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What role will hubs play in the LCC point-to-point connections era? The Spanish experience

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ABSTRACT

Airport systems organized spatially as hub-and-spoke systems where traditional airlines (Full-Service Network Carriers – FSNCs) dominate have been impacted by the continuing expansion of Low-Cost Carriers (LCCs) in mainly point-to-point connection systems. Using a methodology based on linear transfer function models, the objective of this paper is to reflect on the future of hubs and on whether their role as large geographical air transport nodes is in doubt. Although Spanish hubs have continued to strengthen their position of dominance, the consequences of this enforced coexistence has manifested itself in a substitution effect, with LCCs replacing FSNCs at the hubs for international, primarily intra-European, flights. The market for national flights, however, has not experienced any significant changes as this new development of LCCs in this market is fundamentally based on new demand from both new passengers and the greater travel frequency of current passengers. There is also room for complementarity between the two models, as national connections with LCC hubs feed long-distance destinations exploited solely by the FSNCs.

1. Introduction

We currently see the coexistence of alternative spatial models affecting different geographical areas in the aviation industry. On the one hand, there are conventional airlines or Full-Service Network Carriers (FSNCs), whose model is mainly based on the hub-and-spoke (HS) network system and, on the other, the Low-Cost Carrier (LCC) model, generally based on the point-to-point (PP) system.

The hub-and-spoke structure first appeared in the US after domestic liberalization in 1978 (Dennis, 1994; Reynolds-Feighan, 2001). The goal of a hub-and-spoke system is to concentrate traffic at a hub (and on the spokes), increase connectivity and, consequently, to also increase the number of markets that can be served without exponential expansion of the networks. This air transportation management model is especially recommended for markets where the spatial distribution of demand is irregular for different towns and cities and which constitutes, therefore, a small market with a greater need for exploiting economies of density (Alderighi et al., 2005). It is also recommended that the hub airport is in a central geographical location with regard to the market it is to serve, that it has good airport facilities and well-coordinated schedules to minimize the time spent on the ground (Dennis, 1994).

In other respects, the hub-and-spoke model offers major, well-known advantages both with regard to demand and the provision of air-transportation services. With regard to demand, the advantages of the hub-and-spoke strategy for the passenger are, mainly, much higher frequencies than would be the case of a purely point-to-point network (Dennis, 1994) and the maximized number of city pairs provided for in the network, offering the passenger a wide range of destinations (Malighetti et al., 2008). As far as services are concerned, airlines adapt to this system by consolidating their traffic at these hubs in order to achieve the highest possible load factor and to coordinate and centralize their aircraft, crew and maintenance schedules with the resulting reduction in costs that this involves (Button, 2002; Fujii et al., 1992). The airlines that control the hubs have greater market power in a hub-and-spoke system (Fujii et al., 1992) with this verging on a monopoly (Nero, 1999). This dominant position usually translates into high fares for consumers (Goetz and Vowles, 2009) whilst also creating barriers to market entry, blocking entry to new competitors (Graham, 2009) either through the scale of the operation (Dennis, 1994; Zhang, 1996) or control of the scarce airport facilities (Dennis, 1994; Nero, 1999; Zhang, 1996).

However, the hub-and-spoke configuration also has its disadvantages. These affect the passenger, primarily, who is compelled

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to make an extra stop at the hub airport (Rietveld and Brons, 2001), thus having to bear greater costs in terms of time (Elhedhli and Hu, 2005). Customers also have to put up with a greater likelihood of their baggage being lost (Fujii et al., 1992) and an apparent new risk compared to the point-to-point system, the possibility that they will miss their connections (Alderighi et al., 2005). The hub-and-spoke system also tends to concentrate increasing amounts of flow at hubs which results in major congestion problems and delays (Elhedhli and Hu, 2005; Flores-Fillol, 2010). The system using hubs also results in increases in airlines' operational costs (Alderighi et al., 2005; Franke, 2004) as, apart from the fore-mentioned congestion, massive peaks in the hub also generate large-scale fluctuations in the use of ground handling facilities/workers, thus reducing both airside and landside productivity (Franke, 2004). Another additional disadvantage is the possibility of lower yields for the FSNCs structured in a hub-and-spoke system if we consider that the entry of low-cost competitors offering direct flights can compel them to lower their fares to attract passengers on indirect routes (see Windle and Dresner, 1999 on whether FSNCs lower their fares at their hubs because of competition from LCCs). In general terms, the FSNCs are being faced with overall rapidly declining yield levels due to the presence of LCCs on the same routes (Franke, 2004).

The deregulation of the airline industry and the arrival since the middle of the 1990s of the low-cost phenomenon with its point-to-point system has aroused great debate on the hub-and-spoke model (Morrell, 2005), whose expensive strategy is becoming outdated as far as cost reduction is concerned compared to that of the LCCs (Pels, 2008).

The point-to-point strategy has the disadvantage that it is difficult to connect to other destinations. Although there are differences from one airline to another, generally-speaking the LCCs do not allow the purchase of a through ticket with stop-overs (see Graham, 2009). This fact is made worse by some LCCs not accepting responsibility for passengers' missing connections, even if the onward journey is with the same carrier (O'Connell and Williams, 2005). According to Castillo-Manzano and Marchena-Gómez (2010) this leads to passengers preferring FSNCs over LCCs if they have to transfer to another flight, as the possible eventualities (loss of baggage, delays, etc.) are better catered for by network carriers. Nonetheless, for Malighetti et al. (2008), even if LCCs do not guarantee connectivity, the fact that their flights are more highly-concentrated at some airports due to logistic and economic motivations and their better punctuality over traditional airlines can provide room for indirect connectivity.[1]

In contrast to these disadvantages, the point-to-point system also offers a number of advantages for passengers, airlines and spoke airports. The passenger is benefited by the possibility of taking direct flights (Alderighi et al., 2005) and thus reducing waiting times at airports, as point-to-point systems avoid the delays caused by connecting passengers and, normally, by the recording of loyalty program points, which all makes for faster check in (Barrett, 2004a, 2004b). With respect to airlines, the LCC-preferred point-to-point system provides them with a strategic advantage over the FSNCs (Gillen and Lall, 2004). According to Franke, 2004, lean processes and the absence of hubs are the weapons with which LCCs are combating the FSNCs and they make a clear contribution to the cost gap that exists between the two types of airline. Finally, with respect to spoke or peripheral airports, although some authors consider that the hub-and-spoke system benefits them (Dennis, 1994), the point-to-point strategy seems to have greater support in the areas around these airports as they experience greater numbers of tourist visits. As Fujii et al. (1992) state, the tourist industry usually supports local government improvements to airport infrastructure to accommodate direct flights (see also Castillo-Manzano et al., 2011 on spoke airport tourist industry support for LCCs securing public subsidies).

The airlines have identified with one or other type of network configuration, with their advantages and disadvantages. According to Dobruszkes (2006) this has resulted in competition between the two types of networks in Western Europe: HS/FSNCs/main airports vs. PP/LCCs/secondary airports. If we focus on Spain, Spanish airports have traditionally been organized in a hub-and-spoke system, with traffic concentrated at a main hub, Madrid-Barajas (with 26% of total passenger traffic in 2010), followed by a secondary hub, Barcelona (with 15%). The Spanish FSNC is Iberia, which commanded 15% of total passenger traffic at Spanish airports in 2010.[2] When LCCs started to serve in Spain, it was at secondary and regional airports, although quite a few, such as Easyjet, Vueling and Ryanair, have already made the move to the hubs at Madrid and Barcelona given the low airport fees charged by these airports compared to other European airports of a similar size. The LCCs have been located at the older terminals at these airports, apart from exceptions, such as Air Berlin and Vueling.

The competition between the two airline models (FSNC vs. LCC) based on their two network configuration strategies (HS vs. PP) has been the focus of great interest in the academic literature. A number of studies have analyzed this *tour de force* between network configurations (Alderighi et al., 2005; Brueckner and Spiller, 1991; Flores-Fillol, 2009; Pels, 2008) from a theoretical point-of-view. However, from a more empirical standpoint, although there are some studies that compare the two network configurations by measuring the concentration and distribution of LCC and FSNC traffic (Reynolds-Feighan, 2001), there is a lack of studies that quantify the competition by measuring the volume of traffic lost or gained by each category of airlines through their respective network strategies. Our paper therefore aims to model this competition in the Spanish airport system by means of multivariate unobserved component models set up in a state space framework. We will therefore focus on the effects that the arrival of the LCCs has had on the country's two main hubs, Madrid-Barajas and Barcelona, which in 2010 were 4th and 9th among the Top 15 busiest EU-27[3] airports. To do this we shall address the following three issues relating to the Spanish airport system:

1. What impact have LCC point-to-point flights at spoke airports had on FSNC hub traffic? As the two types of airline often compete on the same routes (Alderighi et al., 2005), as Morrell (2005) states, *a priori* the LCCs' point-to-point flights should have some kind of negative impact on FSNC hub traffic as they do not entail stop-overs at hubs. These impacts will be studied individually for each type of traffic (national, international-EU and international non-EU). Also *a priori* a greater impact should be expected on national flights and on intra-European flights, especially.
2. Unlike the major airlines, which seem to be retrenched onto their main hub airports (see Dennis, 2007), the LCCs make the jump to also operate out of the large hubs. So, what impact has the growing presence of LCCs at hubs had on their traffic structure?

[1] To the contrary, for Reynolds-Feighan (2001) the key nodes where the LCCs concentrate their traffic act more as points of entry or exit rather than transfer points.

[2] See Fageda et al. (2011) and Suau-Sanchez and Burghouwt (2011) on Iberia's strategy at both hubs, concentrating in Madrid and promoting its LCC affiliate in Barcelona.

[3] The list can be consulted at Eurostat (http://www.epp.eurostat.ec.europa.eu/statistics_explained/index.php/Passenger_transport_statistics) and is constructed from total per-year passengers carried (embarked and disembarked).

3. With respect to long-haul and intercontinental flights, for which hubs and the FSNCs appear to be much more crucial (Alderighi et al., 2005; Francis et al., 2007), can LCCs' national flights at hubs be products that complement FSNCs' international flights or, on the contrary, are they damaging as they compete with the FSNCs' national flights that serve as a basis for their own international flights?

In short, by answering these and other questions with regard to Spain, we seek to reflect on the future of hubs and on whether their role as major geographical air transport nodes in a market marked by the ongoing expansion of LCCs is in doubt.

From a methodological point of view, the paper takes advantage of methods general enough to be applicable to other case studies. The type of model is the linear transfer functions model with ARIMA noise (see Castillo-Manzano et al., 2012, for a full explanation of this kind of methodology in air transport management). An ARIMA component of this type in the formulation accounts for all the missing variables that may be important, but are not available for the analysis, either because they are not available to us, or because there is no private or public record of them. Compared to alternative approaches, our approach presents at least three major features. Firstly, it is a dynamic analysis that exploits the time series structure of the series involved. Secondly, we take an agnostic approach insofar as we only select the variables that in principle may affect the dependent variable, but the dynamic identification is based on objective statistical criteria. Finally, to avoid spurious or confusing effects that might blur the impact of the LCC, we can easily control for variables that might have influenced Spanish airline traffic in the time period analyzed, such as the level of economic activity, moveable feast days like Easter, the number of trading days per month, the effect of the 11th September 2001 (9/11) terrorist attack, etc. (see a comprehensive list in the next section).

The article is organized as follows. Section 2 lays out the data and presents the methodological approach. Section 3 presents the empirical results. Section 4 contains the discussion whilst Section 5 presents the conclusions of the study.

2. Data and methods

The data used to measure the effects of LCCs on the Spanish hubs can be divided into three groups:

(A) The endogenous variables will be represented by monthly air traffic by the FSNCs at the hub airports (Madrid and Barcelona together). Considering the traffic of both hubs jointly is justified in order to avoid the results being distorted by flights from spoke airports being constantly re-routed from Madrid to Barcelona, or vice versa, especially as a result of the entry of LCCs into the market. We shall therefore study the role of the hubs in the Spanish airport system as a whole.

The analysis hinges on three models, depending on the geographical destinations of flights, namely national territory, the European Union, and outside the European Union.

(B) The exogenous variables, separated into two groups, are as follows:

(B.1) Dummy exogenous variables: a wide range of variables are included in models to estimate a number of intervention variables and outlier effects seen in the data. The most important, with their definitions, are:

(B.1.1) EASTER: Air traffic around this vacation period is especially intense in Spain. Indeed, it is considered to be high season for tourists, amongst other reasons due to the numerous celebrations of the passion of Christ. Accordingly, the moveable feast of Easter variable is defined by assigning different weights to the days in question depending on the expected traffic density at Spanish airports (these weights have to add up to one). Maximum weights are assigned to Wednesday, Thursday, Easter Sunday and Monday. Weights of zero are assigned to the rest of days.

(B.1.2) BUSINESS: Monthly time series that are totals of daily activities can be influenced by each calendar month's weekday and weekend composition. This variable is introduced to take into account the differences between months regarding the proportion of weekdays with respect to weekends. It is constructed as the number of business or trading days with respect to weekend days and holidays in each individual month, i.e. the number of business or trading days minus the number of Saturdays and Sundays multiplied by 5/2. Extra holidays in each month are subtracted from the business days.

(B.1.3) 9/11: The negative effect on air traffic that resulted from the 9/11 terrorist attacks which, as found in earlier studies (Inglada and Rey, 2004), also had a significant effect on the Spanish airport system. The model is consistently a first order transfer function working on an impulse dummy variable (see details below).

(B.1.4) There are other well known public works that may affect the airline traffic at the hub airports, namely the construction of new air terminals like Terminal T4 at Madrid-Barajas airport inaugurated in February 2006 (LST4) or T1 officially opened at Barcelona airport on 15 June 2009 (LST1) and the High Speed Train (HST) connecting Madrid and Barcelona, that commenced operation on 20 February 2008. The dummy variables in these cases are defined as zeros before the suitable dates and ones afterwards.

(B.1.5) Another effect that was taken into account was the eruption of the Eyjafjallajökull volcano in Iceland in April, 2010, which led to the total closure of air space in most of northern Europe and its partial closure in more peripheral countries, such as Spain and Italy, mainly affecting their connections with the rest of Europe.

(B.2) Economic cycle: The literature argues that economic activity is closely linked to air traffic, as a result of which it is generally included as an indicator when modeling air traffic (Inglada and Rey, 2004; Fernandes and Rodrigues-Pacheco, 2010). This variable addresses the impact of the Spanish economic cycle on air traffic, including the economic downtown which began in 2008 and continues to affect the country's economy (see Dobruszkes and Van Hamme, 2011 on the impact of the economic crisis on industry and air traffic).

(C) The Low-Cost Carrier effect (LCC): this measures the impact that the introduction of LCCs at non-hub airports has had on FSNC traffic at hub airports. In the first model this variable is defined as LCC traffic registered at non-hub airports with a national destination other than the hubs. The definition for the second model is non-hub LCC traffic with a European Union destination. Finally, in the third model the definition is identical, albeit with a destination outside the European Union.

(D) The LCC within HUB effect on NATIONAL destinations (LCC-HUB-NAT): this measures how the LCCs at the HUBS with national destinations may affect the FSNC traffic at said hubs. This variable is present in all three models. While in the first it should be expected *a priori* that it signals a substitution effect, i.e., that it affects the FSNC national flights negatively, in the others it could have positive complementary effects. Depending on the model, it could feed Spanish hub FSNC flights to international destinations, both inside and outside the EU.

(E) The LCC within HUB effect on EUROPEAN UNION destinations (LCC-HUB-EU): this measures how the LCCs at the HUBS with European Union destinations may affect the FSNC traffic at said hubs. Obviously in this case the only model that makes sense is the one with the endogenous variable of FSNC traffic at the hub with the same destination.

(F) The LCC within HUB effect on NON-EUROPEAN UNION destinations (LCC-HUB-NON EU): this is the same as the preceding effect except that we focus on destinations outside the European Union.

All the data are collected on a monthly basis from January 2000 to December 2010, with 132 observations to be precise. This is a sufficiently broad sample for a wide number of explanatory variables to be introduced and for robust estimations of their coefficients to be offered. Since the LCC phenomenon in Spain appears and consolidates during this decade, no additional time span is considered.

Moreover, all the data used to construct the above variables are public and primary data, and this obviously facilitates the reproducibility of our empirical results. To be specific, the data on passenger air traffic at Spanish airports for both LCCs and FSNCs have been taken directly from the website of the Spanish Public Authority for Airports and Aerial Navigation (source http://www.aena-aeropuertos.es/csee/Satellite?Language=EN_GB&pagename=estadisticas). The economic activity variable, meanwhile, is represented using a Spanish Ministry of the Economy and Treasury synthetic economic activity index (source: http://servicios-web.meh.es/apps/dgpe/default.aspx).

Fig. 1 shows how the weight of all Madrid-Barajas and Barcelona hub traffic evolved compared to the whole of the Spanish airport system. Fig. 2, meanwhile, shows the time evolution of the endogenous variables in paragraph A, above, namely FSNC passengers at the hub airports in Spain with three distinct destinations (national, EU and non-EU). Both graphs show that while the weight of the hubs has remained stable during the series of years under study, the FSNC traffic has experienced a drastic correction in absolute terms from 2008 onwards (especially for national destinations). This drop could be due, *a priori*, to multiple effects such as the Madrid-Barcelona High Speed Train (HST) service coming into operation in 2008, the change in the economic cycle or the appearance of the low-cost carriers (see Fig. 3). For this reason, the objective of our model is the individualization and quantification of the factors that have influenced FSNC traffic evolution at Spanish hubs during the 2000–2010 period.

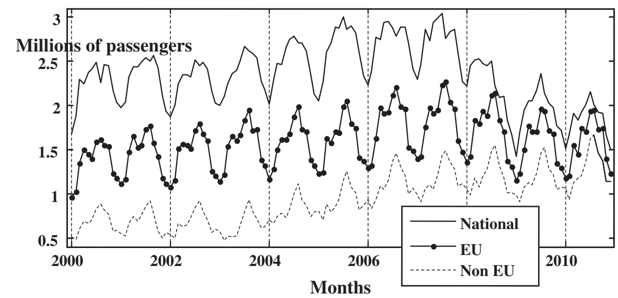

Fig. 2. Millions FSNC air passengers (month) at Madrid and Barcelona airports flying to different destinations.

In other respects, given the nature of the databases used, it is impossible to quantify exactly how many routes on which LCCs and FSNCs compete have been taken into account. However, there is absolutely no doubt that we are talking of an extremely large number of routes where there is, or has been (until one company or another withdrew), strong direct or indirect competition (with one further leg: for example, if the LCC flies SANTANDER–ROME while the FSNC flies SANTANDER–MADRID–ROME) between the two categories of airline. Proof of this is that Ryanair alone (according to its website in January, 2012) flies some 475 routes in Spain, of which about 60 are national (although many do not operate during low-season).

The time series models employed in the analysis are in the class of discrete time linear transfer function models (Box et al., 1994). The general formulation may be expressed as follows:

$$y_{i,t} = \sum_{j=1}^{h} F_{i,j}(B) u_{i,j,t} + N_i(B) e_{i,t} \tag{1}$$

where $y_{i,t}$ are the air passenger total data defined in paragraph A, above; $u_{i,j,t}$ are the inputs defined in paragraphs B, above, on which the output data depend; $e_{i,t}$ is zero mean and constant variance Gaussian white noise; $F_{i,j}(B)$, $(j = 1, \ldots, h)$ are ratios of polynomials in the backshift operator (i.e. $B^k y_t = y_{t-k}$) that may have leading zero coefficients when a pure time delay is necessary; $N_i(B)$ is

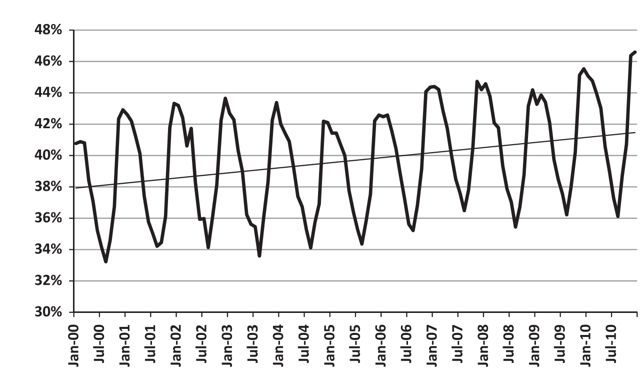

Fig. 1. Percentage of total monthly traffic in the Spanish airport system represented by Madrid and Barcelona airports.

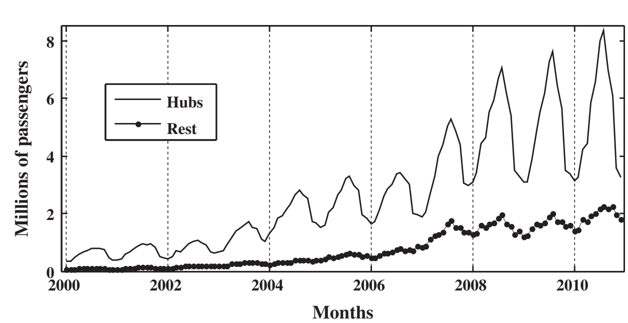

Fig. 3. Millions of LLC air passengers (month) at hub airports and other Spanish airports.

Table 1
The "low-cost" city/airport share during the last year of the sample, 2010, for each of the geographical areas considered, namely national territory, the European Union, and outside the European Union.

Code	Airport	Total Traffic 2010	LCC market share, 2010			
			National	EU	Non-EU	Total
MAD	Madrid-Barajas	49806349	18.27%	31.29%	7.06%	20.26%
BCN	Barcelona	29184048	42.35%	53.67%	16.70%	43.70%
PMI	Palma de Mallorca	21106664	43.28%	75.41%	48.55%	64.69%
AGP	Málaga	12015571	45.64%	82.07%	51.03%	72.41%
ALC	Alicante	9376459	43.76%	93.02%	67.68%	80.14%
LPA	Gran Canaria	9300192	11.06%	53.39%	26.05%	31.46%
TFS	Tenerife Sur	7240641	15.15%	61.54%	23.77%	52.68%
IBZ	Ibiza	5023649	43.75%	78.07%	80.09%	63.44%
VLC	Valencia	4918809	28.34%	83.09%	14.62%	54.33%
GRO	Girona	4859813	98.27%	98.12%	89.39%	97.82%
ACE	Lanzarote	4830505	13.40%	68.92%	38.89%	46.39%
SVQ	Sevilla	4214757	55.48%	91.50%	71.65%	66.40%
FUE	Fuerteventura	4117536	10.39%	54.93%	51.96%	41.48%
TFN	Tenerife Norte	4048451	6.98%	69.92%	0.00%	7.64%
BIO	Bilbao	3883342	31.93%	30.66%	0.00%	31.20%
MAH	Menorca	2496010	29.54%	72.06%	44.42%	48.38%
SCQ	Santiago	2158855	47.70%	95.54%	58.50%	52.58%
REU	Reus	1415570	93.93%	85.42%	96.25%	87.24%
OVD	Asturias	1354501	21.97%	56.66%	58.94%	26.08%
MJV	Murcia-San Javier	1349539	36.19%	96.83%	96.33%	91.75%
LCG	A Coruña	1101208	20.00%	93.00%	0.00%	27.57%
VGO	Vigo	1093206	12.85%	19.11%	0.00%	13.39%
XRY	Jerez de la Frontera	1040100	39.13%	63.93%	0.00%	47.64%
GRX	Granada-Jaén FGL	978237	37.23%	98.53%	25.84%	44.01%
SPC	La Palma	969843	0.16%	60.48%	99.90%	13.52%
SDR	Santander	919526	53.95%	99.55%	0.00%	69.99%
LEI	Almería	780382	25.00%	80.82%	0.00%	44.35%
ZAZ	Zaragoza	604528	32.10%	92.58%	3.02%	67.58%
VLL	Valladolid	391642	22.66%	86.57%	0.71%	52.04%
Other airports (*)		1466462	0.06%	6.56%	1.15%	0.27%

Note: The traffic at the airports is measured in number of passengers.
[a] Sum of traffic at the 18 Spanish airports with fewer than 300,000 passengers in 2010.

an additional ratio of polynomials or ARIMA model, that takes into account the possibility that the noise is correlated. This latter term is necessary to ensure the consistency and efficiency of the parameters in model (1), see e.g. Box et al. (1994). It turns out that all transfer functions are not ratios of polynomials, but just numerators, with the exception of the 9/11 effect, for which the denominator is a first order polynomial. In particular, such a model is shown in Eq. (2), and the implication is that the effect of the 9/11 variable vanishes over time, the closer the parameter c_1 to 1 the longer the transient period. On the limit, if $c_1 = 1$ the effect is permanent.

$$\text{Effect } 9/11 = \frac{1}{(1 - c_1 B)} u_{9/11,t} \tag{2}$$

The general representation of the noise model $N_i(B)e_{i,t}$ in (1) is identified empirically within the family of ARIMA models, and turned out to be an airline model in all cases, as shown in:

$$N_i(B)e_{i,t} = \frac{(1 + a_1 B)(1 + a_{12} B^{12})}{(1 - B)(1 - B^{12})} e_{i,t} \tag{3}$$

Here $(1 - B)$ and $(1 - B^{12})$ are differencing operators necessary to reduce the time series to mean stationarity; and a_1 and a_{12} are unknown parameters. The transfer function and noise model orders and delays are identified by minimizing the Schwarz Information Criterion on a wide range of models, and subsequently estimated by Exact Maximum Likelihood with the aid of the ECOTOOL Matlab toolbox (Pedregal et al., 2012).

Table 2
Estimation results for univariate models with intervention variables.

	1st MODEL FSNC traffic at hubs with national destinations	2nd MODEL FSNC traffic at hubs with EU destinations	3rd MODEL FSNC traffic at hubs with non-EU destinations
EASTER		0.0643***	0.0789***
BUSINESS	0.0016**		−0.0032***
9/11		−0.1009***	−0.1619***
c_1 in Eq. (2)		−0.7225***	−0.6386***
Economic cycle	1.5562**	1.8119***	
LST4 (February 2006 step)			
LST1 (July 2009 step)	0.0681**		
HST (March 2008 step)	−0.1013***		
Eyjafjallajökull (felt April 2010)		−0.1633***	
LCC		−0.0764*** (3)	
LCC-HUB-NAT		0.0387*** (0)	0.0485** (1)
LCC-HUB-EU		−0.0893*** (1)	
LCC-HUB-NON-EU			−0.0068*** (2)
			−0.0081*** (3)
a_1 in Eq. (3)	−0.2225**	−0.5443***	0.2279***
a_{12} in Eq. (3)	−0.6712***	−0.7212***	−0.7886***
σ^2	1.243×10^{-3}	0.781×10^{-3}	1.669×10^{-3}
SBC	−6.326	−6.478	−6.031
Q(12)	18.44	12.56	10.58
Q(24)	29.597	22.71	26.40
KSL	0.06 (0.34)	0.05 (0.52)	0.06 (0.39)

Note: One, two, or three asterisks indicate coefficient significance at the 10%, 5%, and 1% levels, respectively. σ^2 stands for the innovations variance; Q(12) are the Ljung-Box Q statistics for 12; KSL is a Kolmogorov–Smirnov–Lilliefors gaussianity test (*P*-values in brackets).

3. Results

Table 2 shows the models that were estimated sequentially in two steps, with all the non-dummy variables transformed by taking natural logarithms. Initially, all the variables were included at the same time in all the models, but in a second step some had to be left out in order for only the significant coefficients to show up and the size of the effects that we wanted to measure[4] to be estimated appropriately.

It is well-known that the use of natural logarithms for the non-dummy variables actually provides an interesting and powerful normalization in two ways. Firstly, it has the beneficial effect of stabilizing the variance of the time series. Secondly, it allows the coefficients in Table 2 to be interpreted as elasticities in the economic sense, i.e. the percentage change of a dependent variable when one independent changes by 1%. On the other hand, the coefficients affecting the dummy variables imply, however, changes of the dependent by $[\exp(\text{coefficient}) - 1] \times 100\%$.

In Table 2, the endogenous variables are shown in each of the three columns. The exogenous input variables are listed in rows, and include three blocks: (i) dummy variables dealing with moveable feasts, the 9/11 effect, the economic cycle effect and large-scale public works related to new terminals and the high speed train link between Madrid and Barcelona; (ii) the four variables related to the effects of the LCCs, see paragraphs C, D, E and F in the list of definitions (the numbers in parenthesis are the delays applicable to the variables); (iii) parameters of the ARIMA model that seek to capture the effects of additional variables not directly included in the specification. A final block includes additional diagnostic tests of residuals in order to check model appropriateness. The Ljung-Box tests for 12 and 24 lags are low enough to be sure of the lack of autocorrelation and the Kolmogorov–Smirnov–Lilliefors tests show that the residuals are Gaussian by a wide margin, since *P*-values are always greater than 34%. In essence, such diagnostic tests show that the significance of coefficients corresponds to the levels implied by one, two and three asterisks in Table 2.

4. Discussion

The data in the previous section mean that three types of LCC effects on the hubs can be talked of. To be precise, two substitution effects between LCC and NC passenger traffic – one internal, within the hub, and a second, external with regard to the regional or secondary airports – and a complementary effect between the two types of airline.

All these effects are concentrated in international flights or, in other words, the LCC effect on the evolution of NC national passenger traffic at the hubs is to date zero (as can be seen in Table 2, where the LCC and LCC-HUB-NAT coefficients of the first model are not significant). This is surprising given the spectacular growth of the LCCs' inter-city point-to-point connections in Spain that do not need to pass through the hubs. The main explanation for this apparent contradiction is most likely due to the fact that the LCCs have grown in this market niche – national flights – by expanding the market. In other words, there is no effect on the hubs as, for the most part, we are speaking of new flights with new passengers who may have changed from other modes of transportation, such as the train or even the automobile or coach, and not from other companies, or who would simply have not traveled without said LCC national connections. It could also be explained in part through the ever more widely- accepted hypothesis that the LCCs have upped the travel frequency of current passengers defended by Castillo-Manzano and Marchena-Gómez (2010) and Mocica Brilha (2008).

This finding is shared by Campisi et al. (2010), who conclude that, despite their success, there is no evidence to show that the LCCs severely cannibalize the market of the full service carriers as principally on shorter routes – such as the national destinations in our case – a large part of the passengers is newly generated traffic. Pantazis and Liefner (2006) also arrive at the conclusion that LCCs generate their own new demand, although more surveys on passengers

[4] The full table is available from the authors upon request.

to confirm this statement would be desirable. With this reservation, it can therefore be said that the large number of national connections that the LCCs have established with Madrid and Barcelona has not affected the evolution of FSNC traffic at these airports.

Other explanations might justify the absence of an LCC effect on the national market. Firstly, as we are working with air traffic volumes, this means that the Madrid–Barcelona route is extremely important in the case of the 1st MODEL-but only in this case. As the FSNCs continue to play a dominating role on said route, it might have been to undervalue the LCCs' overall effect on the national market. Nevertheless, it should not be forgotten that one LCC also operates on that route, Vueling to be precise.

In other respects, Spain's development in recent years of the largest high-speed train network in all Europe and second-biggest in the world after China could also have affected the results of the 1st MODEL, although a significant part of this effect could have been picked up by the HST variable.

With regard to the effects detected, if we focus on the presence of LCCs at non-hub airports, a small external substitution effect can be observed for international flights within the EU (LCC parameter in the second model in Table 2). This means that as the number of LCC point-to-point flights out of Spanish regional or secondary airports has grown, the number of FSNC flights from hubs to the same destinations has fallen. A gradual substitution process of flights via the hub being replaced by direct LCC flights from secondary airports in the intra-European flights category is being produced (for Malighetti et al., 2008, flights within Europe are becoming more and more an LCC concern). Nevertheless, given the low coefficient value it can be concluded that the evolution of the FSNCs in this traffic is not in significant danger in the medium term. To summarize, it can once more be seen how the expansion of the LCCs at secondary airports has been due more to the opening up of new markets with the attraction of new customers, than to capturing customers from competitors.

Meanwhile, the lack of significance of the LCC variable in the third model might be due to its reflecting the fact that today the hubs and the FSNCs still play a dominant role with no competition in flights outside the EU, which includes mainly long-haul and intercontinental flights (Alderighi et al., 2005; Francis et al., 2007; Franke, 2004).

However, this separation between the intra-European and intercontinental markets might be starting to break down, as the LCCs and the European secondary airports are beginning to make a move towards intercontinental and long-haul flights (see Francis et al., 2006, 2007; Maertens, 2010). For Dobruszkes (2009) and Bel and Fageda (2010), however, the low-cost model and the advantages that LCCs obtain on short-haul flights do not seem easily transferable to long-haul flights. Specifically, most long-haul and intercontinental air transport markets require longer range planes, more leg room and on-board food and drink, which would mean a different fleet for the LCCs. Also, many of the secondary airports where LCCs set up do not comply with the requirements for this market as they do not have long runways, for example, or adequate passport and customs controls or seat allocations. This is why no changes are foreseen in this respect, despite the greater demand for point-to-point intercontinental flights due to economic growth and globalization (Bel and Fageda, 2010).

In other respects, with specific regard to the Spanish case, where there is a large LCC presence at the hubs, two main effects on established FSNC traffic at the hubs can be observed. Firstly, an internal substitution effect between the LCCs and the FSNCs for non-national destinations (measured by the LCC-HUB-EU and LCC-HUB-NON-EU coefficient in Table 2). This effect is statistically significant at one percent in models two and three. Therefore, if we focus on the second model, it once more becomes evident that the LCCs provide tough competition for the FSNCs on intra-European flights, when they operate out of both spoke airports and hubs.

In other respects, it can also be observed that there is a negative effect for the FSNCs for flights with non-EU destinations. The lesser significance of this coefficient would be due to the LCCs' market share of these flights in Spain being marginal, with their presence being limited to non-EU European destinations and North African Mediterranean destinations or, in other words, short-haul flights.

Secondly, there is a positive effect, not described by the previous literature that picks up the complementarity between LCCs and FSNCs at hubs for the two categories of international flights (LCC-HUB-NAT parameter in the second and third models in Table 2). It can be observed that the LCC traffic between the hubs and the other national airports boosts FSNC international traffic with Europe and, to a lesser extent, with the rest of the world. Obviously this complementarity reinforces the role of the hubs in airport systems even more. This positive effect is greater in absolute terms and in significance in the case of international flights outside the EU, where, as has already been commented, the LCCs' market share is marginal, leaving the majority of long-haul and intercontinental flights in the hands of the FSNCs.

To summarize, our findings would seem to show that LCC national flights could have been acting as feeders for the FSNCs' transcontinental flights, establishing *de facto* areas of informal collaboration between the two types of airline. However, this collaboration between the LCCs and the FSNCs can also be formal. Such is the case of the agreement between Vueling and Iberia for feeding long-haul Iberia flights in Madrid, and especially, in Barcelona. In this respect, the fact that Air Berlin has recently joined the oneworld global airline alliance should also be highlighted. The information on the company's own website[5] states that this means that the airline is already offering codeshare flights with FSNCs such as American Airlines, British and Iberia, in this last case, improving the connection options to and from Madrid.

Curiously, this connection between LCC and FSNC flights at the Madrid and Barcelona hubs cannot be gathered by official statistics, unlike transfers between flights by the same airline or between airlines in the same alliance. In short, the official statistics would be underestimating hubs' main function of connecting different flights.

Be that as it may, the debate about LCC–FSNC complementarity at hubs is still running as some authors consider that the introduction of LCCs at hubs would prejudice connecting flights, as the short-haul flights that sustain them might not be cost-effective for the FSNCs. For Fageda et al. (2011), one of Iberia's objectives when it created Clickair (which is currently merged with Vueling) was to create an obstacle to the entry of other FSNCs at Barcelona as the profitability of the spokes could be affected by a big LCC like Clickair (the short-haul flights meant to feed long-haul flights). Within this same idea, Pels (2008) underscored that the hub-and-spoke structure can represent a disadvantage for FSNCs compared to LCCs, as when a route linking a hub with a spoke airport closes due to competition from the LCCs, passengers, and thus profits, are lost in all other markets using this link. With specific respect to Spain, according to Iberia, 70% of passengers who purchase tickets for long-haul flights also buy tickets for connecting flights within Spain.

To be specific, and by way of example, from August 2005 to August 2010, the LCC-HUB-NAT variable was responsible for an almost 22% increase in flights to EU destinations and a little over 33% in international flights outside the EU. During the same time period, the substitution effects were 21.2% for flights to EU destina-

[5] See http://www.airberlin.com/site/company/profile/index.php?cat = oneworld&LANG = eng.

tions (obtained by adding together the effects of the LCC and LCC-HUB-EU variables) and a little over 6% for international flights outside the EU. As a result, an almost zero overall effect of LCCs on FSNC flights could be spoken of for flights to EU destinations at the hubs for said period and an overall positive effect for international flights outside the EU.

Apart from these effects seen on traffic at hubs due to LCC operations at hubs or at spoke airports, there are also two other factors that have influenced said traffic. Firstly, the coming into operation of the Madrid-Barcelona HST, which has had negative effects on national traffic. This finding should come as no surprise as the Barcelona-Madrid air link is one of the densest in the world, especially for business passengers (Fageda et al., 2011) and this, along with congestion problems, *a priori* meant it was ripe for an HST (González-Savignat, 2004). According to our model, the HST effect has led to a 9.63% reduction in flights. This result is slightly less than that found by Román et al. (2007), for whom the potential reduction in the air transport market share caused by the introduction of the Madrid–Barcelona HST was between 10.7% and 12.4%.

The eruption of the volcano in Iceland also had a negative effect on traffic with destinations within the EU as the area affected by the ash cloud was for the most part centered over northern and central Europe (see the maximum extent of the volcanic ash cloud in Miller, 2011). In other respects, the new terminals recently built at the hubs have had a moderate effect. Specifically, only the terminal at Barcelona has resulted in a slightly positive effect on national traffic for both airports. This explanation is due to the combined traffic of the two hubs being used as an endogenous variable. Obviously the effects of each of the new terminals would be concentrated at the airport where they have been implemented.

Finally, further conclusions from our model focus on the above-mentioned delayed effects. As a general rule, it can be observed that the effects between the two airline categories, LCCs and FSNCs, are felt quickly, with a maximum delay of 3 months. Even in one of the extreme cases of 3 months, specifically with regard to the internal substitution effects on non-EU international flights, the first effects can be observed after 2 months (see Table 2). These delays disappear or are reduced to a single month in the case of the complementarity effects between LCCs and FSNCs.

5. Conclusions

Spain is one of the countries where the LCCs have been most developed. This development can be synthesized in the fact that Ryanair has become the second-biggest airline in the country, moving 26.6 million passengers in 2010, and in the rapid and profitable development of Vueling, the national LCC, which during the same year transported almost 16 million passengers (see in Table 1 the importance of the LCC phenomenon at each specific airport). In this context, and starting from the basis that these airlines are based on a point-to-point flight model mainly operating out of secondary and regional airports, it was foreseeable to expect that their extraordinary development should affect the supremacy of the Spanish hub airports, mainly Madrid-Barajas and Barcelona, within the traditional hub-and-spoke system into which air transport is organized.

A simple glance at Fig. 1 enables us to reject this hypothesis. In fact, despite slight stagnation in the middle of the last decade, the supremacy of these airports with respect to passenger traffic has continued to grow both in winter and summer. It only needs to be pointed out that Madrid and Barcelona airports combined represented 45.1% of total system passenger traffic in January, 2010, compared to the 40.8% that they constituted in January, 2000.

However, this article offers a more detailed analysis of the data using discrete time linear transfer function models. It specifically offers a methodological proposal which is sufficiently flexible to be adapted to any other country, as long as sufficiently broad time series are available, which is relatively easy in air transport.

Thanks to the proposed models it can be observed that the development of the LCCs is having statistically significant effects on passenger traffic evolution at the Spanish hubs. To be precise, despite the fact that we have no empirical evidence to support geographical supremacy of the hubs having started to decline, we have nevertheless detected multiple indications of changes in the airports that are destined to become the last bastions of the FSNCs. This is an especially relevant fact in Spain, where the circumstances have been right for LCCs to be able to operate at the hubs. These conditions are, firstly, an excess of leisure capacity, especially in the case of Barajas after the opening of the new Terminal, T4 in 2006, and also at Barcelona with the opening of its new terminal in 2009. And, secondly, airport fees that are not so high as to be incompatible with the LCC philosophy.

Under these conditions, this paper provides empirical evidence of three effects for international destinations, both within and outside the EU. Firstly, substitution effects at the hub when the destinations of the FSNCs and of the LCCs coincide; secondly, complementarity effects between the two types of airline at the hub between long-haul destinations operated solely by the FSNCs (because this market is not usually open to the LCCs) and the LCCs' national connections with the hubs, and, thirdly, the logical substitution effects between LCC traffic at regional airports and FSNC traffic at hubs. Notwithstanding, these effects are not as strong as might have originally been anticipated. One of the reasons that might explain this is that a large part of the expansion of the LCCs is due to the growth of the aviation market that they themselves have brought about.

Looking to the future, the hypothesis that generally informal complementary effects would exist between the two types of airline at the hub could offer us a different scenario to the current situation which has been characterized by fierce competition between the two types of airline. If the current situation continues, with intercontinental flight market being the sole domain of the FSNCs, it could be profitable for both airline categories to examine explicit and formal types of collaboration. A good example of this trend is Air Berlin's recently joining the oneworld alliance, as mentioned previously, which enables it to operate codeshare flights with a wide range of FSNCs. Any possible collaborations of this type would seem today to be quite unworkable with LCCs whose business models are *a priori* incompatible with the FSNCs', such as Ryanair, for example.

To summarize, the conclusions drawn in this paper show that competition between the two airline categories and their coexistence with their *a priori* incompatible point-to-point and hub and spoke geographical organization systems could lead to new hybrid geographical models which are not easy to predict. The geographical model will obviously be even more complex depending on the extent to which the LCCs manage to operate at the hubs, as they do in Spain.

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