	29.9	Marseilles	42.4	Nice-Côte d'Azur	42.0
Milan-Linate	25.3	Toulouse	41.8	Toulouse	34.9
Geneva-Geneve Cointrin	24.6	Lyon	36.2	Lyon	33.1
British Airways					
London-Heathrow	77.7	London-Heathrow	71.2	London-Heathrow	79.4
Manchester	48.8	Manchester	49.7	Manchester	52.1
Glasgow	39.3	London-Gatwick	43.8	Edinburgh	39.1
Edinburgh	37.8	Edinburgh	38.2	London-Gatwick	37.5
London-Gatwick	35.6	Glasgow	37.8	Glasgow	36.8
Iberia					
Madrid	90.1	Madrid	87.7	Madrid	83.4
Barcelona	65.5	Barcelona	73.0	Barcelona	80.0
Palma Mallorca	29.0	Palma Mallorca	29.4	Palma Mallorca	31.5
Malaga	22.0	Valencia	28.0	Valencia	28.3
Valencia	20.8	Bilbao	20.0	Malaga	23.3
Ryanair					
Dublin	95.0	London-Stansted	82.3		
London-Stansted	81.0	Dublin	80.0		
Glasgow-Prestwick	37.4	Glasgow-Prestwick	38.3		
Manchester	29.7	Hamburg-Blankensee	37.6		
Birmingham	26.8	Venice-Treviso	24.1		
easyJet					
		London-Stansted	100.0	London-Luton	59.9
		Copenhagen	39.3	Amsterdam	44.3
		Milan-Malpensa	39.3	London-Stansted	43.8
		Malaga	34.6	Nice-Côte d'Azur	39.0
		Rome-Ciampino	33.0	London-Gatwick	37.6
Air Berlin					
		Palma Mallorca	87.2	Palma Mallorca	73.6
		Paderborn	47.3	Dusseldorf	52.0
		Berlin-Tegel	45.7	Berlin-Tegel	45.5
		Muenster	40.7	Vienna	44.0
		Cologne	40.5	London-Stansted	33.3
Virgin Express					
		Brussels	100	Brussels	99.8
		London-Heathrow	65.6	Nice-Côte d'Azur	43.8
		Barcelona	51.2	Barcelona	36.8
		Rome-Fiumicino	50.1	Athens	36.8
		London-Gatwick	21.1	Malaga	36.8

Scores are the values of the first eigenvector that resulted from the factor analysis. Only the top five values are reported.

dominant global pattern of distance. Indeed, one can identify three main structures for the German carrier (three factors explain around 70% of the distance variation) in 1996 and two in 2004. Lufthansa appears to have strengthened its global structure in 2004, meaning a rationalization of its network. Table 5 shows that Munich and Frankfurt act as central hubs. In 1996, Frankfurt was the most central hub, followed by Munich, Berlin, Hamburg and Dusseldorf, which have a lower centrality. However, in 2000 and 2004 note that Munich is becoming as central as Frankfurt with the other three airports reducing their centrality scores.

In 1996, Berlin, Hamburg and Dusseldorf offered 28, 39 and 44 destinations, respectively; while in 2004 these decreased to 11, 20, 35, respectively. Munich increased its links from 62 to 82.[11] It can thus be concluded that Lufthansa has pursued a multi-HS strategy but still with a relevant number of airports with PP connections in Europe.

Regarding Air France, the local and global factors capture the differences in the domestic network and intra-Europe network. In 1996, Paris-Charles de Gaulle was the unique hub for both domestic and international routes. In 2000 and 2004, note the rapid development of Paris-Orly. The French carriers freed up capacity in Charles de Gaulle by deploying all domestic capacity in Orly. Today, this second hub offers a well-developed domestic network and a relatively small number of European destinations. This means that Charles de Gaulle is the hub for intra-Europe and intercontinental connecting traffic, and Orly is mainly the airport for PP domestic traffic between French airports and Paris.

The British Airways network is characterized by four principal factors indicating that this network is more complex than that of Lufthansa and Air France. While London-Heathrow acts as the central hub, other airports such as Manchester, Glasgow and Edinburgh represent central European bases not acting as connecting hubs. In 1996, the second hub London-Gatwick was less central than these bases. In 2000 and 2004, Gatwick did not develop enough to become the second hub for a European network. Manchester is still today the second base for British Airways. This airport is not a hub, but a base for PP connections. Similarly, Glasgow and Edinburgh are still network bases for PP links in Europe. Although British Airways designs its global network around the two London airports, Heathrow works as the central hub for the intra-European network more than Gatwick.

Finally, the network of Iberia is described by one global structure with Madrid as the first and Barcelona as the second hub for both the domestic and the intra-European network. These are much more central than any other airport, and similar in number of connections and destinations. As captured by the Freeman centrality index, the Spanish carrier clearly shows a two-hub radial network.

LCCs have only recently entered the European market and only data from 2004 allow a cross-comparison. Both easyJet and Air Berlin present four principal factors indicating the presence of many local structures. No global structure dominates the network. easyJet started in the late 1990s from London-Stansted and—by the merger with the LCC Go—it increased the centrality of London-Luton, Amsterdam, Nice, London-Gatwick and Liverpool. The Air Berlin network is central in one of the most popular resort destinations in Germany, Palma de Mallorca, followed by the capital Berlin, Vienna, and London-Stansted. An obvious shortcoming of the centrality index for the LCCs seems to be that it assumes there are connecting flights, whereas in most cases there are no such connections because the hubs are only technical bases. This point will further be investigated in the next section.

Temporal Concentration of HS Versus PP

The above sections have investigated how the spatial dimension of European airline networks has changed between 1996 and 2004. Analysing both the Freeman index and the Gini index, it was found that only a few elements differentiate the network organization of FSCs from that of LCCs. This section shows that by extending the analysis to the temporal dimension, some differences will emerge.

The temporal configuration, according to Bootsma (1997), can be defined as the number and quality of indirect connections offered by an airline or alliance by adopting a wave-system structure in the airline flight schedule.

Ideally, the HS maximum number of city pairs with n airports is equal to $n(n-1)/2$, and the total number of direct routes between the hubs and the spokes are $(n-1)$. Therefore, the number of city-pairs connected by indirect service is equal to $n(n-1)/2-(n-1)=(n-1)(n-2)/2$. The ratio between the indirect and the total number of connections is $(n-2)/n$, which = 1 for $n \to \infty$. It means that for a high number of airports included in the HS network, the indirect connections tend to be equal to the total number possible connections and the number of direct connections becomes, relatively speaking, very small or irrelevant.

In the real world, carriers face the logistic problem of designing their wave structure so as to maximize the connectivity under a certain number of constraints. The elements that determine the connection waves are: the airport capacity, i.e. the maximum number of the flights that can be scheduled per time period; the minimum connection time at the airline hub (mct); the maximum connection time (MCT); and the routing or circuity factor (cf). The mct is required to allow passengers and baggage to transfer between two flights as well as to turn around the aircraft. Indirect connections not meeting the mct criterion cannot be considered as realistic ones. Minimum connection times are unique for every hub airport and are reported in the OAG.

From the demand side not every connection is attractive for travellers. The longer the connection time, the less attractive it is. In this respect, Bootsma (1997) has defined standard MCT for different types of connections: the quality thresholds (Table 3). The present study focuses only on Europe–Europe type of connections, and a minimum connection time of 45 min and a maximum connection time of 180 min have been chosen (note that the city-pairs connected with more than two connecting flights are excluded from the analysis).

The routing or circuity factor (cf) of the connections can be defined as:

$$cf = IDT \,/\, DTT\,,$$

where IDT is the actual in-flight time indirect connection; and DTT is the estimated in-flight time of the direct connection. The maximum routing factor is

Table 3. Connection quality thresholds for different types of connections

Type of connection	Time (min) excellent	Time (min) good	Time (min) poor
Europe–Europe	90	120	180
Europe–intercontinental	120	180	300
Intercontinental–intercontinental	120	240	720

Source: Bootsma (1997, p. 68).

typically 1.25 (Bootsma, 1997). The maximum cf excludes the 'back-tracking routes' such as Milan–Paris–Nice or Manchester–Amsterdam–London. Even if the carriers' network is accidentally able to offer these connections, the passengers perceive them as not attractive, especially if there are direct flight alternatives offered by other carriers.

Following Bootsma's definition, the analysis of the temporal dimension is based on the ratio between the direct and indirect connections (calculated by setting the mct, MCT, cf) provided by the HS structure versus the PP structure. The ratios are computed in terms of the number of frequencies and city-pairs supplied and are calculated for the same data set of the spatial concentration analysis presented in the third section.[12] The authors expect the connectivity ratio to provide a measure of the hub connectivity and therefore the number of real city-pair combinations supplied by the carriers.[13]

The number of indirect connections within Europe is calculated by setting the mct = 50 min, MCT = 120 min, and cf = 1.25 in line with Bootsma (1997). Tables 4 and 5 present the results for the network composition and the hub connectivity for the flag carriers and the LCCs, respectively. Specifically, they present the number of frequencies supplied from spokes to hubs, between the hubs, and between the spokes and the connectivity evaluation. The same calculation is carried out in terms of flight frequencies between the city-pairs. Hence, two connectivity ratios are calculated, i.e. the number of one-stop city pairs and the frequency of these indirect connections, both divided by the concerned total.

Lufthansa appears to have increased the number of HS connections and decreased the PP links (spokes to spokes). The frequency–connectivity ratio has

Table 4. Flag carriers network composition and hubs connectivity

	Lufthansa			Air France			British Airways			Iberia		
	1996	2000	2004	1996	2000	2004	1996	2000	2004	1996	2000	2004
Frequency of flights												
Spoke-to-hub	2678	3248	4010	1075	3119	2960	2061	2410	2198	1047	2359	2750
Hub-to-hub	84	85	85	0	0	0	0	0	0	217	275	198
Spoke-to-spoke	1977	1989	1414	215	1194	1350	1482	2004	1351	196	450	680
Total	4739	5322	5509	1290	4313	4310	3543	4414	3549	1460	3084	3628
Number of connected city-pairs												
Directly connected	304	404	251	71	164	197	231	251	214	103	152	221
Indirectly connected	2122	2819	3340	706	1769	1893	1214	1245	974	271	1027	1259
Total	2426	3223	3591	777	1933	2090	1445	1496	1188	374	1179	1480
Frequency of connected city-pairs (weekly)												
Directly connected	4739	5322	5509	1290	4313	4310	3543	4414	3549	1460	3084	3628
Indirectly connected	21292	39553	51163	7121	20447	23472	9243	12182	9775	2610	12833	15755
Total	26031	44875	56672	8411	24760	27782	12786	16596	13324	4070	15917	19383
Connectivity ratio												
Indirectly connected city-pair (%)	87	87	93	91	91	91	84	83	82	72	87	85
Indirectly connected frequencies (%)	82	88	90	85	83	84	72	73	73	64	81	81

Table 5. LCC network composition and hubs connectivity

	easyJet			Ryanair			Air Berlin			Virgin Express		
	1996	2000	2004	1996	2000	2004	1996	2000	2004	1996	2000	2004
Number of connected city-pairs												
Directly connected		36	73	8	37			122	28		5	14
Indirectly connected		5	–	–	1			2	4		5	8
Total		41	73	8	38			124	32		10	22
Frequency of connected city- pairs (weekly)												
Directly connected		657	1,613	263	656			266	292		29	192
Indirectly connected		67	–	–	3			3	37		12	53
Total		724	1,613	262	659			269	329		41	245
Connectivity ratio												
Indirectly connected city-pair (%)		13	0	0	3			2	14		52	38
Indirectly connected frequencies (%)		9	0	0	0			1	11		30	22

increased over the years from 82 to 90%, meaning that 90% of all connections in Europe take place via the hubs. Over the year the frequency–connectivity ratio of Air France has remained stable at about 85%. Despite the development of Paris-Orly, transfer traffic is mainly concentrated in Charles de Gaulle. British Airways presents the lowest frequency–connectivity ratio, around 70%, meaning that 30% of its network is PP. The British carrier has a mixed HS and PP structure. Finally, Iberia started in 1996 with a relatively small network covering only 375 city-pairs, the 2427 of Lufthansa and it grew at 1480 city-pairs with almost 20 000 connections, consequently its frequency–connectivity ratio increased from 64 to 81%.

LCCs present a very low frequency–connectivity ratio: easyJet offered in 2004 only PP connections, being therefore a pure PP network. Similar results exist for Ryanair. Differently, Air Berlin and Virgin Express have developed a mixed HS and PP strategy. Those carriers fly to the primary airports of a city such as Milan-Linate, Amsterdam-Schiphol or Berlin-Tegel, whenever possible, but they still negotiate lower fees when not making use of the airport service components. However, they avoid congested hubs by using a secondary airport such as Milan-Orio al Serio or London-Stansted. In general, their network strategy is still focused on PP connections, principally viewing transfer passengers as a coincidental consequence of the network.

Network Organization

This section analyses the overall network organization in terms of spatial and temporal concentration. Figure 6 plots the Freeman index[14] and the frequency–connectivity ratio to identify the network organization of FSCs and LCCs. The two dimensions are useful when detecting the differences between the HS and PP choices. The ideal HS configuration is in the north-east of the graph and the ideal PP configuration is in the south-west. Note that FSCs are characterized by high temporal and spatial concentration, while LCCs have almost a zero temporal concentration but high spatial concentration. This means that the temporal dimension provides a clear distinction between FSCs and LCCs, while the spatial dimension can be useful to identify the peculiarities within groups.

Among the FSCs, note that Lufthansa has the highest temporal concentration. This may be explained by the development of the second hub Munich and by the high degree of timetable coordination between Frankfurt and Munich (Rietveld and Brons, 2001). On the other hand, it records the lowest spatial concentration, meaning that there is still a considerable number of PP connections. Both time and spatial concentration have increased from 1996 to 2004, indicating that although the German carrier presents a mixed PP and multi-HS network, it has pursued a clear HS network choice. British Airways shows the lowest time concentration due to the centrality of Manchester and Edinburgh acting as PP bases. Moreover, the British have not developed Gatwick as a second hub like Munich for Lufthansa. A second reason is the capacity congestion of Heathrow that present the hub development (Rietveld and Brons, 2001).

The network design has not changed considerably over the periods considered. Iberia is the most spatially concentrated HS network. The development of Barcelona as second hub for both domestic and intra-European network with no relevant PP international connections (the exceptions are some domestic PP links) has increased both the temporal and spatial concentration.

Finally, Air France has reduced its spatial concentration since it freed capacity in Charles de Gaulle by deploying all its domestic capacity at Orly. Today the

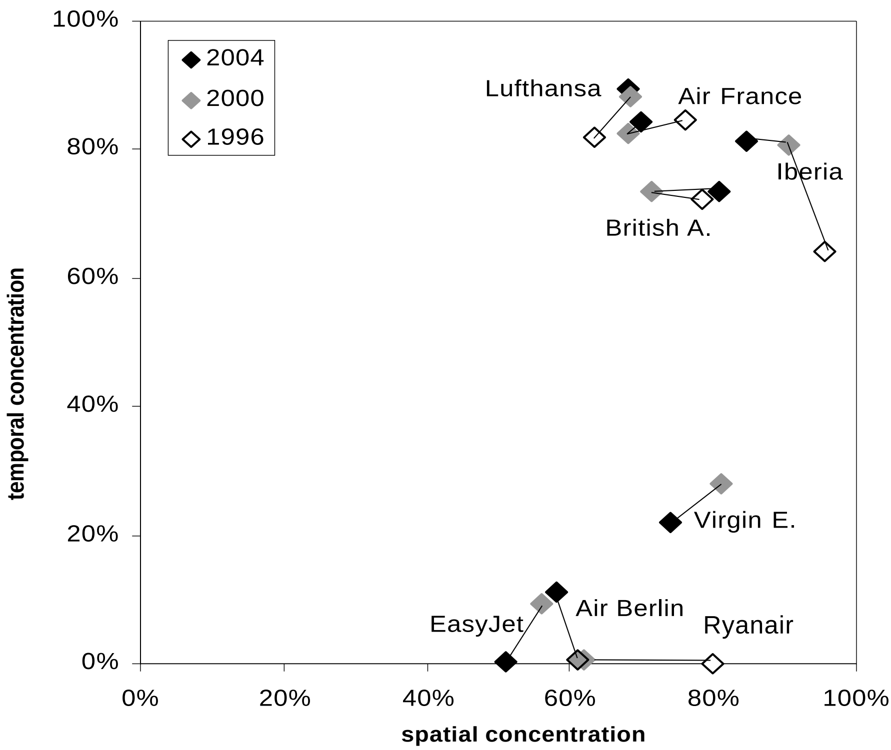

Figure 6. Network configuration of a full-service carrier (FSC) and a low-cost carrier (LCC) in terms of the Freeman index and the frequency–connectivity ratio

second hub offers a well-developed domestic network and a relatively small number of European destinations. This means that Charles de Gaulle is the hub for intra-Europe and intercontinental connecting traffic and Orly is mainly used for PP domestic flights.

The LCC results show that there are some different network strategies adopted by the four selected LCCs. First, note that Virgin Express and Air Berlin are offering a modest percentage of connecting flights and not only PP links. Moreover, they operate from primary airports, sell via travel agents, and have a frequent flyer programme and in-flight entertainment. Air Berlin also offers two classes on board and pre-assigned seats. On the contrary, Ryanair and easyJet do not offer any flight connections and are pure PP network carriers. They do not offer any service (or offer certain services separately at extra cost), while Ryanair uses under-utilized secondary and tertiary airports. Services can often be acquired separately by passengers to replicate the full service of flag carriers. Even some of the most characteristic rules and conditions attached to the airfares of flag carriers, such as the possibility of reservation changes or the one-way ticket fare, can be purchased with the LCC concerned.[15]

Conclusions

This paper has provided new measures for assessing airline network configurations in order to investigate the complexity of modern carriers' network design and, if possible, to account for differences between LCC and FSC networks in Europe. The network configuration (HS, PP, and more complex structures) was assessed in terms of spatial and temporal concentration. The paper evaluated the spatial dimension by means of the Gini and Freeman indexes. It also used the Bonacich method to identify the global structure, as well as the national and regional substructures of the network.

The analysis of the temporal dimension was based on the frequency–connectivity ratio, i.e. the share of indirect connecting flights to the total number of flights connecting city-pairs. The empirical analysis demonstrated that the temporal dimension provides a clear distinction between FSCs and LCCs, while the spatial dimension helps to identify the differences within groups.

Some evidence was found that the FSCs have developed their networks as mixed multi-HS and PP systems with a strong dominance of the HS. These configurations vary from Iberia, which has the most spatially concentrated HS network with a two-hub radial network (Barcelona and Madrid), to British Airways, which has the most mixed HS and PP network configuration. In particular, British Airways network is organized such that London-Heathrow is the main hub, and Manchester, Glasgow and Edinburgh are bases with several direct connections to European and domestic destinations. The Lufthansa network developed into a two-HS with mixed PP structure. In particular, the hubs are Munich and Frankfurt; and the bases with PP connections are Berlin, Hamburg and Dusseldorf. Finally, the Air France network (before the KLM merger) is classified as a single HS configuration with Charles de Gaulle as the hub for intra-European and intercontinental traffic, and Paris-Orly acting as a PP airport base for domestic traffic within France.

In addition, the results reveal that LCCs have a lower centrality than FSCs, mainly for the temporal dimension and slightly lower for the spatial dimensions. Time-based measures were able to differentiate the airline market. The empirical evidence is that the FSCs have developed a multi-HS network strategy, while LCCs show a considerable orientation towards a PP network growth. The analysis shows variations among LCCs network configurations. While Ryanair and easyJet have developed a pure PP structure, Virgin Express and Air Berlin offer a modest percentage of connecting flights in Brussels and Berlin. However, Virgin's connectivity ratio has grown in the last few years, and it is possible that the bases of this LCC can turn into small hubs if this trend continues in the years to come.

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Notes

1. This reorganization took place between 1978 and 1985, according to Reynolds-Feighan (2001). Many authors (e.g. Borenstein, 1989; Berry, 1994; Oum *et al.*, 1995; Button *et al.*, 2000; Burghouwt *et al.*, 2003) put much effort into explaining the reasons for the change and the advantages of carriers. Above all, it was emphasized that both trunk and regional carriers adopted the HS structure to exploit the dominant position of the hub and the cost advantages of a centralized network, such as economies of density and scale.
2. The authors thank an anonymous referee for suggesting this clarification.
3. For a theoretical and empirical investigation of hub connectivity, see Bootsma (1997), Button *et al.* (1998), Dennis (1998), Rietveld and Brons (2001), Veldhuis and Kroes (2002), and Burghouwt and De Wit (2003).
4. Intra-European flights are considered to be within the EU 25 Member States plus Romania, Bulgaria, Switzerland, Turkey and the Canaries Islands.
5. Comparing the LCC networks (which are focused purely on the intra-European market) with the European segments of the FSC might seem somewhat problematic. The FSCs jointly optimize the intra-European market and the intercontinental market, and overall the intra-European segments are also functioning as feeders to intercontinental flights. However, the intra-European market still represents a considerable part of their revenue and deserves a dedicated strategy (integrated with the intercontinental market strategy). On the other hand, a comparison of the whole flag carriers network with that of the LCC makes even less sense. Note that the present aim is also to detect if the FSCs are changing their network strategy as a reaction to LCCs in a liberalized market.
6. Ryanair data are present in the OAG database only until 2000; therefore, they the data for 2004 are missing in the present analysis. Virgin Express is not the fourth largest LCC but is seventh in terms of network seats supplied. It is included in the analysis as representing a known case of a different LCC model philosophy. This will also emerge in the results.
7. A traveller who needs to fly from one point (origin) to another (destination) first prefers direct flights, then connected flights with one stop, etc. If an airport is on the shortest path between an origin and a destination, this means the traveller will probably choose to pass through that airport.
8. The Freeman index was calculated with UCINET 6 for Windows (Borgatti *et al.*, 2002).
9. The original version of the Bonacich (1972) index was produced using the adjacency matrix. The present paper uses an extension of the Bonacich index using the value matrix (Bonacich, 1987). The adjacency matrix that represents the network contains a '1' when there is a link between the nodes; and zero otherwise. In the value matrix the '1' is replaced by a measure of the strength of the link. In the present case the value matrix is constructed with the number of flights per week between the airports.
10. A complete overview of factor analysis output and the first eigenvector values are available upon request to the authors.
11. It is remarkable that the most decreasing airport in terms of centrality is Berlin, where the LCC Air Berlin developed one of the biggest bases.

12. The analysis refers to intra-European flights and data cover 1996–2004 for the summer season schedule (a representative week in August).
13. The present paper does not aim to identify the characteristics of the wave-system structure as many studies have done. It aims to find a simple temporal concentration measure to make comparisons between carriers during the time periods.
14. The analysis can be performed by using the Gini index. As the results are similar, the analysis is omitted.
15. Primary airport operations can be considered as an additional service as they often reduce passenger travel costs from the city to the airport.

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