

**FARE EFFECTS AND DYNAMICS OF NETWORK
STRUCTURE IN THE AIR TRANSPORT INDUSTRY
EMPIRICAL STUDIES FROM THE UNITED STATES AND EUROPE**

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**FARE EFFECTS AND DYNAMICS OF NETWORK STRUCTURE
IN THE AIR TRANSPORT INDUSTRY: EMPIRICAL STUDIES
FROM THE UNITED STATES AND EUROPE**

ACADEMISCH PROEFSCHRIFT

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PREFACE

I cannot imagine that I finally have the opportunity to write the preface of my PhD dissertation! It has taken me four and half years to reach this destination. There is Chinese proverb saying that ‘there is no royal road to learning (书山有路勤为径，学海无涯苦作舟)’. I would say that it has been an intelligent, psychological and physical challenge for me to pursue a doctoral degree abroad. I am so happy and proud of myself to complete this dissertation. However, this dissertation would not be what it is now without the great help, encouragement and support of many persons I met during this wonderful journey.

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LIST OF ABBREVIATIONS

2SLS	Two-stage least squares
ADI	Airport Data Intelligence
ARIMA	Autoregressive integrated moving average
CAB	Civil Aeronautics Board
CNU	Connectivity unit
ECAA	European Common Aviation Area
EU	European Union
FAA	Federal Aviation Administration
FFP	Frequent flyer programs
FSC	Full-service carrier
GDP	Gross domestic product
GDS	Global distribution system
HH	Hub-to-hub
HHI	Herfindahl-Hirschman Index
HS	Hub-and-spoke
HST	High-speed train
LCC	Low-cost carrier
MAS	Multi-airport system
MR	Metropolitan region
O&D	Origin and Destination
OLS	Ordinary least squares
OSA	Open Skies agreement
PP	Primary-primary
PS	Primary-secondary
PTP	Point-to-point
REC	Regional carrier
SABM	Stochastic-actor based modelling
SS	Secondary-secondary
UK	United Kingdom
US	United States
VIF	Variance inflation factor

1 INTRODUCTION

1.1 Main objective of the dissertation

The overall aim of this dissertation is to contribute to ongoing research on fare effects and dynamics of network structure in the air transport industry. In the past twenty years, managing carriers and airports from the perspective of *network* has become a prevalent and crucial rationale for both operators and economic policy makers.

For any carrier, its network structure not only links to the business model of the carrier but also has impact on its pricing strategy which is a crucial determinant of profitability (Holloway, 2008). As the leading and longstanding ‘species’ in the airline industry, full-service carriers (FSCs) have established and maintained hub-and-spoke (HS) network configurations to distribute huge numbers of passengers daily through their hubs. The large concentration of traffic, connections and flights has led to FSCs playing dominant roles at their selected hub airports, which may grant them market power to charge higher airfares on routes from and to their hubs – i.e. the well-known ‘hub premium’ debate in the airline industry (Borenstein, 1989; Lee and Luengo-Prado, 2005). Moreover, the ongoing market consolidation has increased the differences among hub airports *per se*. For example, Air France’s primary hub Paris Charles de Gaulle is 20 times larger than its secondary hub Paris Orly and about 5 times larger than Austrian’s primary hub Vienna in terms of the number of weighted indirect connections per day in 2003 (Burghouwt, 2007). This implies that the service levels of hubs are not always even and vary not only within an individual carrier’s network but also among different carriers. The emerging ‘hub hierarchy’ raises great interests to study the structure of hub-to-hub (HH) networks that are formed by hub airports as a separate group of airports, and link this with the ‘hub premium’ debate.

For airports, they have been increasingly taking prominent and ever proactive roles in attracting air services and developing their networks of destinations through constant business transformation (Airports Council International, 2014). In both regional and intercontinental markets, airport networks have been evolving at an unprecedentedly fast pace in terms of traffic growth, new destinations, routes establishment and capacity expansion. These changes may be facilitated by several significant external factors, such as a series of liberalization policies (e.g.,

the deregulation in the United States (US), three subsequent liberalization ‘packages’ in Europe and the ‘open skies’ agreements between the European Union (EU) and the United States) (Budd and Goetz, 2014; Button, 2009; Goetz, 2002; Graham, 1997), the low-cost phenomenon (Dobruszkes, 2009; Fan, 2006), globalization and technology revolution (Goetz and Graham, 2004; O’Connor and Fuellhart, 2012). Nonetheless, the development of airport networks can be exposed to risks, such as the cyclical economic crises (Dobruszkes and Van Hamme, 2011) or the spatial spreading of infectious diseases (Balcan et al., 2009). The volatile external environment urges airports to continuously inspect the dynamics of their networks in a more comprehensive way, i.e., from a *networked* perspective.

However, to date few literature has been dedicated to: (i) examining how network structure affects the pricing behaviors of FSCs by solely focusing on their hub markets, and (ii) exploring both internal and external factors that drive the changes of air transport networks by considering an airport’s shifting role as a proactive ‘actor’ in their network development. This dissertation attempts to fill these gaps by addressing both issues, which is achieved by systematically examining the position and function of an airport in the structure of the overall carrier or airport networks.

In this dissertation we embed network structure analysis into econometric models, integrate carrier and airport operational practices with social network analysis and apply them in different geographical regions. This brings a new and more comprehensive perspective on the air transport network management, and therefore, contributes to the academic literature theoretically, methodologically and empirically. First, theoretically, we demonstrate that hub hierarchies characterizing route structure should be incorporated into a pricing model to better control inter-route heterogeneity. In addition, we propose that conceptual parallels can be established between the analysis of dynamic air transport network structures and longitudinal social network analysis. Second, this dissertation introduces a stochastic actor-based modeling method to contribute to literature on exploring the mechanisms driving the evolution of air transport networks. Finally, we apply the deployed frameworks to three geographical markets, i.e., the domestic market in the United States and Europe, respectively, and the transatlantic market between the two regions.

This dissertation is organized into six chapters. This first introductory chapter continues by focusing on the background of this study. We then establish the theoretical framework, review literature on factors influencing airfares in HH markets and introduce the overall objectives and

research questions which guide the substantive work presented subsequently. Chapter two presents how network structure affects pricing of the US FSCs in their hub markets, and chapter three continues this stream of research by applying the refined framework to Europe. Chapter four examines the dynamics of network structure by introducing an advanced technique. Chapter five addresses this issue by focusing on the impact of air transport liberalization policy. These four chapters are presented as academic papers three of which were published in peer-reviewed international scientific journals: *Journal of Air Transport Management*, *European Journal of Transport and Infrastructure Research* and *Networks and Spatial Economics*. In the final chapter, we summarize the main findings of the entire work, provide further discussions, and outline some avenues for further research in this realm.

1.2 Context

1.2.1 Air transport liberalization

Liberalization in the air transport industry has been considered as one of the most significant forces shaping the market structure, network configuration and business models of carriers in the 21st century. In a regulated regime, the growth of the industry was restricted as it was regulation authorities (such as the Civil Aeronautics Board (CAB) in the US) that controlled route entry and exit, fares, frequencies, capacities and carrier mergers and acquisitions (Goetz and Sutton, 1997). While in a liberalized environment, carriers have more freedom to do business driven by revenue maximization and it is market force that determines the survival of carriers. We first review the impact of air transport liberalization in domestic markets of the worldwide regions including the US, Europe and other regions in the world, and then in the intercontinental markets.

The US

The first air transport liberalization regime was the Airline Deregulation Act in 1978 aiming to deregulate the US domestic airline industry. Following deregulation, large carriers intensified or shifted to HS networks whereby passengers have to transfer via an intermediate airport (i.e., the so-called hub) to reach their final destinations. The HS network configuration can benefit carriers from economies of density, scale and scope (Brueckner and Spiller, 1994) and also grant the dominant carriers market power at hubs (Borenstein, 1989). In this way, large carriers have transformed into FSCs by adopting a full-service strategy which bundles multiple services, such

as sophisticated yield management systems, fleet with various aircraft types, in-flight entertainment, VIP waiting lounges, and other ‘frill’ services (Hazledine, 2011). In this period, the US domestic airline industry tended to be controlled by fewer FSCs through their HS configurations. Consequently, strong domestic hubs (e.g., Dallas, Chicago or Atlanta) and international gateway cities (e.g., Los Angeles, New York, or San Francisco) played the core control roles in the system, while putting the non-hub airports in a peripheralized place (Goetz and Sutton, 1997). However, a major revolution was looming in the airline industry during 1990s, with low-cost carriers (LCCs) (Brueckner et al., 2013). Southwest pioneered the low-cost model which is characterized by point-to-point (PTP) network structure and simpler business model, such as a single passenger cabin class, standardized aircraft utilization and gradually became the sixth largest carrier in the US (Air Transport World, 2003). Since its inception, Southwest’s success has been the blueprint for the launch of other LCCs in the US and around the world. We will discuss the impact of LCCs in the subsequent section. Reviewing the story so far, we observe that deregulation has led to i) the market structure of the US airline industry to be the competition mainly between FSCs and LCCs, and ii) the network structure to be the longstanding debate between HS and PP.

The single European market

In parallel to the US, a single European aviation market was gradually established through the three- stage deregulation ‘packages’ in 1988, 1990 and 1992, respectively. The aforementioned outcomes of the US deregulation can still apply to the case of Europe, even though there are variations in terms of the construction of a space-time continuum HS network (Burghouwt and de Wit, 2005) and the trend of LCCs going forward hybrid (Klophaus et al., 2012). First, even before the liberalization, FSCs (the erstwhile national carriers) in Europe has spatially established HS networks whereby a vast majority of traffic and flights were naturally concentrated at their hubs, but lack of a wave-system structure to coordinate time schedules. In contrast to FSCs in the US, many European FSCs are still on the way of refining their HS network practices. Second, LCCs have gained rapid growth in their market share following their entry into the European market since 1995. Over several years’ development, researchers found that LCCs have changed their business model towards a hybrid strategy by blending low-cost traits with those of FSCs (Klophaus et al., 2012). For example, Klophaus et al. (2012) categorized LCCs into four types: pure LCCs (e.g., Ryanair), hybrid carriers with dominating LCC characteristics (e.g., easyJet), hybrid carriers with dominating FSC characteristics (e.g.,

Norwegian) and FSCs (e.g., Air Berlin). In addition, the development of LCCs in Europe shows great volatility and fragility. Francis et al. (2006) found that 28% of the LCCs which started between 1997 and 2002 were withdrawn, compared to an average of 2% for FSCs. These findings suggest that any research involving LCCs should provide a concise and real-time definition of LCCs.

Other regions in the world

In other geographical regions, the air transport industry is either tightly regulated such as China or not as liberalized as that in the US and Europe such as Canada, Australia and New Zealand. As air transport liberalization has frequently been considered as a catalyst for the launch and development of LCCs (Francis et al., 2006), the success or failure of LCCs, to some degree, reflects the extent of liberalization. Even though the LCC phenomenon occurred in some of these regions, most of them collapsed soon. When survived, it seems that they have not dramatically changed the market structure of the regions as their US and European counterparts have done. This is due to the fact that, in addition to deregulation, other factors such as entrepreneurial drive and resources also attribute to the proliferation of LCCs (Francis et al., 2006).

The intercontinental markets

In contrast to the deregulation within domestic borders, intercontinental aviation markets have been relatively regulated and only become feasible based on a portfolio of liberalized air service agreements, open skies treaties, regulation and deregulation of national/regional aviation markets, and traditional Bermuda-type air service agreements (Burghouwt, 2014). The EU/US ‘Open Skies’ agreement (OSA) signed in April 2007 marks one of the most significant and substantial regimes of international air transport liberalization, which grants any licensed European Union (EU) carrier the right to fly between any EU airport and any United States (US) airport. In addition, it does give US carriers full fifth freedom rights between EU countries, provided that the flight originates from or is destined for an airport in the US. This makes the EU/US transatlantic market an interesting area to study the impact of such liberalization policy on traffic, market competition and fares.

This dissertation, therefore, focuses on the more liberalized US domestic market, the single European market and the EU/US transatlantic market as empirical case studies. Any

(un)successful lessons from practices of these more matured markets can be learned by other regions in the world.

1.2.2 The low-cost phenomenon

“Probably the most significant development in the US airline industry during the past decade has been the continued expansion of Southwest Airlines and the resurgence of low-fare entry generally.”

(The Transportation Research Board, 1999)

“We went to look at Southwest. It was like the road to Damascus. This was the way to make Ryanair work.”

(Michael O’Leary, Chief Executive, Ryanair)

As a new phenomenon sweeps the worldwide air transport industry, the ‘low-cost’ concept has been one of the greatest achievements of the deregulation in the US and Europe and profoundly affected both airline and airport industry in various aspects. Centering on the objectives of this dissertation, we examine what entry strategies in terms of network construction have been taken by LCCs to occupy markets, how the presence of these LCCs affects the airfares of the predominant FSCs and how airports adapt to accommodate the services of LCCs.

As the airline deregulation unleashed the restrictions on routes entry and fares, LCCs can choose whatever entry strategy and network structure fit into their business models. The literature generally distinguishes between three types of competition from the entry of LCCs: actual, adjacent and potential competition (Brueckner et al., 2013; Dresner et al., 1996; Krista, 1996; Morrison, 2001; Vowles, 2006). The actual competition is caused by the entry of LCCs to serve the market in question and impose an head-to-head competition. The adjacent entry is due to the operation out of secondary airports within large metropolitan areas (e.g., Midway in Chicago and Baltimore in the Washington, D.C. area). Moreover, if LCCs exhibit significant presence at the endpoints of a route but not serving the route itself, LCCs are said to provide potential competition.

Although it is well-known that the archetypical network structure of LCCs is PTP as originally adopted by the pioneer of LCCs (Southwest), the reality is far more complex. For LCCs with

sound PTP networks, such as Southwest, it is possible to leverage their networks by providing connecting services between existing airports within their networks to enjoy economies of airport costs (Boguslaski et al., 2004). In addition, newly launched LCCs revolutionarily altered the PTP model and implemented the quasi-HS network of FSCs (e.g., AirTran at Atlanta and JetBlue at New York JFK). The motivation behind this network structure divergence is to ease entry barriers through providing connecting flights. For instance, Müller et al. (2012) found that if the number of one-stop connections JetBlue could serve after a non-stop entry between two airports increased by one, the hazard (i.e., the probability of starting to serve a route directly within a short interval of time, conditional on not having entered that route up to the starting time of the interval) of entry increased by 11.2%. The coexistence of these two types of network structure among LCCs has complicated the way of competition from LCCs. A recent research done by Brueckner et al. (2013) suggested that a comprehensive analysis of competition from LCCs should consider not only the way of competition *per se* but also the entry type of route structure (i.e., a non-stop or connecting service).

Several studies have confirmed that the LCC competition has dramatically reduced fares, whether the resource is from in-market competition, at adjacent airports, or as potential competition (Brueckner et al., 2013; Dresner et al., 1996; Krista, 1996; Morrison, 2001; Vowles, 2000; Windle and Dresner, 1995). In the studies for the US markets, researchers have particularly distinguished Southwest from other LCCs due to the much larger fare impacts of the former. For instance, Brueckner et al. (2013) found that the presence of nonstop competition from Southwest reduced fares by 26%, while nonstop competition from other LCCs had a smaller 12% effect. In addition, the potential competition from Southwest reduced fares by 8%, while other LCCs had no fare effect in this way of competition.

The proliferation of LCCs not only significantly affects the pricing strategies of other carriers but also reshapes the relationship between airports and carriers. The business model of LCCs makes them favor secondary airports due to lower charges and less congestion, and their rapid growth substantially benefits the chosen secondary airports in terms of traffic growth and revenue-generating opportunities. This encourages many airport managers to proactively take actions to attract LCC services in order to achieve the economies of scale (Francis et al., 2004). In addition, metropolitan regions (MR) even develop a number of secondary airports to support LCC services (e.g., Liverpool in Manchester MR for Easyjet or Skvasta in Stockholm MR for

Ryanair) (De Neufville, 2004). All these actions imply that the traditional airport-airline relationship in which airlines go forward airport to seek business has been changed.

The dramatic impacts of LCCs spreading in various aspects of the air transport industry suggest that academic research should also incorporate this factor into modeling.

1.3 Theoretical framework

This section elaborates the theoretical framework emanating from which we describe the structure of air transport networks, demonstrates the position of an airport in these structures and define the ensuing route structure. In specific, we review the empirical literature on the analysis of air transport networks from the perspective of a spatial dimension, a temporal dimension and complex network theory.

1.3.1 Spatial dimension

The spatial approach has been the most extensively used approach to help researchers conceptualize, describe and compare the geographical variation of air transport networks in space (Burghouwt, 2007). The position or role of an airport varies in different types of networks, i.e., whether in an individual carrier's network or a *gross* network aggregated by all individual carrier networks. This distinction is important in that: first, in an individual carrier's network, an airport plays a less active role and act merely as a network-service provider. In this way, the network strategy taken by the carrier may have drastic impact on the airport in terms of traffic and connectivity. Second, in an aggregated network, the role of an airport can be enlarged and diversified as the air transport industry becomes increasingly liberalized. This implies that airports also compete for airline services and consumers. We, therefore, examine which spatial indicators can adequately describe the position of an airport by distinguishing between individual carriers' networks and aggregated networks.

Since the deregulation of the US airline industry in 1978, the FSCs have intensified the adoption of the HS network structure, broadening the service differences between hub and non-hub airports. A series of research have emerged to focus on identifying and defining hubs in the networks of FSCs. For instance, Bania et al. (1998) proposed a hub index which is the actual nonstop connections divided by the hypothetical maximum nonstop connections of an airport in a given carrier's route network. Then they used a cluster technique to identify the number and location of hubs for a carrier. Shaw (1993) defined hubs based on three different measures (i.e.,

standardized degree, standardized Shimmel shortest-path index and valued-graph index considering geographical distance) by analysing the top 10 lists. In his research, he explicitly discussed the hierarchical structure of hubs in a carrier's network and stressed that this issue deserves research attention in topics such as the hub network design problem, hub location modeling and carriers competition research. The indicators applied by Bania et al. (1998) and Shaw (1993) share some similarities and *de facto* originate from the graph theory¹, even though they did not explicitly mention or discuss this. Moreover, several other researchers applied economic concentration indices to define hubs or to examine the network structure. For example, US General Accounting Office defined airports with more than 60% of passenger enplanements by one carrier or 85% by two carriers as hubs (Goetz, 2002; US Department of Transportation, 2001). Reynolds-Feighan (2001) and Burghouwt et al. (2003) applied the Gini index to describe the spatial configurations of carriers in the US and the Europe. However, Martín and Voltes-Dorta (2008) and Martín and Voltes-Dorta (2009) criticized that these economic concentration indices overlooked the connecting behavior of passengers and justified that the number of connecting passengers is a more adequate index to measure the hubbing practices in carrier networks.

When analyzing the aggregated air transport networks, researchers tend to combine the aforementioned spatial indicators with airline operational practices. Ivy (1993) developed a gross vertex connectivity index to evaluate the country-level accessibility of pre-defined carriers' hubs (i.e., based on the percentage of connecting passengers) by considering both direct and indirect connections. Grubestic and Zook (2007) used the number of non-stop, one-stop and two-stop flights to categorize the 156 busiest airports in the US into eight groups. Moreover, Derudder et al. (2007a) examined the hubs in the global air transport networks based on the number and the percentage of connecting passengers and the standardized degree index.

1.3.2 Temporal dimension

The indicators expressing the temporal dimension of carrier networks still center on the questions about how to adequately describe the HS network structure and how to measure the competitive role of hubs. This strand of research was motivated by the fact that a *real* HS network where traffic is concentrated not only spatially around a few hubs but also temporally through a

¹ Graph theory is a branch of mathematics studying how networks can be encoded and their properties measured (Gross and Yellen, 2004).

wave-system structure has not been well established by European carriers after deregulation as ‘a substantial number of services at these airports only provided transfer connections by accident’ (Burghouwt and de Wit, 2005; Dennis, 1994). The adoption of a wave-system structure in the carrier flight schedule can create a number of indirect connections with longer travel time but higher frequencies or cheaper prices which is likely to be attractive to passengers (Veldhuis, 1997). Several studies have, therefore, emerged to develop connectivity models by emphasizing the importance of indirect connections. Burghouwt and Redondi (2013) provided a systematic overview of eight different connectivity models deployed in air transport literature and concluded that the choice of these models depends on: i) the acceptable level of information loss, ii) the number of steps required, and iii) considering whether a connection is the shortest or quickest connection among all possible connections for a particular origin-destination market. Table 1.1 shows the definition and calculation complexity of the eight models presented in the work of Burghouwt and Redondi (2013).

Table 1.1 Definition and calculation complexity of connectivity models

Model	Short definition	Calculation complexity	Main references
WNX (weighted number of indirect connections)	Number of direct and indirect connections weighted by their quality in terms of transfer and detour time	Medium complexity (Microsoft Access)	Burghouwt and de Wit (2005); Burghouwt (2007)
Netscan connectivity units	Number of direct and indirect connections weighted by their quality in terms of transfer and detour time relative to a theoretical direct flight	Medium complexity (Microsoft Access)	Veldhuis (1997)
Bootsma connectivity	Number of connections. Indirect connections meet conditions of minimum & maximum connecting time and are classified as 'excellent', 'good' and 'poor'	Low complexity (Microsoft Access)	Bootsma (1997)
WCN (weighted connectivity number)	Number of direct and indirect connections weighted by their quality in terms of transfer and detour time	Medium complexity (Microsoft Access)	Danesi (2006)
Doganis and Dennis connectivity	Number of connections. Indirect connections meet conditions of minimum & maximum connecting time and routing factor	Low complexity (Microsoft Access)	Doganis and Dennis (1989)
Number of connections patterns	Number of statistical significant patterns of incoming and outgoing flights	High complexity (Matlab)	Budde et al. (2008)
Shortest path length	Number of connections lying of O-D shortest paths. The shortest path is the path involving the minimum number of steps from O to D	High complexity (Matlab)	Malighetti et al. (2008)
Quickest path length	Number of connections lying of O-D quickest paths. The quickest path is the path involving the lower travel time from O to D	Very high complexity (Matlab)	Malighetti et al. (2008)

Resource: Burghouwt and Redondi (2013)

1.3.3 Complex networks theory

In addition to the spatial and temporal dimensions, air transport networks are widely studied using the theory of complex networks which has developed a great variety of techniques to study real-world systems consisting of a large portfolio of interacting nodes and experienced dramatic changes in the last decade (Zanin and Lillo, 2013). We review the application of the complex networks theory in the air transport networks based on three methods, i.e., unweighted topological analysis, weighted topological analysis and integrated analysis combining the complex networks theory with the spatial or temporal aspects as discussed before. First, focusing on measuring the unweighted topological structure where only the existence or absence of direct connections between pairs of airports is considered, researchers find that air transport networks share the universality of the complex network phenomena as a small-world, scale-free and modular network (Bagler, 2008; Barrat et al., 2004; Guimera and Amaral, 2004; Neal, 2014; Xu and Harriss, 2008). The metrics commonly used are degree (distribution), betweenness (distribution), the average length of shortest paths and clustering coefficient and can be measured at both network and individual airport level². The contributions of this type of method are: i) its finding about scale-free feature confirms the airline practice of hub-and-spoke network configuration; ii) the degree centrality is widely used to identify the most important airports (i.e., hubs) in an airline network (Shaw, 1993); iii) the betweenness centrality at the network level can be used to identify the distinct network characteristics within the same carrier group (i.e., either an FSCs group or an LCCs group) (Cento, 2008). However, it also has great limitations in that: i) the lack of considering the weight and type of flows between pairs of airports can mask substantively important structural differences (Neal, 2014; Xu and Harriss, 2008); ii) the sole analysis of topology cannot well explain the emerging questions in specific. For example, Guimerà et al. (2005) found that the most connected cities (largest degree) are typically not the most central cities (largest betweenness centrality) when analyzing the world-wide airport network and termed this as the ‘large-betweenness/small-degree’ puzzle. In addition, Cento (2008) concluded that the network-wide betweenness centrality cannot

² Degree is the number of topological connections of a node to other nodes. Average short path is defined as the minimum number of ties linking two nodes. Betweenness centrality measures the number of shortest paths that passes through a node. The clustering coefficient is defined as the fraction of existing edges of a node in its neighborhood. Readers interested in social network analysis are referred to Wasserman and Faust (1994).

distinguish between FSCs network and LCCs network. These drawbacks enable the creation of the weighted complex networks theory and the complementary methods.

Drawing on the framework of the unweighted complex networks theory, researchers also considered the most important performance or operation indicators (i.e., weights) in the air transport industry, such as the number of flights, the number of available seats, passenger volumes, distance and fares (Barrat et al., 2004; Xu and Harriss, 2008) and found that there exists a strong correlation between the degree of an airport, and the number of flights and passengers. However, these findings add little new knowledge to the literature as it appears to be commonsensical that an airline's hub with more connections, will handle more passengers and accumulate higher quantities of frequencies.

Recently, several studies have complemented a complex network approach by the spatial or temporal methods. For instance, Malighetti et al. (2008) deployed a time-dependent minimum path approach coupling with the analysis of the shortest path lengths to systematically examine the connectivity of the European airport network. The same research group also combine the traditional clustering tools with the innovative simulated annealing methodology in the realm of the complex networks theory to classify airports in Europe into clusters and modules by considering both their characteristics and positions in the network (Malighetti et al., 2009). Moreover, Cento (2008) integrated the betweenness centrality analysis with the analysis of temporal dimension by considering the number and frequency of one-stop city-pairs and concluded that the combined method can better compare the differences between the network configurations of FSCs and LCCs. In addition, a recent study conducted by Ryerson and Kim (2013) re-defines the hub hierarchy in the US by including the flight frequency along with the degree centrality and passenger volumes. These studies illustrate that the complementary methodology provide a more profound direction for research analyzing air transport networks.

1.4 Factors influencing airfares

Examining the impact of network structure on fares requires establishing a formal econometric model that should also control for other crucial factors due to the complex process of airfare setting. Market structure is commonly considered as an important determinant of airfares apart from network structure. This section thus focuses on reviewing literature on how general determinants of network structure and market structure influence airfares in the airline industry, even though subtle variations can exist depending on data availability, aggregation

level (e.g., route or route-carrier level) of observation units and scale of the investigated markets (e.g., entire or focused part of an air transport system).

Network structure

The role of network structure in airfare pricing has been closely related to the HS type of network where one or, occasionally, two FSCs have large market share of enplaned passengers or scheduled flights at their hubs, which is commonly termed as hub dominance. Researchers have shown that the hub dominance can confer FSCs market power to charge higher fares on routes involving their hubs (Borenstein, 1989; Chi and Koo, 2009; Giaume and Guillou, 2004; Lee and Luengo-Prado, 2005). The ensuing hub premium naturally raises the question whether dominance at any airport other than the hub can lead to higher fares. The operationalization of airport dominance has also been proved to have a significant effect on fares (Evans and Kessides, 1993). Moreover, having a large market share on a route (i.e., route dominance) may also grant carriers certain degree of market power to raise fares (Fischer and Kamerschen, 2003; Piga and Bachis, 2007; Stavins, 2001). An example is the European market where many routes can be considered ‘natural monopolies’ due to their limited size, were charged higher prices by their dominant carrier (Piga and Bachis, 2007). Researchers, therefore, often incorporate both airport dominance and route dominance into a pricing model to capture the influence of network structure on airfares.

As the scope and market presence of a HS network configuration are limited in the international aviation due to relatively restrictive regulation policies, alliances have become the major means for FSCs to expand and strengthen their global networks (Oum et al., 2001). Interlinking each other’s networks via their hubs leads to the development of explicit and implicit multi-hub-and-spoke networks. Given the findings of a ‘hub premium’, an alliance may also increase the market power of allied carriers at their hubs, and thus causes higher fares (Brueckner and Pels, 2005; Youssef and Hansen, 1994). This indicates that strategic alliances (when existed) are also relevant in airfare settings.

In addition, the nature of the HS network gives rise to the complexity of route type where non-stop and one or two-stop connecting services coexist. In a more liberalized market, carriers can choose either non-stop or connecting strategy to capture market share. The competition between route types has been found to influence prices (Brueckner et al., 2013; Lee and Luengo-Prado, 2005).

Market structure

Airfare pricing is driven not only by the internal carrier-specific considerations but also by the structure of external markets, such as overall degree of market concentration, the proliferation of LCCs and competition from other transportation modes. First, market concentration frequently measured as the Herfindahl-Hirschman Index (HHI) at route level has mixed impact on prices. On the one hand, increases in route HHI can raise prices to some degree due to collusion among a few carriers (Chi and Koo, 2009) or booking tickets near departure days (Piga and Bachis, 2007). On the other hand, a negative relationship exists caused by technological advantages of the dominant carrier over its rivals (Fischer and Kamerschen, 2003) or high inequality of market share between carriers (Giaume and Guillou, 2004). Second, as discussed in section 1.2.2, LCCs have directly and indirectly affected airfares in the airline industry, and thus serve as a significant determinant of pricing models. Moreover, air transport increasingly confronts competition from other transportation modes, mainly high-speed train (HST), in regions such as Western Europe and China (Dobruszkes, 2011; Yang and Zhang, 2012). Research relating to these regions should consider this effect into modelling.

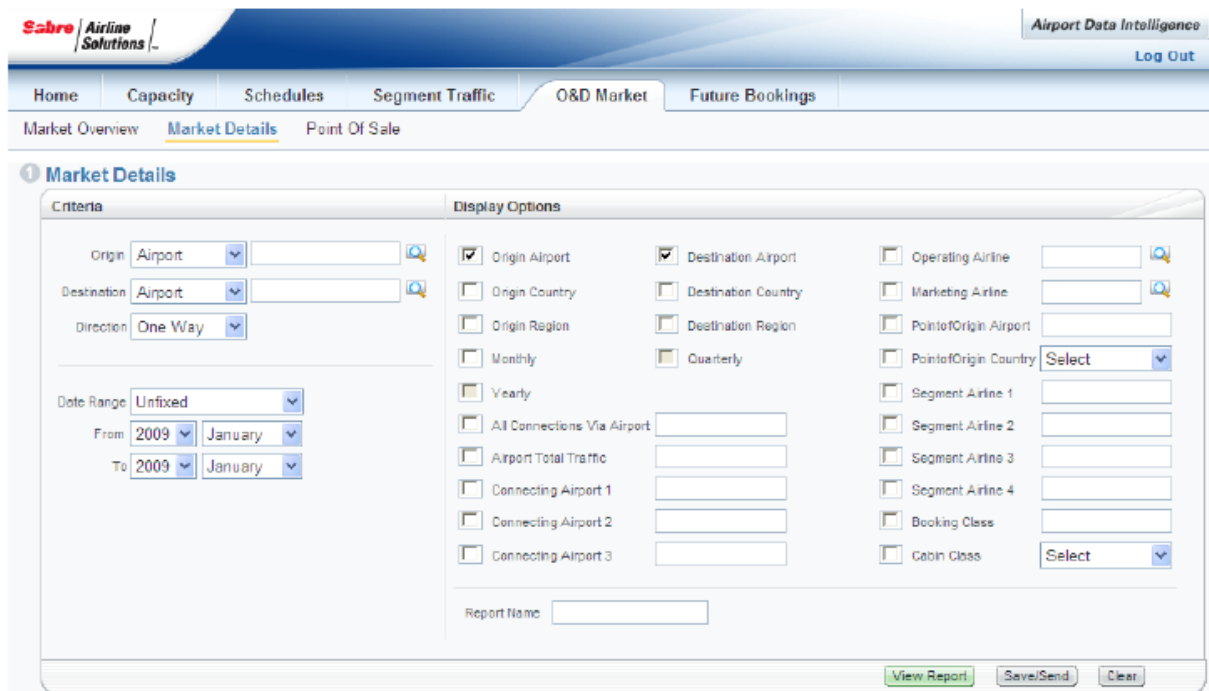
1.5 Dataset

The main dataset used in this dissertation was collected in December 2010 through a research cooperation with Sabre Airline Solutions' on-line data provider - Airport Data Intelligence (ADI). Sabre's ADI seeks to establish the most complete dataset for carriers and airports by collecting and validating data from: 1) global distribution systems (GDSs), 2) travel agencies, 3) Global Demand Data that adjusts for direct bookings, low-cost carriers, charter operations, 4) Industry data from carriers, airports, or government agencies, and 5) Internal carrier data such as ticket coupon data from revenue accounting and post departure traffic data from the departure control system. The validation process involves both automatic and manual clean-up of the raw data, as well as the removal of passive and duplicate bookings. The processed and adjusted data is then calibrated using various statistical and model-estimation techniques such as linear and logistic regression, clustering, maximum-likelihood and demand based on sampling techniques (Pradhan, 2014). The consistent and accurate calibration can help all types of carriers, including the two main types of players (i.e., FSCs and LCCs), to define and execute their short-term and long-term planning in terms of network design, demand forecasting, profitability evaluation and other principal factors. Moreover, The ADI dataset allows

monitoring and tracking real-time fare information as passenger data is updated monthly and schedule data is renewed weekly.

The ADI dataset contains valuable information on global passenger and schedule data³. In particular, its central part (i.e., the ‘O&D Market’ section) provides the most detailed origin and destination (O&D) level data in terms of airports (i.e., origin, destination and connecting airports), carriers (i.e., operating, marketing and segment carriers), cabin class, the number of passengers, the total revenues and other salient information. Figure 1.1 shows an overview of the screen design of the O&D Market section. These indicators can help carry out research in at least four aspects relating to this dissertation: (1) The true origin, destination and connections between airport-pairs allow us to establish reliable networks and analyze network strategies adopted by carriers. (2) The indication of connecting airports is crucial to analyze the performance of hubs and competition between hub airports. (3) As one of the main players in the air transport industry, carrier information can help identify different types of carriers and analyze market structure. (4) The number of passengers and total revenues are two fundamental economic metrics which determine operating strategies of carriers and airports on the demand side.

³ http://www.sabreairlinesolutions.com/home/software_solutions/airports/



Source: User support documentation of Sabre Airline Solutions' Airport Data Intelligence

Figure 1.1 Screen design of Sabre ADI's O&D Market section

We collected the required data to satisfy four research objectives. First, in order to proceed the proposed pricing analysis in Chapter 2 and 3, we extracted information on passenger numbers, revenue, cabin class and distance at the route and carrier level in May 2009, the most recent year of data available at the time of writing. It has thereby acknowledged that seasonality may influence the pricing behaviours of carriers. For instance, the third quarter in general shows high demand for air travel and may have a positive impact on airfares. The month of May (i.e., the median month of a year) lies not only between cold seasons (i.e., Winter and Spring) and warm seasons (i.e., Summer and Fall) in the Northern Hemisphere, but also after the Easter holidays in April and before summer holidays beginning in June. Data regarding this month can in principle better control for the impact of the seasonality and provide a relatively unbiased estimation of airfares. Routes are connected by origin and destination airports located in either the US (Chapter 2) and/or the Western/Central parts of Europe (Chapter 3). Intermediate stops are also indicated when connecting services are available.

Second, as examining network dynamics requires evolutionary data at different time points, we collected data on actual connections between airports in Europe in 2003 and 2009 to construct the network data that serves as the dependent variable in the model (Chapter 4) and

on passenger numbers of routes connected by airports located in the EU and the US during the time period 2005-2008 (Chapter 5).

Although the ADI dataset has been adjusted and calibrated via an extensive process, there are still some limitations. First, as outputs are saved in Excel files with limited capacity, it is difficult to analyze the outputs stored in multiple sheets in Excel and multiple Excel files. More advanced databases, such as Access, were applied to proceed a secondary storage of the outputs and to facilitate the analysis. Second, a significant number of records contain routes with passenger numbers less than 100. It is unclear whether this is due to input errors or is the actual passenger numbers transported by a carrier. As it seems unreasonable for a carrier to transport only one or two passengers monthly, we carried out a second-round clean-up of the data based on market share of a route or a carrier. In particular, routes or carriers with at least 1% of market share in terms of passenger numbers are included in the analysis. Finally, as Sabre's ADI system is commercial, it is costly to be used by academic researchers.

1.6 Aims and research questions of the dissertation

As illustrated in the Introduction section, the concept of network management has brought new insights for today's carriers and airports when doing business in the air transport industry. Substantial progress has been made within the academic literature of i) examining the effects of hub dominance and carrier competition on airfares by economists (Borenstein, 1989; Brueckner et al., 1992; Brueckner et al., 2013; Dresner et al., 1996; Evans and Kessides, 1993; Morrison, 2001; Morrison and Winston, 1990), ii) investigating network configurations of carriers, or connectivity and accessibility of airports by geographers (Burghouwt, 2007; Derudder et al., 2007a; Derudder and Witlox, 2009; Derudder et al., 2007b; Dobruszkes, 2006), and iii) examining large air transport networks using the advanced complex network theory in network science by physicists (Barrat et al., 2004; Ducruet and Beauguitte, 2014; Guimera and Amaral, 2004). However, due to a lack of inter-discipline cooperation, the achievements obtained in these fields still cannot be fully utilized by each other. This dissertation, therefore, attempts to fill this gap and bridge a connection among these disciplines. At the backdrop of the background and our theoretical framework about network structure analysis, we propose two major goals which address the two under-studied issues as detected in the Introduction and serve as the basis of formulating our research questions later on:

(i) Although hub-and-spoke networks have been extensively researched, hardly any literature focuses on hub-to-hub (HH) networks in which nodes are full-service carriers (FSCs)' designated hubs and links are airport-pairs connected by hubs. It is unclear whether the 'hub premium' imposed by FSCs also exist in such networks where hierarchical structures exist. The first goal of this study is, therefore, to establish a refined route structure for HH networks and examine whether such a route structure has impact on the pricing strategies of FSCs. This is achieved by establishing econometric models that also consider the market competition environment of FSCs in the era of LCCs in two different geographies, i.e., the US (Chapter 2) and Europe (Chapter 3).

(ii) Air transport networks are dynamic in nature as routes can be established and flourished, or retreated and weakened. Research related to this topic is still limited due to under-implementation of the advanced methodologies in network science or a lack of literature focusing on intercontinental markets which appear to experience slower changes under the condition of relatively strict regulation policy. The second goal of this study is, therefore, to contribute to on-going research on dynamics of air transport networks. This is accomplished by introducing a profound methodology – Stochastic Actor-based Modelling (SABM) technique to examine the evolution of the air transport network in Europe (Chapter 4) and by investigating how the new signed EU/US 'open skies' agreement influences traffic change in the transatlantic market (Chapter 5).

Figure 1.2 shows the overview scheme of this dissertation.

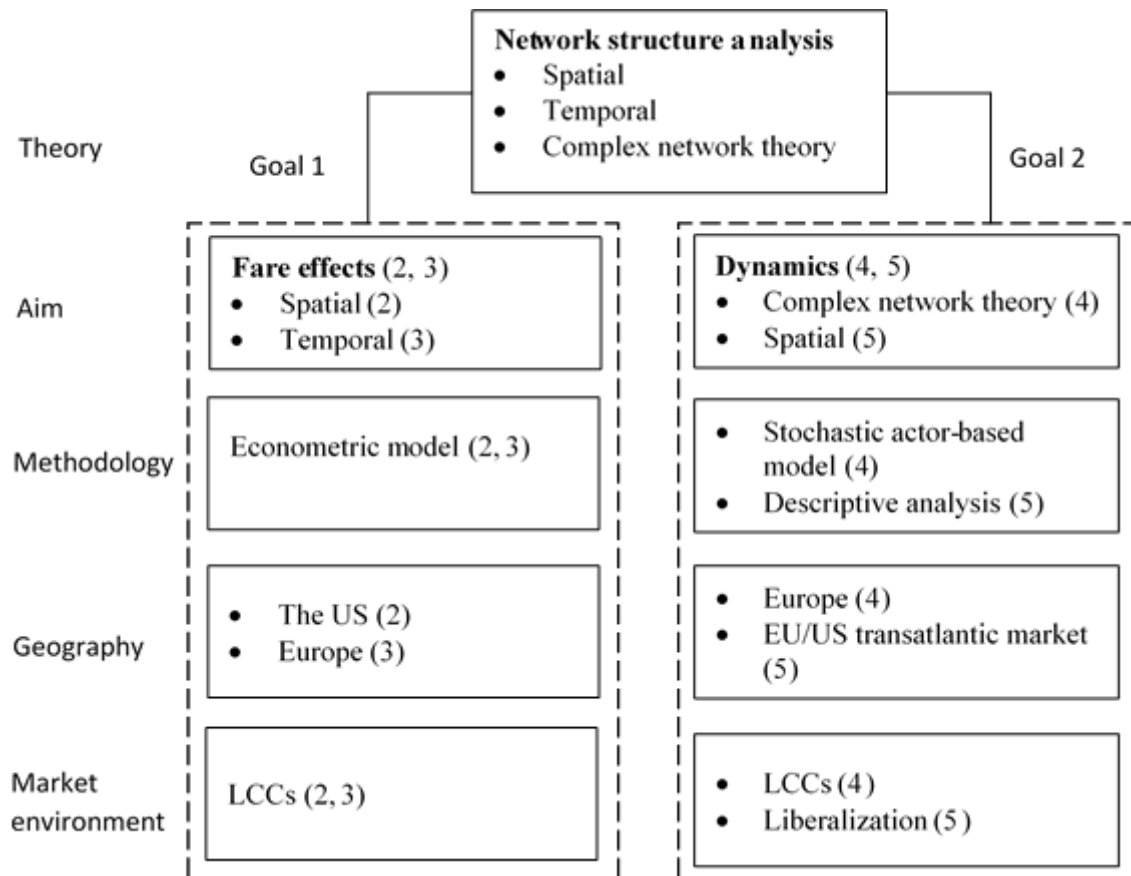


Figure 1.2 Overview of the dissertation (chapter number is shown in brackets)

Below, these goals are explicated in greater detail by formulating four research questions as presented in the following four chapters.

In Chapter 2, we explore the factors influencing the pricing behaviour of FSCs by giving a central attention on the HH markets in the US. The research questions are devised as: *What factors affect the fares of full-service carriers in the US hub-to-hub markets? In particular, does an airport's position in carrier's hub hierarchies impact fares?* A spatial indicator is applied to define hubs for the investigated FSCs which further determines the ensuing route structure of the HH network. We then introduce an econometric model to estimate the impact of network structure (i.e., hub hierarchy) and market structure (i.e., competition from LCCs) on the average fares charged by US FSCs by controlling for other demand and supply variables (i.e., passenger numbers, vacation destinations, slot-controlled hub, and distance). In the analysis, we also highlight the differences between Southwest and other LCCs as regards the extent to drive prices down in markets dominated by FSCs.

As a subsequent study, we apply the same rationale to European HH markets. However, given a different geography and market structure from the US, a systematically exploratory analysis is preceded before the formal econometric analysis. As such, we raise the following research question in Chapter 3: *What factors determine the airfares of full-service carriers in European hub-to-hub markets?* A temporal indicator is used to define hub hierarchy. We then consider network structure variables as represented by hub hierarchy and alliances, and market structure variables including market concentration, competition from LCCs and high-speed train as potential determinants. Meanwhile, we also compare the result obtained in the European market with that in the US case.

Chapter 4 attempts to broaden our understanding on the spatial-temporal development of air transport networks in a more comprehensive way by addressing the mechanism of changes in the process of opening, canceling and maintaining routes between airports. We explore a stochastic actor-based modelling (SABM) technique which to date is the first time that it is applied in a longitudinal analysis for air transport networks, even though it has been extensively applied in many other fields, such as friendship networks, inter-organizational networks or political networks, to examine network dynamics (Andrew, 2009; Liu et al., 2013; Snijders et al., 2010). The empirical case study is the European air transport market. We pursue answers for the following question: *What factors drive changes of the European air transport network drawing on the explanatory framework of the stochastic actor-based modelling technique?* We incorporate endogenous effects representing the current network structure itself and exogenous effects describing the characteristics of airports (i.e., actor covariates) and airport-pairs (i.e., dyadic covariates) into the models. The studied period is between 2003 and 2009.

Air transport liberalization has been considered as a catalyst for network evolution as airports and routes can be freely entered or exited. As stated in section 1.2, even though under the condition of the ownership and cabotage restrictions, the EU/US ‘open skies’ agreement (OSA) has gradually liberalized the EU/US transatlantic markets and may bring opportunities for airports other than FSCs’ primary hubs which traditionally handled a vast majority of the long-haul traffic, such as secondary airports. In addition, research have shown that there is a tendency of long-haul traffic towards dispersion in favor of secondary airports (Bel and Fageda, 2010; Maertens, 2010; O’Connor and Fuellhart, 2013; Sismanidou et al., 2013; Weber and Williams, 2001). We, therefore, propose the following research question in Chapter 5: *To what extent does transatlantic traffic change at secondary airports in the European Union and the United*

States in the context of the EU/US 'open skies' agreement? The investigated time period is 2005-2008.

The sixth and final chapter of this dissertation summarizes the main findings drawn from the combined conclusions of the previous four chapters, and outlines some avenues for further research.

With regards to my role in the aforementioned chapters given that some of these are co-authored papers, I have independently completed the first and final chapter, and conducted the data collection, analysis and interpretation in the other chapters of this dissertation. In collaboration with my co-authors, the original manuscripts of these chapters throughout the dissertation have been significantly improved in terms of research objectives, statements and language.

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2 THE IMPACT OF HUB HIERARCHY AND MARKET COMPETITION ON AIRFARE PRICING IN US HUB-TO-HUB MARKETS

Zhang, S., Derudder, B., Witlox, F., 2013. The impact of hub hierarchy and market competition on airfare pricing in US hub-to-hub markets. *Journal of Air Transport Management* 32, 65-70

Abstract

This paper explores factors influencing the pricing behaviour of full-service carriers in hub-to-hub markets, which to date have rarely been the exclusive focus of research. Drawing on a 2009 dataset containing route and airfare information, we estimate a pricing model for hub-to-hub markets in the United States. Our econometric analysis suggests that an airport's position in carriers' hub hierarchies, competition from low-cost carriers, and other market structure variables influence average airfares.

2.1 Introduction

Air travel demand in the United States is expected to increase to 1.2 billion passengers in 2032, a near-doubling compared to the 731 million passengers in 2011 (Federal Aviation Administration, 2012). In principle, such further growth of the domestic market implies major business opportunities for US carriers. However, there are on-going concerns about the poor financial performance of US carriers. American Airlines' recent filing for Chapter 11 bankruptcy implies that the largest full-service carriers (American, Continental, Delta, Northwest, United and US Airways) have recently gone through a period of major restructuring. Part of the recent financial woes can of course be attributed to the on-going financial and economic crises that began in 2007, which have temporarily stifled demand (Dobruszkes and Van Hamme, 2011). Nonetheless, whatever the source of the poor financial performance of US carriers, it is clear that constantly (re)examining pricing strategies will be of key importance in order to reap the potential benefit of an expanding market.

The extensive literature on airfare pricing strategies in the US aviation market predominantly focuses on (i) individual carriers' overall route networks (Chi and Koo, 2009; Lee and Luengo-Prado, 2005), (ii) the United States air transportation network as a whole (Borenstein, 1989; Brueckner et al., 1992) or (iii) specific airports (Borenstein, 2005; US Department of Transportation, 2001). As a consequence, there has been relatively little research exclusively focused on how carriers determine airfares in hub-to-hub (HH) markets, where both origin and destination are to some degree dominated by a full-service carrier (FSC). A major exception is the work of Vowles (2006), who found that route structure and competition between carriers (especially from low-cost carriers) play prominent roles in determining airfares in HH markets.

In his analysis, Vowles included two route structure variables: routes where a single carrier controls both endpoints (i.e., ROUTE1, such as Newark -Houston in the erstwhile Continental network) and routes where two different carriers control the endpoints (i.e., ROUTE2, such as Salt Lake City-Cleveland for Delta and Continental). However, what remains unclear is how hubs and their service levels are defined because 'the lack of any universally accepted definition of hub can be confusing in debate' (Button, 2002, p.180). In addition, the operationalization of ROUTE1 did not consider the variation in the 'levels' of hubs within a carrier's network. However, previous research has shown that service levels do not simply vary between 'hubs'

and ‘non-hubs’, but also amongst a carrier’s hubs⁴. For instance, Shaw (1993) divides hubs into ‘national hubs’ and ‘regional hubs’ based on the ‘importance’ of an airport in a carrier’s network, while Ivy (1993) distinguishes between ‘primary hubs’ and ‘secondary hubs’ based on the levels of transfer traffic. This ‘hierarchy of hubs’ suggests that the service levels of the routes connecting these hubs within a carrier’s network will also be different, while the ensuing difference in HH routes may thus also impact the pricing strategies of the different carriers: it can be hypothesized that routes involving more dominant hubs can be related to higher airfares. This information is important for carriers and global alliances willing to maintain or establish multi-hub-and-spoke networks when they determine airfare pricing, frequencies and capacities for inter-hub routes (Holloway, 2008).

The purpose of this paper, therefore, is to extend Vowles’ research through a more refined analysis of the impact of hub hierarchies on pricing in US HH markets. We hypothesize that (1) the presence of hub hierarchies may be relevant as there may be differential impacts based on the level of ‘hubness’ of both points on a route, while (2) there may be duopolistic effects or intensive competition in routes connecting hubs of different carriers. In our model, we therefore adopt a more refined operationalization of the notion of ‘hub-to-hub routes’ and hierarchies among hubs. Our empirical framework is thereby centred on the overall HH market as ‘produced’ by the six largest FSCs (at the time of the data gathering) in the US.

The remainder of this paper is organized as follows. Section 2.2 reviews previous studies on the ways in which network structure and market competition determine airfares and yield in the US airline industry. Section 2.3 defines HH networks in the US and introduces our data and model. This model is operationalized in section 2.4, where the results of the overall HH market are used to illustrate how network structure, market competition, demand and cost variables, and market structure influence pricing strategies. In section 2.5, we summarize the main implications of our analysis and outline some avenues for further research.

2.2 Literature review

⁴ It is worth noting that this angle of defining hubs is different from that of the Federal Aviation Administration (FAA), who classifies hubs based on the share of the total number of US domestic airline passengers rather than an airport’s place in a carrier’s network.

2.2.1 Network structure in the business models of US carriers

Network structure is related to the business model adopted by US carriers and has dramatically shifted since the industry deregulation in 1978. Although devising carrier typologies becomes an increasingly difficult task, the literature generally distinguishes between two types of carriers: full-service carriers (FSCs) and low-cost carriers (LCCs).

FSCs are associated with a hub-and-spoke (HS) network structure, whereby a significant proportion of national and international flights is concentrated at their hubs (Button, 2002; O'Kelly, 1998). HS network structures allow airlines to exploit productive efficiencies from economies of traffic density (Nero, 1999). Associated with this type of network structure, FSCs run a complex business model by bundling a series of services. For instance, they develop sophisticated yield management techniques to utilize their fleet with multiple aircraft types. In addition, they offer in-flight entertainment, VIP waiting lounges, and other 'frill' services (Hazledine, 2011).

LCCs deploy a different network strategy from FSCs: point-to-point (PTP) network structures offering more direct flights (Gillen and Morrison, 2005). The PP organization has distinct productivity advantages, such as reduced transaction costs and travel time related to the absence of a transfer system (Taneja, 2004). LCCs also have a simpler business model in terms of the 'extra' services being offered beyond the mere connection. For instance, the US Department of Transportation definition of LCCs focuses on dimensions like (i) the presence of a single passenger cabin class, (ii) 'no frills' service, (iii) standardized aircraft utilization and other characteristics.

Although this distinction between FSCs and LCCs continues to stand as the foremost difference amongst carriers, the reality is far more complex. For LCCs with sound PP networks, it is possible to leverage their networks by providing connecting services between existing airports within their networks to enjoy economies of airport costs (such as Southwest's network strategy) (Boguslaski et al., 2004). This strategy is, however, markedly different from the FSCs' HS network, whereby network economies are realized by adding more new destinations to their hubs and profitability heavily depends on connecting traffic. Moreover, recently launched LCCs tend to organize HS networks (e.g., Air Tran at Atlanta, Frontier at Denver and JetBlue at John

F. Kennedy) (Reynolds-Feighan, 2001). It should be noted that their entry pattern (such as JetBlue) is still dominated by providing non-stop services, while opening new one-stop connections may be considered after non-stop entry (Müller et al., 2012). Meanwhile, FSCs have launched their own low-cost subsidiaries in response to the low-cost competition (e.g. Song by Delta) (Graham and Vowles, 2006).

2.2.2 The impact of network structure and market competition on the pricing behaviour of US carriers

Broad literature deals with the factors influencing airfares and yields. This paper focuses on studies that explicitly consider the role of network structure and competition. In the next section we will use this review to select variables in our analysis of the HH market.

The relationship between network structure and pricing originates from the dominance of carriers adopting a HS business model at their hubs. Pricing tends to be influenced by dominance for two reasons. First, the very presence of hubbing tends to reproduce its engendered monopolistic tendencies as it deters other carriers from entering (Goolsbee and Syverson, 2008; Oum and Tretheway, 1990). Second, and more implicitly, carriers may dominate airport facilities at hubs (e.g., slots and gates), thus providing a better level of service (Ciliberto and Williams, 2010; Williams and Snider, 2011). Based on these advantages, carriers adopting a HS network can charge higher fares on routes to/from their hubs (Borenstein, 1989; US Department of Transportation, 2001), especially on the routes connecting their hubs (henceforth termed ‘dominant routes’). Even though this so-called ‘hub premium’ has decreased over the last 10 years, some routes from/to hubs (e.g., those centred in Charlotte, Cincinnati, Minneapolis, and Memphis) are still characterized by significantly higher fares (Borenstein, 2005).

A carrier’s pricing strategy is, however, also strongly influenced by its competitors’ behaviour (Bresnahan and Reiss, 1991). This includes the routes between hubs of different carriers (henceforth termed ‘strategic routes’) characterized by either fierce competition to ‘steal’ passengers or the replication of hub premiums because of duopolies.

The dramatic growth of LCCs has been a principal driver for shifting airfares in the US airline industry. Research by Windle and Dresner (1995) and Dresner et al. (1996), for instance, has

shown that LCCs tend to lower airfares on the routes they enter. It is useful to distinguish between the influence of Southwest Airlines and other LCCs, as the former has had the most significant impact in this regard. Dresner et al. (1996) found that yield was reduced by approximately 53% when Southwest served a route, while a 38% yield reduction occurred when other LCCs were included in the model. Incumbent FSCs also continue to respond differently to the entry of Southwest compared to the entry of other LCCs. Daraban (2007) suggests that incumbents cut their fares twice as much when Southwest entered the market compared to other LCCs.

Addressing the relevance of a competitor's behaviour is, however, more intricate because of the presence of airports in close proximity to hubs. Airports are increasingly part of multi-airport systems (MAS) (de Neufville, 1995; Derudder et al., 2010), implying multiple gateways for accessing metropolitan areas. Recent research has shown that LCCs not only influence pricing and traffic patterns at the airports they serve, but also at the other airports in a MAS (Brueckner et al., 2013; Tierney and Kuby, 2008; Vowles, 2001). This competitive effect has, for instance, been observed after the entry of Southwest in the Baltimore-Midway route: the significantly lower price offered on this route connecting the Washington and Chicago metropolitan areas forced carriers operating on other routes between Washington and Chicago to reduce the fares to protect their market share, which Vowles (2001) has dubbed the "spatial Southwest effect." More recently, Brueckner et al. (2013) reappraised the impact of airline competition on domestic US airfares and confirmed that LCCs have dramatically reduced airfares whether they provide services in the airport-pair markets or at adjacent airports.

In addition to the potential effect of network and market-related processes, there are also a number of other variables that influence pricing. Operating costs related to the distance, the total demand, and market structure variables such as slot-control policies and the relative proportion of tourism-related travel are the most important examples here and will serve as control variables.

2.3 Methodology and data

2.3.1 The US hub-to-hub market

As the main function of a carrier's hub is to reroute passengers, our working definition of hubs in US domestic markets focuses on the relative volume of transfer passengers. In this paper, we adopt the classification of Lee and Luengo-Prado (2005), who define hubs as airports with more than 10% transfer passengers in a given carrier's network (see also Ivy, 1993). A further distinction is made between 'primary hubs' (>50%) and 'secondary hubs' (10%-50%). Table 2.1 presents an overview of the primary and secondary hubs in the US according to this classification. The table also lists 'competing' airports⁵ in the wider metropolitan area (MA), and thus provides the scope of our study as the HH market is taken to consist of all origin and destination (O&D) pairs where the airports are hubs (see Figure 2.1).

⁵ Competing airports are defined as airports located less than 75 miles away from the hub airports. Morrison Morrison, S.A., 2001. Actual, adjacent, and potential competition estimating the full effect of Southwest Airlines. *Journal of Transport Economics and Policy* 35, 239-256. found that a distance of 75 miles provided the best fit compared with distances of 25, 50, 100 and 125 miles.

Table 2.1 Categorization of hubs for US FSCs and their competing airports

Hub Airport	Carrier	Transfer Passengers (%, in 2000)	Competing Airport
<i>Primary Hubs</i>			
Dallas-Fort Worth (DFW)	American	59.2	Dallas Love (DAL)
Chicago O'Hare (ORD)	American	50	Chicago Midway (MDW)
Houston-George Bush (IAH)	Continental	56.4	Houston Hobby (HOU)
Cincinnati (CVG)	Delta	75.3	Dayton (DAY)
Atlanta (ATL)	Delta	64.7	
Salt-Lake City (SLC)	Delta	63.3	
Minneapolis-St. Paul (MSP)	Northwest	53.3	
Detroit (DTW)	Northwest	50.9	
Memphis (MEM)	Northwest	76.9	
Chicago O'Hare (ORD)	United	48.9	Chicago Midway (MDW)
Denver (DEN)	United	59	
Charlotte (CLT)	US Airways	78.4	
<i>Secondary hubs</i>			
Miami (MIA)	American	38.2	Fort Lauderdale (FLL), Palm Beach (PBI)
Newark (EWR)	Continental	13.1	John F. Kennedy (JFK), LaGuardia (LGA)
Cleveland (CLE)	Continental	38.5	Akron-Canton (CAK)
Washington Dulles (IAD)	United	37.6	Washington National (DCA), Baltimore-Washington (BWI)
San Francisco (SFO)	United	26.5	Oakland (OAK), San Jose (SJC)
Philadelphia (PHL)	US Airways	41.9	

Source: Lee and Luengo-Prado, 2005.

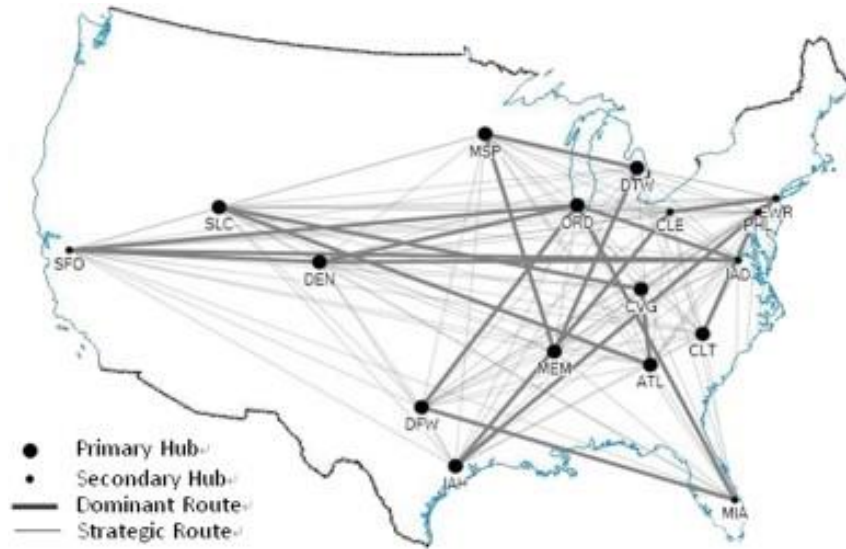


Figure 2.1 O&D routes connected by hubs of the six largest US FSCs

2.3.2 Data

The main dataset used in this paper was collected through a research cooperation with Sabre Airline Solutions, and contains information drawn from Airport Data Intelligence (ADI) on actual air travel bookings. In comparison with other commonly used datasets (e.g., DB1B data), the Sabre ADI has two major advantages when analyzing pricing and scheduling strategies in the airline industry. First, ADI datasets allow monitoring and tracking real-time fare information as passenger data is updated monthly and schedule data is renewed weekly. DB1B data, in contrast, combines quarterly fare information, and can therefore not be used by researchers to capture the rapid industry changes occurring within a three-month period. Second, the DB1B consists of a 10% sample of airline tickets. Even though a sampling of 10% is in principle quite large, it is possible that low-density routes are not sufficiently sampled (Grubestic, 2005). Datasets drawn from ADI paint a more complete picture by combining and calibrating data from 1) global distribution systems (GDS), 2) travel agencies, 3) airline direct bookings, low-cost carriers and charter operations and 4) other non-IATA distribution channels.

Sabre's ADI database provides the required data for the proposed pricing analysis, including information at the route and carrier levels on passenger numbers, revenue, and distance. It also indicates the intermediate stops when connecting services are available. As the focus is on US

domestic HH markets, the unit of observation is the O&D market connected by 17 hubs in the networks of US FSCs, as given in Figure 2.1. We do not consider the directionality of a market (i.e., Atlanta-Detroit is assumed to be the same as Detroit-Atlanta). The data used in this paper is for May 2009. There are 131 routes in total, on which about 2.2 million passengers were carried during this time period⁶.

2.3.3 Model specification

We devise an econometric model that tries to explain the variability of earnings on HH routes in US domestic air passenger markets. Earnings are measured through average one-way fares⁷, which serves as the dependent variable in our model. The independent variables in the model combine control variables, network structure indices, and market competition variables. The empirical pricing model for the HH network is specified as follows:

$$\begin{aligned} \text{AVGFARE} = & \alpha_0 + \alpha_1 \text{PASS} + \alpha_2 \text{DIST} + \alpha_3 \text{VACATION} + \alpha_4 \text{SLOTCONTROL} + \\ & \alpha_5 \text{DOMROUTE1} + \alpha_6 \text{DOMROUTE2} + \alpha_7 \text{DOMROUTE3} + \alpha_8 \text{STRROUTE1} + \\ & \alpha_9 \text{STRROUTE2} + \alpha_{10} \text{STRROUTE3} + \alpha_{11} \text{SOUTHWEST} + \alpha_{12} \text{WNMA} + \alpha_{13} \text{OTHERLCCS} \end{aligned} \quad (1)$$

Where:

α_0 is the intercept and α_i are the estimated coefficients for the independent variables;

AVGFARE is the average one-way fare charged by the six largest FSCs on a route;

PASS is the total number of passengers on a connection regardless of how it was realized (non-stop or with intermediate stops), and aggregated for both directions. We calculated the Pearson correlation coefficient to explore the potential relationship between PASS and AVGFARE. The result shows that PASS is negatively correlated with fares (correlation

⁶ In theory, the number of observations should be 136 (i.e., $n*(n-1)/2=17*(17-1)/2=136$, where n is the number of airports). However, five routes (i.e., CVG-CLE, CVG-DTW, CVG-MEM, CLE-DTW and EWR-PHL) were not served by any of the six FSCs in May, 2009, and are therefore excluded from the model.

⁷ For the case of a roundtrip ticket, the Sabre ADI treats inbound and outbound as two separate one-way observations.

coefficient $r = - 0.189$, $P < 0.05$): increasing passenger volumes lead to higher load factors (Devriendt et al., 2009) so that the per-passenger cost of the flight declines, thus lowering the price (Borenstein, 1989). However, above all, it can be hypothesized that bigger markets will be characterized by lower prices because of fierce competition. For instance, in addition to HS networks, almost all major US FSCs will offer LAX to JFK flights, which reflect the size of the market and the concomitant importance of being present in it. Given the correlation analysis and the ever-increasing levels of competition in the airline industry, the sign of PASS can be hypothesized as negative.

DIST is the non-stop distance (measured in miles) between two hubs. As distance increases, average fares can be expected to rise since carriers' operating costs with regard to fuel, in-flight service and wages will increase (Borenstein, 1989; Vowles, 2006; Windle and Dresner, 1995). Because it can readily be assumed that passengers are not willing to pay for longer routing because of intermediate stops, the model uses the non-stop distance of a route irrespective of the actual route segments (Chi and Koo, 2009). The expected sign for DISTANCE is positive.

The VACATION control variable determines whether or not the origin or destination of a HH route is a clear-cut holiday destination. Researchers have found that airfares to cities in Florida, Hawaii, Nevada and Puerto Rico are lower because those cities are likely to have high competition for holiday travellers (Borenstein, 1989; Chi and Koo, 2009; Dresner et al., 1996; Windle and Dresner, 1995, 1999). In our framework, Miami (MIA) is the only holiday destination. A negative relationship is expected between VACATION and airfares.

The SLOTCONTROL control variable determines whether the origin or destination of a HH route is a slot-controlled airport. Air carriers and other authorities impose regulatory limits on the number of takeoffs and landings each hour at the four highly congested airports (Chicago O'Hare, New York La Guardia, New York JF Kennedy and Washington National). The only slot controlled airport in our research is Chicago O'Hare (ORD), which is reported to be extremely congested, especially in the late afternoon and early evening (Johnson and Savage, 2006). The severe delays and the longer departure procedure at ORD may increase passengers' travel time and reduce the service level. This may decrease demand and lead to a decline in airfares (Chi and Koo, 2009). The expected sign of SLOTCONTROL is negative.

The three dominant route variables (i.e., DOMROUTE 1, DOMROUTE 2 and DOMROUTE 3) identify routes where both endpoints are hubs for the same carrier. The DOMROUTE 1 variable captures routes where both endpoints are the primary hubs of the same carrier (e.g., Atlanta (ATL) - Cincinnati (CVG) for Delta); the DOMROUTE 2 variable captures routes where one endpoint is the primary hub and the other is the secondary hub for the same carrier (e.g., Dallas-Fort Worth (DFW) – Miami (MIA) for American); and the DOMROUTE 3 variable describes routes whereby both endpoints are the secondary hubs for the same carrier (e.g., Newark (EWR) - Cleveland (CLE) for Continental). As the carrier is dominant at both airports, it can charge significantly higher prices on this route; the expected sign of these variables is therefore positive. However, the impact can be expected to lessen as we move from DOMROUTE 1 to DOMROUTE 3 because of the reduced dominance at the secondary hub.

The three strategic routes variables (i.e., STRROUTE 1, STRROUTE 2 and STRROUTE 3) identify routes where both endpoints are hubs for different carriers. The STRROUTE 1 variable captures routes whereby both endpoints are the primary hub for different carriers (e.g., Atlanta (ATL)-Charlotte (CLT), as ATL and CLT are the primary hub for Delta and US Airways); the STRROUTE 2 variable captures routes whereby one endpoint is the primary hub for a particular carrier and the other endpoint is the secondary hub for another carrier (e.g., Atlanta (ATL)-Philadelphia (PHL) because ATL is a primary hub for Delta and PHL is a secondary hub for US Airways); and the STRROUTE 3 variable identifies routes where both endpoints are the secondary hubs for different carriers (e.g., Miami (MIA)-Newark (EWR), as MIA is a secondary hub for American and EWR is a secondary hub for Continental). The expected sign and strength of such routes on pricing is harder to predict than for routes between hubs for the same carrier. These routes may have lower average fares because of fierce competition to ‘steal’ passengers, but nonetheless maintain higher fares because the monopoly of the previous set of HH routes is merely replaced by a duopoly. For instance, the Miami (MIA)-Philadelphia (PHL) market is dominated by American and US Airways with nearly equal market shares (48.6% for American and 46.7% for US Airways), and pricing strategies may go both ways (and also be contingent on other factors).

The SOUTHWEST variable measures the effect of the presence of Southwest when it is directly present in a market. The expected sign is negative.

The WNMA variable (WN is the IATA code for Southwest) measures the effect of the presence of Southwest in competing markets. For instance, the Oakland (OAK)-Cleveland (CLE) route would be a competitor to the San Francisco (SAN)-Cleveland (CLE) route, since OAK is within the San Francisco MA. The expected sign is negative.

OTHERLCCS is a variable examining the impact of the direct presence of low-cost carriers other than Southwest on a HH route. Low-cost carriers are taken to be present in a market when they collectively have a market share that is larger than 1% of passengers in a market (Ito and Lee, 2003; Lee and Luengo-Prado, 2005; Windle and Dresner, 1995). The other low-cost carriers included in this paper are Air Tran, Frontier, Jet Blue, Virgin America and Sun Country. The expected sign is negative.

2.4 Result and discussion

Summary statistics for the variables used in the model are presented in table 2.2. Both dependent and independent variables (i.e., AVGFARE, PASS and DIST) are transformed into natural logarithmic form to facilitate the interpretation of the coefficients as elasticities. We also perform two diagnostic tests for heteroscedasticity and endogeneity to produce a robust and unbiased model. First, the White test is applied to check for heteroscedasticity in the model (White, 1980). The result shows that the null hypothesis of homoscedasticity cannot be rejected at the 5% significance level. Second, we conduct the Durbin-Wu-Hausman test to detect possible endogeneity of explanatory variables (PASS in particular may potentially be endogenous) (Hausman, 1978). The result shows that the null hypothesis of exogeneity cannot be rejected at the 5% significance level for PASS.

Table 2.2 Descriptive statistics of variables for the overall markets (monthly data)

	Mean	Std.	Min	Max
AVGFARE (\$)	186.02	51.46	80.64	354.25
PASS	16933.97	15793.95	252.14	80821.64
DISTANCES (miles)	1001.52	562.64	212.72	2591.52
VACATION	0.12	0.33	0	1
SLOTCONTROL	0.12	0.33	0	1
DOMROUTE1	0.06	0.24	0	1
DOMROUTE2	0.07	0.26	0	1
DOMROUTE3	0.02	0.12	0	1
STRROUTE1	0.35	0.48	0	1
STRROUTE2	0.42	0.50	0	1
STRROUTE3	0.08	0.28	0	1
SOUTHWEST	0.03	0.17	0	1
WNMA	0.29	0.46	0	1
OTHERLCCs	0.11	0.31	0	1

Table 2.3 summarizes the key statistics for the overall model applying the Ordinary Least Squares (OLS) regression, whereby 10 out of 12 independent variables are found to be statistically significant at the 10% level, collectively explaining about 70% of the variation in the pricing in the US HH market.

Table 2.3 Overall model

	Unstandardized Coefficients B	Standardized Coefficients Beta
(Constant)	3.869*** (0.197)	
LnPASS	-0.042*** (0.016)	-0.179
LnDISTANCE	0.255*** (0.027)	0.544
VACATION	-0.318*** (0.047)	-0.379
SLOTCONTROL	-0.162*** (0.053)	-0.193
DOMROUTE1	0.367*** (0.064)	0.320
DOMROUTE2	0.328*** (0.063)	0.302
DOMROUTE3	0.474*** (0.118)	0.212
STRROUTE2 ⁸	0.039 (0.035)	0.069
STRROUTE3	0.211*** (0.062)	0.213
SOUTHWEST	-0.402*** (0.085)	-0.252
WNMA	-0.062* (0.035)	-0.103
OTHERLCCs	-0.081 (0.053)	-0.092
R Square	0.694	

Note: Standard errors are reported in the parentheses. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Control variables

The coefficient for PASS is negative: as the number of total passengers in the US HH markets increases by 1%, prices are predicted to fall by 0.04%⁹. The impact of distance, in turn, is indeed positive, and indicates that 1% increase of the distance results in an average increase in fares of 0.25%. And finally, the coefficients for VACATION and SLOTCONTROL are, as anticipated, negative: HH routes involving Miami and Chicago O’Hare imply smaller ‘hub premiums’.

Hub hierarchy

Routes where both nodes are hubs for the same carrier do indeed result in significantly higher fares¹⁰. However, our results show that this effect is uneven in the sense that hub *hierarchies*

⁸ STRROUTE1 is excluded from the model due to its high collinearity with STRROUTE2.

⁹ When both independent and dependent variables are natural logarithmic transformed, back-transformation is compulsory to accurately interpret the results. The equation is $((1 + 1\%)^\beta - 1) * 100\%$. For all the dummy variables, the equation applied to interpret the results is $(e^\beta - 1) * 100\%$.

¹⁰ We performed a separate regression model excluding the variable PASS and found that the regression results as a whole did not change.

also play a significant role: the standardized beta coefficients¹¹ reveal that DOMROUTE1 has a bigger impact than DOMROUTE2, which in turn has a bigger impact than DOMROUTE3. Fares on routes between a carrier's primary hubs are on average 44% higher than general fares, while these for primary-secondary routes are raised by 39%. Although the standardized beta coefficient is lower on secondary-secondary routes, the price increase is bigger (61% for DOMROUTE3). This can be explained by the specific nature of the two secondary-secondary routes in our dataset; i.e., Cleveland (CLE)-Newark (EWR) for Continental and Washington Dulles (IAD)-San Francisco (SFO) for United. In May 2009, Continental carried about 96.6% of the passengers (as measured in our Sabre Database) in the CLE-EWR market, while United had the largest market share with 62.8% in the IAD-SFO market. Both examples are therefore specific in the sense that, although connecting secondary hubs, the routes are de facto monopolies, hence the disproportionately inflated fares.

Market competition

Routes between hubs for different carriers do not result in higher fares, except for an average increase of 23% on secondary-secondary routes.

Southwest drives down prices in the US HH markets: its direct presence cuts prices by 49% (all other things being equal) and its presence in the competing markets reduces prices by 6%. It is worth noting that the other LCCs have no significant impact on prices in the overall markets, which corroborates Daraban's (2007) research on the particular effect of Southwest.

2.5 Conclusion

This paper explored the factors influencing the pricing strategies of US full-service carriers in specific hub-to-hub markets. The results confirm Vowles' (2006) observations regarding higher airfares in these markets, but also extend his findings by showing that hub hierarchies play a role. As hypothesized, the monopolistic effects on airfares diminish as the hubs become less crucial in a carrier's network. Meanwhile, duopolies in routes connecting the hubs of different carriers have no or limited effects on airfares. This indicates that the variant ability of

¹¹ Standardized coefficients are applied to estimate which of the independent variables has a greater effect on the dependent variable when the variables are measured in different units of measurement.

FSCs' hubs to reroute passengers leads to inter-HH route heterogeneity, which further drives the pricing variation in HH markets. We suggest that inter-HH route heterogeneity should also be incorporated when studying the 'hub premium' issue. Our model controls for other crucial pricing factors, such as the competition from low-cost carriers and market structure, and thereby corroborates earlier research regarding the differential impact of Southwest viz. other low-cost carriers.

The air transport world is, of course, in constant flux, and future research should thus assess the impact of these changes on our observations. In the US, for instance, further rounds of consolidation (e.g., the Northwest/Delta merger) and rapidly unfolding new trends (e.g., the increased impact of self-hubbing) could well alter the profoundness of the patterns revealed here. In addition, given the unfolding integration and concomitant consolidation of other markets (the European Union, and increasingly the ASEAN region), the time seems ripe for analyses of the pricing effects of emerging hub-to-hub markets in these regions as well.

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3 THE DETERMINANTS OF FULL-SERVICE CARRIERS AIRFARES IN EUROPEAN HUB-TO-HUB MARKETS

Zhang, S., Derudder, B., & Witlox, F., 2014. The determinants of full-service carriers airfares in European hub-to-hub markets. *European Journal of Transport and Infrastructure Research*, 14(4), 449-467.

Abstract

This paper explores the factors influencing the pricing behaviour of full-service carriers in European hub-to-hub markets. Drawing on a 2009 dataset containing route and airfare information, we establish an econometric model to estimate the impact of route structure, alliances, and market concentration on the pricing of European full-service carriers in these markets. The results suggest that alliances on routes connecting two primary hubs, airport concentration, market share inequality and competition from low-cost carriers influence average airfares of full-service carriers in the European hub-to-hub markets.

3.1 Introduction

Air transport deregulation in Europe has led to dramatic changes in the network configuration and business models of erstwhile national carriers. First, they have implemented or intensified the adoption of hub-and-spoke networks by concentrating traffic and flights around their hubs to accomplish network economies (Burghouwt and de Wit, 2005; Button, 2002; Caves et al., 1984; Janic and Reggiani, 2002). Second, sophisticated revenue management techniques have replaced the traditional regulated pricing mechanisms. Offering more differentiated products - such as in-flight entertainment, VIP waiting lounges, and other 'frills' - has gradually transformed national carriers into so-called 'full-service carriers' (FSCs) (Tretheway, 2011). Third, the industry has been consolidated via cross-border mergers to address the excess capacity caused by establishing too many airlines in the outdated flag-carrier system (Brueckner and Pels, 2005), as well as through establishing global alliances (Benacchio, 2008; Doganis, 1994). In addition, the emergence of low-cost carriers (LCCs) has been a competitive challenge for FSCs due to the former carriers' well-known cost advantages (Alderighi et al., 2012). These changes force FSCs in Europe to constantly (re)examine their pricing strategies in order to achieve profitability in what have become (relatively more) liberalized markets.

The literature examining the pricing strategies of FSCs in Europe is not as extensive as the one focused on the aviation market in the United States. Some of the exceptions include research on 1) flights from Nice Airport (France) to 9 European countries (Giaume and Guillou, 2004), 2) domestic routes and airport-pairs between the United Kingdom and 14 European countries (Piga and Bachis, 2007), and 3) city-pairs between Italy and the main destinations in the UK, Germany and the Netherlands (Alderighi et al., 2012). As a consequence, to the best of our knowledge there has been no research exclusively devoted to how carriers determine airfares in the emerging European hub-to-hub (HH) markets, where both origin and destination are to some degree dominated by a FSC.

An analysis of pricing in European HH markets is relevant for three reasons. First, hubs are typically located in Metropolitan Regions characterized by large populations, major levels of economic development, and an economic structure that is conducive to business travel (Dijkstra, 2009). Carriers operating HH routes can therefore not only expect to realize economies of density, but also capture more high-yield business travellers (Neal, 2011). Second, hubs assume different service levels in individual FSCs' networks, i.e. the so-called 'hub hierarchy' that is also emerging in the US (Burghouwt and de Wit, 2005; Burghouwt and

Hakfoort, 2001; Dennis, 2005; Derudder and Witlox, 2009; Frenken et al., 2004; Malighetti et al., 2009; Thompson, 2002). Burghouwt (2007), for instance, clusters airports into 1st tier, 2nd tier and 3rd tier hubs based on the number of weighted indirect connections in a carrier's network, while Malighetti et al. (2009) distinguish between 'worldwide hubs', 'hubs' and 'secondary gates' based on traffic volume, destination of connections, connectivity and topology of service. The ensuing 'hub hierarchy' implies that the routes connecting different levels of hubs may vary in their pricing: routes involving more dominant hubs can in principle be related with higher airfares because of 'hub premiums' (Vowles, 2006; Zhang et al., 2013).

Third, strategic alliances have complicated the route structure of HH networks. European FSCs have over time joined one of the three global alliances, thus leading to the development of explicit and implicit multi-hub-and-spoke networks: carriers extend their reach by interlinking each other's networks (often via their hubs), so that the scope of their network grows without having to internally extend their own networks. Alliance carriers can, as a consequence, increase frequencies on their nonstop HH routes to facilitate customers, especially time-sensitive business travellers. Doganis (2006), for instance, found that the Lufthansa-SAS alliance increased daily departures between Frankfurt and Copenhagen for both carriers. As a consequence, carriers that do not ally on HH routes may lose competitive advantages comparing to allied carriers, so that the resulting market concentration can be expected to play an important role in explaining price discrimination (Borenstein, 1989; Piga and Bachis, 2007).

The emerging 'hub hierarchy', the growing importance of alliances and their combined impact (i.e., a route connected by two hubs with different levels of hubness may also be an allied route) gives rise to an inherently complex European HH network. This raises questions on the major factors influencing the pricing strategies of FSCs serving the hub markets. The objective of this paper, therefore, is to investigate to what extent the emerging hub hierarchy, strategic alliances and the ensuing landscapes of market concentration influence the price-setting of FSCs in the European HH markets. The remainder of this paper is organized as follows. Section 3.2 reviews previous studies on how alliances and market structure determine airfares and yield in the US and European airline industry. Section 3.3 defines the European HH network, and introduces our data and methods. Section 3.4 presents an analysis of the complex market structure of the European HH markets, and examines how route structure, alliances and market concentration influence the pricing strategies of FSCs. In section 3.5, we summarize the main implications of our analysis and outline some avenues for further research.

3.2 Literature Review

3.2.1 Hub dominance and airfares in HH markets

Hub-and-spoke networks are associated with the dominance of a hub airport by one or, occasionally, two carriers (Borenstein, 1992). If a carrier provides a large number of competitive indirect connections (Burghouwt and de Wit, 2005) or connects large volumes of transfer passengers (Lee and Luengo-Prado, 2005), then this carrier is said to ‘dominate’ its hub airport. The debate about the relationship between hub dominance and airfares rests on the question whether carriers can wield market power by charging higher airfares on routes from/to their hubs than on other routes. There is no consensus as to whether a carrier’s pricing power at its hub airport can be conveyed to all routes involving the dominant airport, so that this relationship is discussed at both the airport and the route level to obtain unbiased estimations.

In US airline markets, researchers had found that the market power exercised by carriers has not been undermined since deregulation. Borenstein (1989) found that a carrier dominating at both the airport and the route level has the ability to charge higher fares, whereby the sources of this market power originate from 1) the dominant carriers’ ability to deter the entry of potential competitors by controlling airport facilities, as well as 2) the marketing devices such as frequent flyer programs (FFP). However, Evans and Kessides (1993) found that dominance at the airport level, but not the route level, can confer substantial market power upon the carrier when unexplained inter-route heterogeneity is considered. Aircraft can be switched relatively easily and costlessly between different routes making these routes naturally contestable, whereas airport facilities, product differentiation barriers arising from FFPs and other impediments make these harder to contest. More recently, researchers have offered new evidence for US markets and found that a carrier dominating at the route level can also charge higher fares (Fischer and Kamerschen, 2003; Stavins, 2001).

Marín (1995) was the first to address the issue in the European context and found that, in contrast to the US situation, European carriers tended to compete in terms of prices by exploiting cost advantages after liberalization. Captain and Sickles (1997) further found that the reasons why some ‘flag carriers’ cannot exploit such cost advantages is due to technically inefficient use of inputs and high labour wages rather than wielding market power between 1976 and 1990. However, it is clear that these studies deal with the earlier stages of European aviation deregulation. As the European aviation sector has gone through dramatic changes in

the last decades, the impact of market dominance on airfares has also been altered by factors such as the proliferation of low-cost carriers (LCCs). Piga and Bachis (2007) concluded that the impact of market dominance on fares in European airline market depends on the type of carriers (i.e. FSCs versus LCCs). FSCs' dominance at an airport plays a crucial role only for the fares associated with a particular set of booking days, i.e. the late booking dates, whereas LCCs' dominance at an airport is highly correlated with fares on any booking day before departure due to their ability to operate at lower costs. Dominance at the route level enables FSCs to exercise market power, but limits LCCs' ability to charge higher fares only for late booking fares. They also argue that the limited size of many 'natural monopoly' routes contribute to the route dominance enjoyed by European carriers.

3.2.2 Alliances and airfares in HH markets

An alliance can increase the market share and market power of alliance carriers at their hubs, and reduce or eliminate competition on specific routes. However, when alliances or mergers significantly reduce competition in the relevant markets, the European Commission has imposed conditions such as giving up airport slots or route licenses to encourage the entry of new carriers (Doganis, 2006). The vast majority of dense intra-European routes are short-haul routes with less than two-and-a-half hours of flying time, implying that alternatives via transfer routes are not very attractive. Joining in an alliance can therefore very effectively reduce competition on those routes by turning the previous duopoly into a de facto monopoly (Doganis, 2006). However, the degree to which alliance partners (ab)use their strengthened dominance to charge higher fares on their hub-to-hub routes remains unclear. Oum et al. (2000) study 22 international airlines for the 1986-95 period and find that partner airlines lowered prices by 1.3% after entering an alliance, and ascribe this result to the reduced cost because of efficiency or productivity gains. They particularly find that an airline with a longer average route length charged lower prices than that with a short average route length due to the competitive advantage of longer routes (e.g., reduced fuel consumption). At the same time, researchers have found that fares in markets served by an alliance were higher than those in non-alliance markets because of reduced competition, as in the SAS-Swissair alliance (Youssef and Hansen, 1994) and the Air France-KLM merger (Brueckner and Pels, 2005). Meanwhile, Wan et al. (2009) investigate the impact of airline alliances on airfares on transatlantic HH routes, and come to the conclusion that the net effect on airfares is uncertain as it depends on the ability of an alliance to coordinate fares.

3.2.3 Market concentration and airfares in HH markets

A carrier's pricing strategy is driven not only by the internal carrier-specific considerations but also by the structure of external markets. As a market (i.e., individual airport-pair market) is comprised of carriers, passengers, air travel products, and competing mass travel modes such as railway links, the external market structure in which the carriers are operating depends upon four aspects: 1) the number of carriers and passengers, 2) ease of market entry, adaptation, and exit, 3) the extent of product differentiation or distinctiveness, and 4) the availability and cost of information (Holloway, 2008).

The structure of the European airline markets can in practice be mainly categorized through three types, based on the number of carriers: monopoly (i.e., one carrier), duopoly (i.e., two carriers) and oligopoly (i.e., more than two carriers) (Alderighi et al., 2012). However, the number of carriers per se on a route is not the best measure of market structure and the competitive behaviour of carriers as it does not evaluate concentration (i.e., the market share distribution of carriers) (Giaume and Guillou, 2004; Shepherd, 1999). The concept of concentration has been extensively applied to represent market structure in research focused on the relationship between market structure and pricing. Aiming to reflect the entire market share distribution of carriers in a single indicator, researchers frequently use the Herfindahl-Hirschman Index (HHI) to quantify market concentration (Hannan, 1997).

The impact of route HHI on prices can be mixed and depends on the geographical areas. In the US airline markets, researchers have found that increases in route HHI raise prices to some degree as a few carriers in a concentrated market may collude more easily to charge higher prices (Borenstein, 1989; Chi and Koo, 2009; Evans and Kessides, 1993). However, a negative relationship between route HHI and prices also occurs when the dominant carrier enjoys technological advantages over its rivals and forces the other carriers to reduce prices to compete (Fischer and Kamerschen, 2003). In the European airline markets, Piga and Bachis (2007) found that prices were raised by FSCs and LCCs as route HHI increased, but only for the prices associated with late booking days. Giaume and Guillou (2004) observed a negative relationship between route HHI and prices in the European markets and attributed it to the high inequality of market share leading to strong price competition between carriers.

These findings suggest that the impact of changing market structure on fares for European markets will probably not be a copy of the US case, which calls for a systematic appraisal of its

role in European aviation markets. Moreover, we also consider the impact of LCCs' presence at secondary airports and high-speed train (HST) competition on airfares, which to date are rarely incorporated in a pricing model related to European market.

3.3 Data collection and descriptive analysis

3.3.1 Data collection procedure

A first step is to define the geographical scope of our research. As there are no generally recognized boundaries of 'Europe', the scope of this study is confined to those Western/Central parts of Europe where the air transport industry is relatively more liberalized and developed. This paper considers the following countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The second step is to define European FSCs and their established hubs as well as secondary airports close to these hubs. Researchers have long defined all 'flag carriers'¹² of the countries listed above as FSCs in Europe (Alderighi et al., 2012; Burghouwt et al., 2003). However, on-going deregulation has broadened the differences amongst these erstwhile flag carriers, as can be seen in the cases of Aer Lingus's (i.e., Ireland's flag carrier) transformation into a LCC (Barrett, 2006; O'Connell and Williams, 2005; Wallace et al., 2006) and the demise of Sabena (i.e., Belgium's former flag carrier) in 2001. Moreover, some flag carriers, such as Icelandair, Luxair and Olympic Airlines, did not join one of the major airline alliances. As per our research objective, FSCs are defined as the current flag carriers of countries locating in Western and Central Europe which run a complex business model by bundling a series of services, and have also joined one of the three global alliances (i.e., Star, Oneworld and SkyTeam) at the time of our research (column 2, table 3.1). Next, we identify these FSCs' hubs, thus establishing the hub-to-hub network in Europe. As the main purpose of a FSC's hub is to concentrate flights through synchronized waves and reroute passengers, our working definition of hubs in the European airline market focuses on the number of competitive indirect connections as presented

¹² A flag carrier (also known as national carrier) is one that is substantially owned and effectively controlled by nationals of that state in the EU (Doganis, 2001; Barrett, 2006). However, waves of deregulation and privatization have changed the ownership of some flag carriers whereby they have become partially or even fully owned by the private sector. However, most of them are still considered to be flag carriers today as they are often interpreted as a sign of their home country's international presence (Smith, 1991).

by Burghouwt (2007). In his work, hubs are defined as airports with more than 200 indirect connections per day¹³ and served by FSCs. A classification scheme based on the number of indirect connections is then applied to distinguish between ‘primary hubs’ (>2500) and ‘secondary hubs’ (200-2500). Table 3.1 presents an overview of the European FSCs’ hubs and their adjacent secondary airports¹⁴. This provides the scope of our study as the HH market is taken to consist of all connections where both origin and destination are hubs (see Figure 3.1). As a result of the presence of this ‘hub hierarchy’, European HH network consists of three different types of routes, i.e., primary-primary (PP), primary-secondary (PS), and secondary-secondary (SS) routes.

¹³ Burghouwt (2007) considered all the airports having indirect connections in an FSC’s network as hubs or primary nodes. However, we set a minimum threshold as 200 indirect connections per day as this tends to select more important hubs through which airlines strive to establish a wave-system structure.

¹⁴ Secondary airports are defined as airports located less than 75 miles away from the hubs.

Table 3.1 Categorization of hubs for European FSCs and list of secondary airports

Hub Airport	Carrier	Number of weighted indirect connections per day (2003 ¹⁵)	Competing Airport
Primary (8)			
Charles de Gaulle (CDG)	Air France	14005	Beauvais (BVA)
Frankfurt (FRA)	Lufthansa	13616	Frankfurt Hahn (HHN)
London Heathrow (LHR)	British Airways	9439	London Luton (LTN), London Stansted (STN)
Amsterdam (AMS)	KLM	8713	Rotterdam (RTM)
Madrid (MAD)	Iberia	6941	
Munich (MUC)	Lufthansa	4184	
Copenhagen (CPH)	SAS Scandinavian	2576	Malmo (MMX)
Vienna (VIE)	Austrian	2553	
Secondary (10)			
Rome Fiumicino (FCO)	Alitalia	2384	Ciampino (CIA)
Barcelona (BCN)	Iberia	2128	Girona (GRO)
Milan Malpensa (MXP)	Alitalia	1946	Linate (LIN), Bergamo (BGY)
Oslo (OSL)	SAS Scandinavian	1139	Torp (TRF)
London Gatwick (LGW)	British Airways	979	London Luton (LTN), London Stansted (STN)
Helsinki (HEL)	Finnair	957	
Lisbon (LIS)	TAP Air Portugal	792	
Paris Orly (ORY)	Air France	709	Beauvais (BVA)
Brussels (BRU)	Brussels ¹⁶	452	Charleroi (CRL)
Dusseldorf (DUS)	Lufthansa	214	Kolon/Bonn (CGN)

Source: Burghouwt (2007)

¹⁵ Burghouwt (2007)'s work to the best of our knowledge is the most detailed source on the hub-and-spoke practices of FSCs in Europe. Even though this classification was developed using pre-2005 data, it is still a valuable source because FSCs and their hubs tend to have longstanding, symbiotic relationships. Only in the cases of bankruptcy or the very drastic decision to fundamentally restructure their network, it would be possible for an FSC to either abandon a hub (Redondi et al., 2012) or establish a new one (Düdden, 2006). For the sake of data consistency, we investigated the network evolution of route maps of FSCs, and found that Alitalia was the only example here through its partially abandoning of Milan Malpensa (MXP) in 2008. However, excluding MXP from our dataset did not alter the results of our improved model. Taken together, then, Burghouwt's classification is still relevant for our research, in spite of it predating our own analytical framework.

¹⁶ Brussels Airlines is the new flag carrier of Belgium. It started operations in 2007 after the merger between SN Brussels Airlines (i.e., the former national carrier of Belgium, inherited from Sabena) and Virgin Express.

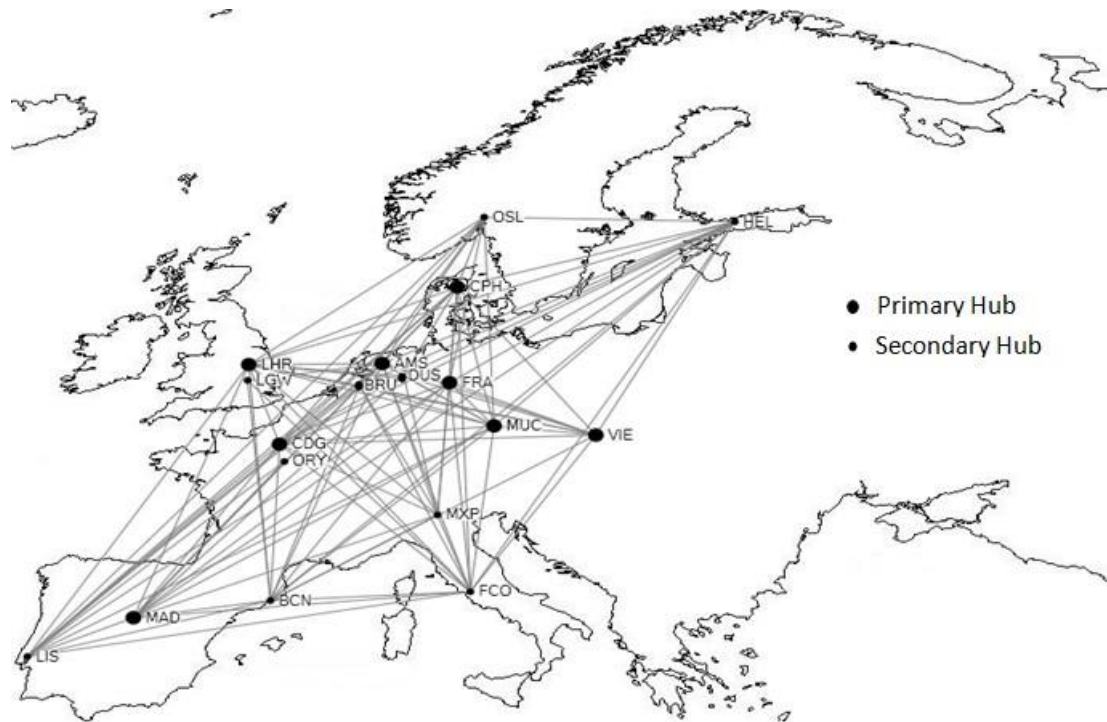


Figure 3.1 Non-stop connections between hubs of the European FSCs

We also identified types of carriers other than FSCs (e.g., LCCs and regional carriers) to examine the overall market structure. As not all the carriers registered in Europe can readily enter the European HH markets due to high entry barriers, we collected a list of carriers that actually served the HH markets (i.e., with a market share larger than 1%) in May 2009 from our database (see below). By comparing the combined lists of LCCs recently developed by Dobruszkes (2009) and Klophaus et al. (2012), we establish a list of LCCs for this study. All the other carriers are then defined as regional carriers (RECs)¹⁷. The overview of carriers is represented in table 3.2.

¹⁷ Even though some RECs are partial- or fully-owned subsidiaries of FSCs, we treat them separately as 1) their combined market shares would cause severe anti-competition issues due to monopolistic or duopolistic tendencies; 2) the integration may mask the roles played by RECs in reducing prices on routes with fierce competition from LCCs or those with unanticipated schedule disruptions (Forbes and Lederman, 2007).

Table 3.2 Overview of carriers and alliance for FSCs

Carrier Type	Carrier Name
FSCs	Air France (SkyTeam), Alitalia (SkyTeam), Austrian (Star), British Airways (OneWorld), Brussels (Star), Finnair (OneWorld), Iberia (OneWorld), KLM (SkyTeam), Lufthansa (Star), SAS Scandinavian (Star), TAP Air Portugal (Star)
LCCs	Aer Lingus, Air Europa Lineas Aereas, Air Berlin, EasyJet, Germanwings, Niki, Norwegian Air Shuttle, Spanair, Transavia.com, Vueling, Ryanair, Wind Jet
RECs	Adria Airways, Aigle Azur, Air Comet, Air Dolomiti, Blue1, BMI british midland, Brit Air, Cimber Sterling, Eurowings, Lufthansa Cityline, Regional, SAS Norge, Tyrolean Airways

Note: Alliance membership for FSCs is shown between parentheses.

The main dataset used in this paper is collected through a research cooperation with Sabre Airline Solutions, and contains information drawn from Airport Data Intelligence (ADI) on actual bookings for different carriers. The Sabre ADI has at least one major advantage when analysing pricing and scheduling in the airline industry: it seeks to establish a complete dataset by adjusting and calibrating data from 1) global distribution systems (GDS), 2) travel agencies, 3) direct bookings, low-cost carriers, charter operations and 4) other non-IATA distribution channels. Sabre’s ADI database provides the required data for the proposed pricing analysis, including information at the route and carrier level of passenger numbers, revenue, cabin class and distance. It also indicates the intermediate stops when connecting services are available. The units of observation in our analysis are the non-stop connections between the 18 hubs in the overall network ‘produced’ by the 11 European FSCs given in Figure 3.1. An observed route is selected only if its monthly traffic volume is at least 100 passengers, and a carrier is considered to serve the route only if its market share is at least 1%. The data used in this paper is for May 2009. In addition, the population of the hub cities is obtained from www.World-Gazetteer.com. The data related to the presence of LCCs on competing routes whereby either endpoints are connected by secondary airports are collected from www.skyscanner.net¹⁸. Finally, HST data are collected from the official website of HST companies in Europe, such as TGV, ICE, Eurostar and other companies.

¹⁸ This data were not available for the year 2009 in our Sabre dataset. Skyscanner providing information about routes and carriers allows us to control for the impact of LCCs competition at secondary airports, even though the online data are about scheduled flights in 2014. Competing routes are assumed to be actually served by LCCs only if nonstop return services are provided every week in May, 2014. The website was accessed on 4th April, 2014.

3.3.2 Exploratory analysis of market structure

Market concentration depends on the actual structure of individual hub airport-pair markets. Given the complex nature of market structure in the EU (partly because of the shorter distances between hubs and the alliance formation), we first perform a descriptive analysis of market structure before proceeding to the econometric analysis.

Market structure by route type

As competition has not been homogeneous at the route level in Europe (Giaume and Guillou, 2004), it is necessary to analyze the market structure for each HH route separately. Table 3.3 shows that European HH markets exhibit three types of market structure in terms of the number and type of carriers: monopoly (10% of routes), duopoly (49% of routes) and oligopoly (42% of routes)¹⁹. Previous research carried out by Alderighi et al. (2012) has shown that the entry of LCCs has increased the competition of the European aviation market. They particularly distinguish between symmetric duopoly (two FSCs) and asymmetric duopoly (one FSC and one LCC), and also between oligopolistic routes with or without the presence of LCCs. Drawing on their categorization method, we find that 11 duopolistic routes and 28 oligopolistic routes have been entered by LCCs. These fundamental statistics indicate that European HH markets are 1) served by few carriers and characterized by high concentration, and 2) penetrated by LCCs.

Table 3.3 An overview of market structure by route structure

	Monopolistic routes	Duopolistic routes			Oligopolistic routes				Total
		FSC	FSC&LCC	FSC&REC	FSC	FSC&LCC	FSC&REC	FSC&LCC&REC	
PP	2	11	0	2	1	2	4	4	26
PS	5	13	8	7	1	9	6	6	55
SS	3	2	3	3	1	6	1	1	20
Total	10	26	11	12	3	17	11	11	101

The presence of LCCs and RECs indicates the possible inequality of market shares among carriers. Route concentration measured by a regular HHI (i.e., the sum of squared market

¹⁹ For instance, Barcelona-Frankfurt is a monopolistic route as Lufthansa is the only carrier serving this route at the time of data collection. Amsterdam-Charles de Gaulle is a duopolistic routes served by two carriers – Air France and KLM. The oligopoly markets have three or more carriers in services. Note that from an alliance perspective the CDG-AMS link will be monopolistic.

shares) may, therefore, be inadequate to represent concentration, as it does not separate the effects of the number of carriers and share inequality²⁰. We thus use the decomposed HHI to measure the market concentration when both asymmetries of market shares and the number of competitors on a route should be accounted for. The decomposed HHI index is measured as:

$$\text{Decomposed HHI} = H1 + H2 = CV^2/N + 1/N \quad (1)$$

Where CV is the coefficient of variation of market shares, and N is the number of carriers on a route. The first part of this equation ($H1$) is of particular importance as it represents the market share inequality of carriers on a route, while the second part ($H2$) describes the value of HHI when all the carriers have equal market share (Laderman, 1995).

The impact of alliances on airfares

Alliances allow FSCs to form multi-hub-and-spoke networks and cooperate with carriers in the same alliance. 34 out of 101 routes in our study are connected by the same alliance's hubs in our study (table 3.4). We categorize six types of routes by considering both the degree of hubness and alliances: PP*Alliance (e.g., FRA-CPH), PP*NonAlliance (e.g., FRA-CDG), PS*Alliance (e.g., FRA-OLS), PS*NonAlliance (e.g., FRA-FCO), SS*Alliance (e.g., OLS-LIS) and SS*NonAlliance (e.g., FCO-OLS). For instance, as Lufthansa, SAS Scandinavian, Brussels and TAP Air Portugal all belong to the Star alliance, FRA-CPH is thus a PP*Alliance route whereby FRA and CPH are the primary hubs of Lufthansa and SAS Scandinavian, respectively. The same approach was applied to the other route types. Based on the disaggregated market share of the carriers in the same alliance, five allied routes are monopolistic and 21 are duopolistic. When the market shares of the alliance carriers are aggregated, about 90% of alliance routes are monopolistic or duopolistic.

²⁰ Our econometric analysis also proves that the regular HHI index does not have significant impact on fares. In addition, the different effects of number of carriers and market share inequality on fares also indicate that the decomposed HHI is more appropriate to represent market concentration in this study.

Table 3.4 The effects of alliances on market structure by route type

	Monopolistic routes	Duopolistic routes	Oligopolistic routes	Total
Before alliance				
PP*Alliance	2	4	2	8
PS*Alliance	2	13	5	20
SS*Alliance	1	4	1	6
Total	5	21	8	34
After alliance				
PP*Alliance	6	2	0	8
PS*Alliance	9	9	2	20
SS*Alliance	3	2	1	6
Total	18	13	3	34

We also carried out an exploratory analysis to examine whether allied carriers exercise pricing power when their joint market share increases. Table 3.5 shows that the alliance carriers charge significant higher fares only on PP routes, but not on the other types of routes. There are two possible reasons. First, the raised market concentration on the other types of routes is offset by the economies of density, resulting in statistically insignificant impact on airfares. Second, allied carriers coordinate their pricing decisions on the main PP routes, implying that they primarily wield market power on PP routes.

Table 3.5 The t-test results for average fares by route type

Average fares	N	Mean \$	Std.dev.	Std.err.	t-value
PP route					
Same-alliance routes	8	188.75	25.16	8.89	3.964
Different-alliance routes	18	151.02	21.16	4.99	(0.001)
Difference		37.73		9.52	
PS route					
Same-alliance routes	20	170.70	58.33	13.04	1.22
Different-alliance routes	35	153.49	45.09	7.62	(0.227)
Difference		17.21		14.08	
SS route					
Same-alliance route	6	134.73	46.14	18.84	-0.737
Different-alliance routes	14	158.46	72.15	19.28	(0.471)
Difference		-23.73		32.19	

Note: H_0 : mean (diff) = 0; H_a : mean (diff) > 0; the significance level is shown between parentheses.

The results in table 3.5 suggest that market concentration influences airfares, but previous research has shown that without taking mediating demand and cost variables into account such simple comparative approach can be misleading (Borenstein, 1989; Lee and Luengo-Prado, 2005). In the next section, we therefore establish an econometric model to assess the influence of hub hierarchies, alliances and concentration on airfares by controlling for these potentially intervening variables.

3.4 Econometric analysis

3.4.1 The empirical model

We establish an econometric model that explains the variability of earnings on non-stop HH routes in the intra-European air passenger markets. Earnings are measured through average one-way fares, which serve as the dependent variable in our model. The independent variables in the model combine demand, cost, route structure, and market structure variables. Continuous variables (i.e., population, business/economy traffic mix, distance and average fare) are transformed into their natural logarithms to reduce the impact of outlying observations and facilitate the interpretation of the coefficients as elasticities. The empirical pricing model for the HH network is specified as follows:

$$\begin{aligned}
 \text{Ln(Avgfare)} = & \beta_0 + \beta_1 \text{Ln(Population)} + \beta_2 \text{RegionalEffects} + \beta_3 \text{Ln(Business)} \\
 & + \beta_4 \text{Ln(Distance)} + \beta_5 \text{PP} + \beta_6 \text{PS} + \beta_7 \text{AllianceRoutes} \\
 & + \beta_8 (\text{PP} * \text{AllianceRoutes}) + \beta_9 (\text{PS} * \text{AllianceRoutes}) + \beta_{10} \text{OneStop} \\
 & + \beta_{11} \text{Ln(AirportHHI)} + \beta_{12} \text{H1} + \beta_{13} \text{H2} + \beta_{14} \text{LCCs} \\
 & + \beta_{15} \text{LCCSecondary} + \beta_{16} \text{HST}
 \end{aligned}
 \tag{2}$$

Where: β_0 is the intercept and β_i are the estimated coefficients for the independent variables. *Avgfare* is the average one-way fares measured by the total revenues divided by the total number of passengers of all the European FSCs on a route.

Demand variables

Population is the average population of cities where the hub airports locate, indicating the potential market size of a given route. The impact of *Population* on airfares can be mixed. On

the one hand, larger population imply that more people will buy air tickets to travel, thereby increasing prices. On the other hand, higher population enables carriers to reduce prices by using larger and more cost efficient aircraft (Wan et al., 2009). The estimated influence of population cannot be predetermined.

The *RegionalEffects* variable is designed to control the unobserved regional effects in nature, for instance, warm weather (Morrison, 2001) or the coastal mass tourism belt in Southern Europe (Bramwell, 2004). Specifically, Wan et al. (2009) defined airports locating in “European countries on the Mediterranean Sea coast and Portugal” as vacation destinations. We, therefore, control routes whereby either of the two endpoints is located in Barcelona or Lisbon to account for regional effects. A negative relationship between regional effects and airfares is expected.

Business (i.e. a traffic mix continuous variable) is measured as the proportion of passengers travelling for business on a HH route²¹. We aggregated four types of tickets (i.e., first, business, discount business, and premium coach) together as ‘business’ passengers because carriers have largely blurred the distinction among these categories of premium tickets (Lee and Luengo-Prado, 2005). Morrison (2001) applied this variable to reflect the adoption of yield management techniques by airlines (i.e., charging business travelers higher fares than leisure travelers) and found that fares are 28 % higher on routes with 75% business travelers than comparable routes with 25% business travelers. The US Department of Transportation (2001) also concluded that high fares in hub markets can be explained by passenger mix when routes are lack of price competition. HH markets have a large proportion of demand coming from business travellers with a relatively high ‘willingness-to-pay’, making the demand curves for these markets steeper than is the case in respect of more price-elastic markets (Holloway, 2008). In other words, the price increase in HH markets may theoretically lead to a relatively small demand decline. The expected sign for business traffic indicator is thus positive.

Cost variable

²¹ We use metropolitan-level data instead of airport-level data in 2008 (i.e., an earlier year) to measure ‘BUSINESS’ in order to guarantee its independence and exogeneity, which is similar to the setting of Morrison (2001).

Distance is the non-stop distance (measured in miles) between two hubs. As distance increases, average fares can be expected to rise since carriers' operating costs with regard to fuel, in-flight service and wages will increase (Borenstein, 1989; Windle and Dresner, 1995; Vowles, 2006). The expected sign for *Distance* is positive.

Route structure variables

We include two variables *PP* and *PS* to account for the 'hub hierarchy' effects and one variable *AllianceRoutes* to consider the impact of alliances on fares²². The expected sign for those variables are difficult to predetermine as discussed in the literature review.

In order to study the interactive effect of alliances and route structure on airfares, we also establish two variables based on the exploratory analysis above. The *PP * AllianceRoutes* dummy variable represents routes connected by two primary hubs served by carriers within the same alliance. As carriers operating on this type of routes may exercise certain pricing power²³, the expected sign of this variable is positive. *PS * AllianceRoutes* is a dummy variable detecting the effects of alliance carriers serving PS routes. As the pricing power may be offset by the increased traffic and economies of density on this type of routes, the expected signs cannot be predetermined.

The *OneStop* dummy variable represents routes whereby one-stop flights are also available. We consider a HH route with more than 1000 one-stop passengers on both directions in May, 2009 as a competitive one-stop alternative. The influence of providing indirect service on airfares can be complicated. On the one hand, it may reflect carriers' entry strategy into high-yield routes whereby both endpoints are dominated by incumbent carriers and have a positive relationship with airfares. This requires the entry carriers to develop strong and competitive hubs capable of diverting passengers. On the other hand, a central hub enables its dominant carriers to provide competitive indirect flights on long-haul HH routes with strong directionality (i.e., North-South or South-East), and thus reduce the prices. In addition, the narrower European

²² In order to avoid the so-called dummy variable trap (Wooldridge, 2010), *SS* and *Non-Alliance Routes* are chosen to be the benchmark group for 'hub hierarchy' and 'Alliances', respectively, and thus not included in the model.

²³ We use dummy variables instead of market share of the leading carrier to define route dominance as it explicitly examines the relationship between route structure resulting from hub hierarchies and pricing.

market and reduced use of hub-and-spoke networks may make ‘hubbing’ insignificant on airfares (Giaume and Guillou, 2004). The expected sign of this variable is uncertain.

Market structure variables

AirportHHI is the simple average of Herfindahl indices at the two endpoints of a route. Researchers have found that concentration at the endpoint airports will lead to higher fares (Borenstein, 1989; Piga and Bachis, 2007). *AirportHHI* is expected to be positively associated with prices.

H1 and *H2* are the two components of the decomposed HHI index. As more than half of the European HH markets are routes where a large FSC competes with a small LCC or REC (table 3), the market share distribution of those carriers is highly unequal. The smaller carrier is likely to reduce the price to maintain its presence, leading to a strong price competition between carriers (Giaume and Guillou, 2004). The sign of *H1* is, therefore, expected to be negative. In a market characterized by perfect competition, higher market concentration due to a smaller number of carriers may increase the airfares on a route. Given that European HH markets appear to be imperfectly competitive, *H2* may have insignificant impact on airfares.

The *LCCs* dummy variable examines the impact of the presence of LCCs. *LCCs* are taken to be present in a market when they collectively have a market share larger than 1% of passengers in a market (Ito and Lee, 2003; Lee and Luengo-Prado, 2005; Windle and Dresner, 1995). The expected sign of this variable is negative.

The *LCCSecondary* dummy variable investigates the competitive influence of LCCs at secondary airports. Extensive literature has proved that this variable has significant negative impact on airfares in US airline industry (Brueckner et al., 2013; Morrison, 2001). However, its impact is rarely examined and uncertain in European market. Even though FSCs in Europe has perceived the competitive pressure in prices from LCCs and are willing to adapt to these changes, their high cost structure and complex business model seems to hamper their swift transformation and response to the direct or adjacent competition from LCCs (Markus, 2004). The expected sign of this variable is uncertain.

HST is a variable examining the competition from high-speed train in Europe. We only consider the direct high-speed train connections including eight HST lines between cities where

hubs locate (i.e., Paris to Brussels, Amsterdam, Dusseldorf and London; Madrid to Barcelona; London to Brussels; Munich to Dusseldorf and Frankfurt). Competition from HSTs may reduce FSCs' airfares due to shorter access time, the ability to hand large passenger volumes and better adaption to fluctuations in demand (Roman et al., 2007). However, Dobruszkes (2011) found that the ability of HSTs to compete with air transport was limited, particularly on routes with high flight frequency. The expected sign of this variable is, therefore, uncertain.

3.4.2 Summary statistics of variables

The summary statistics for all the variables are presented in table 3.6.

Table 3.6 Descriptive statistics of variables

	Minimum	Maximum	Mean	Std. Deviation
Avgfare (\$)	53.70	371.95	158.83	48.96
Population (thousands)	581	5601	1985	1343
RegionalEffects	0.00	1.00	0.24	0.43
Business (%)	1.70	59.13	19.56	14.74
Distance (miles)	186	1834	683.53	341.94
PP	0.00	1.00	0.26	0.44
PS	0.00	1.00	0.54	0.50
AllianceRoutes	0.00	1.00	0.34	0.48
PP*AllianceRoutes	0.00	1.00	0.08	0.27
PS*AllianceRoutes	0.00	1.00	0.20	0.40
OneStop	0.00	1.00	0.12	0.33
AirportHHI	1000	4500	2200	600
H1	0.00	0.67	0.08	0.11
H2	0.17	1.00	0.47	0.20
LCCs	0.00	1.00	0.38	0.49
LCCSecondary	0.00	1.00	0.30	0.46
HST	0.00	1.00	0.08	0.27
# obs	101			

3.4.3 The econometric methodology

We perform a diagnostic test for multicollinearity, heteroskedasticity, and endogeneity to produce a robust and unbiased model. First, based on the variance inflation factor (VIF) for each independent variable (Baum, 2006), we do not find evidence of a multicollinearity problem. Second, as variables in our model are averaged, heteroskedasticity may occur in this

situation (Baum, 2006), and we therefore report the robust standard errors for both OLS and 2SLS as developed by White (1980). Third, based on previous research (Borenstein, 1989; Piga and Bachis, 2007), we know that the *AirportHHI* variable may be endogenous, and we therefore apply a two-Stage Least Squares (2SLS) estimation method to correct this endogeneity problem. The instrument used in the 2SLS is the average airport HHIs in other markets, which is similar to the approach of Piga and Bachis (2007). It could be argued that other market structure variables may still confront potential endogeneity. However, it is difficult to find an instrument set to correct endogeneity in the airline industry given a large number of competition measures in the model, especially since the model already includes some route characteristics variables that might otherwise serve as instruments (Brueckner et al., 2013). As a result, we do not correct for the potential endogeneity bias of other variables.

3.5 Results and Discussion

Table 3.7 summarizes the regression results for the OLS and 2SLS models, whereby 9 out of 16 independent variables are found to be statistically significant, collectively explaining 55% of the price-setting of FSCs in the European HH markets. As the results for 2SLS with robust-standard errors are more reliable, we focus on these results.

Table 3.7 Coefficients for the regression model

	OLS	2SLS
Constant	3.449***(1.122)	3.309***(1.041)
Ln(Population)	-0.083*(0.046)	-0.082**(0.042)
RegionalEffects	-0.209***(0.061)	-0.207***(0.056)
Ln(Business)	0.094***(0.035)	0.095***(0.032)
Ln(Distance)	0.189***(0.070)	0.189***(0.064)
PP	-0.012(0.098)	-0.013(0.089)
PS	0.008(0.089)	0.007(0.081)
AllianceRoutes	-0.037(0.120)	-0.037(0.109)
PP*AllianceRoutes	0.276**(0.133)	0.278**(0.121)
PS*AllianceRoutes	0.091(0.140)	0.092(0.127)
OneStop	0.197**(0.081)	0.199***(0.074)
Ln(AirportHHI)	0.180**(0.087)	0.196**(0.087)
H1	-0.667*(0.381)	-0.681**(0.354)
H2	0.045(0.116)	0.037(0.107)
LCCs	-0.093*(0.056)	-0.093*(0.051)
LCCSecondary	-0.023(0.064)	-0.024(0.058)
HST	-0.091(0.106)	-0.091(0.096)
R Squared	0.55	0.55

Note: Robust standard errors are reported between parentheses.

*, **, *** Significance at the 10%, 5% and 1% level, respectively.

Demand variables

The negative coefficient of *Population* indicates that carriers operating on the European HH routes can realize economies of scale by using larger and more cost efficient aircraft. As the average population increases 1% in the European HH markets, the prices are predicted to fall by 0.1%²⁴. Routes centred on what are identified as predominant ‘vacation destinations’ are negatively related to airfares and are about 23% lower than the other routes. We also find that the ‘traffic mix’ is indeed a factor in the price setting of European FSCs in their HH markets. The estimates show that an increase of 10% in the proportion of business passengers leads to an increase of about 0.9% in fares charged by European FSCs. The relative small coefficient may reflect that business passengers may be becoming sensitive to fare (Gillen and Morrison,

²⁴ When both independent and dependent variables are natural logarithmic transformed, back-transformation is compulsory to accurately interpret the results. The equation is $((1 + 1\%)^\beta - 1) * 100\%$. For all the dummy variables, the equation applied to interpret the results is $(e^\beta - 1) * 100\%$.

2005). In the European airline markets, researchers have found that business travellers working for small companies are more willing to trade in-flight service, frequency and FFP points for lower fares than those working for larger companies (Mason, 2001), suggesting a shift of pricing strategies for FSCs.

Cost variable

Distance is positively related to the airfares as shorter routes are cheaper to run (in absolute terms) than longer ones. An increase of 1% in the route's length leads to an increase of about 0.2% in fares. The elasticity of less than one shows, however, that the airline's cost of carrying a passenger does decrease in relative terms with the distance of his/her trip.

Route structure variables

Prices are found to be about 32% higher on primary-primary routes operated by carriers within the same alliance than the other routes, indicating that alliance carriers wield some pricing power due to reduced market competition. The insignificant influence of the other types of alliance routes on airfares can be explained by the less intense use of hub-and-spoke network in intra-European airline markets compared to the US, corroborating the findings of Giaume and Guillou (2004). For instance, Paris Orly (ORY) and Brussels (BRU) are de facto specialized switching points for African markets rather than intra-European hubs (Burghouwt and de Wit, 2005). On the other hand, smaller airports have become more important in carrying intra-European traffic. Piga and Bachis (2007) found that lower fares are charged by LCCs on the routes from their hubs such as Stansted for Ryanair due to cost advantages.

In addition, the *OneStop* variable has a positive relationship with airfares, indicating that carriers choose high-yield routes to enter by providing one-stop flights²⁵. Overall, prices on HH routes with the coexistence of nonstop and one-stop services are 22.1% higher than for the other routes. Lufthansa at Frankfurt and Swiss at Zurich contributed most to the transfer traffic on those routes due to their strong hub operations. As European FSCs gradually intensify the configuration of their hub-and-spoke network with less waiting time and lower routing factor,

²⁵ The counterintuitive positive effect of *OneStop* variable found in this paper also occurred in Brueckner et al. (2013) and could be caused by endogeneity bias. When nonstop fares charged by FSCs are too high, other FSCs could provide more extensive onestop options for passengers.

indirect connections can become more attractive and competitive in intra-European markets (Burghouwt and de Wit, 2005).

Market structure variables

As predicted, concentration at the endpoint airports is positively associated with airfares. The market concentration measured as the market share inequality (*HI*) has a negative impact on fares, which contrasts with the US experience in which concentration leads to higher airfares. Assuming that there are two routes (i.e., route 1 and route 2) whereby each of them is served by three carriers, the market shares of the carriers for route 1 are 0.5, 0.25 and 0.25, whereas those for route 2 are 0.4, 0.3 and 0.3, respectively. In other words, the distribution of market shares among carriers on route 1 is more unequal than that on route 2. Based on equation 1, the value of *H1* for route 1 (i.e., 0.063) is higher than that for route 2 (i.e., 0.01) by 0.053, implying that the average fares charged by FSCs on route 1 is 4% (i.e., 0.053 multiplied by the coefficient of *H1* in table 3.7) lower than that on route 2. This finding also supports the exploratory analysis of the market structure of European HH markets whereby 61% of routes served by FSCs confront competition from at least one LCC or REC. The large difference of market share forces the only carrier to reduce its prices to compete with FSCs. This can be explained in two aspects. First, when the smaller carrier such as a LCC or a REC choose not to follow the general industry price set by the large carrier, the latter finds it difficult to execute market power to make its rival 'suffer' due to the small size of its market share (Barla, 2000), while at the same time suffering losses by having to decrease its price on a large market share. These effects diminish as market shares converge, so that prices may decrease as the market share inequality rises. Second, at the same price levels, if passengers prefer the FSC with a larger capacity or a better service, cutting prices is likely to be the best strategy for the LCC or REC to increase its market share (Giaume and Guillou, 2004).

The presence of *LCCs* can largely influence FSCs' pricing decisions in the European HH markets. Their head-to-head competition with FSCs drives prices down by 9.7%. Finally, we do not find significant impact of competition from LCCs at secondary airports and HSTs on FSCs' fares.

3.6 Conclusion

The main purpose of this paper was to explore factors influencing the pricing of the European full-service carriers in the specific hub-to-hub markets. We find that five factors (i.e., route type, airport concentration, market share inequality, competition from low-cost carriers, and providing competitive one-stop alternative routings) contribute to explain the pricing in Europe's HH markets. As a consequence, we conclude that through strategic alliances, FSCs in Europe do charge higher fares on the routes connected by their primary hubs. However this finding only holds for connections between primary hubs, which may be related to the fact that – in contrast to the US market that has a longer history of deregulation and straddles a larger geographic area – an extensive multi-hub-and-spoke network does not yet exist in Europe (at least in terms of its potential pricing consequences).

Our finding that the market share inequality is negatively related with airfares corroborates the results obtained by Giaume and Guillou (2004). The specific characteristics of the European HH markets suggest that more new entries should be encouraged to compete with the incumbent FSCs. The low-cost carriers function as a main force for driving prices down in the HH markets, and will likely continue to influence the more extensive markets due to the enlargement of the European Union (i.e. the so-called 'new Europe, new low-cost air services' discussed by Dobruszkes, 2009).

Even though nonstop HH routes generally have high barriers to enter, we find that carriers, such as Lufthansa and Swiss, who have established strong hubs tend to enter some routes with high profitability by providing one-stop routings (i.e., the positive relationship between one-stop variable and prices). However, it is unclear how these carriers attract sufficient passengers to order these one-stop tickets along with sacrificing the longer travel time, given the short distances between airport-pairs in Europe. Future research may therefore focus on examining how FSCs in Europe set pricing strategies on one-stop connecting flights by considering factors such as, travel time, the competition from nonstop flights (Lijesen et al., 2004) and passengers' willingness to pay (Garrow et al., 2007).

Following Vowles (2006) and Zhang et al. (2013), this paper contributes to the literature in the field of examining pricing strategies in the hub-to-hub markets. Even though applying different geographical regions as empirical study, this paper confirms Zhang et al. (2013)'s finding that hub hierarchies characterizing route structure should be incorporated in a pricing model to better control inter-HH route heterogeneity. Furthermore, comparing the model and

results of current paper with Zhang et al. (2013) also suggests that the determinants of FSCs' airfares seem to be different in the European and the US markets. First, the monopolistic effects on airfares diminishing as the hubs become less crucial in a carrier's network occur in the US case, but not in the Europe. This may reflect the fact that a multi-hub-and-spoke network configuration has been deeply established by the US FSCs, while the European FSCs are still on their way to construct such a network practice via alliances or mergers. Second, the extent that LCCs' direct presence reduces FSCs' prices is less in Europe than in the US (9.7% versus 49%). We also do not find a significant impact of the competition from LCCs at secondary airports on FSCs' fares in Europe, which contrasts the US case.

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4 DYNAMICS IN THE EUROPEAN AIR TRANSPORT NETWORK, 2003-9: AN EXPLANATORY FRAMEWORK DRAWING ON STOCHASTIC ACTOR-BASED MODELING

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Abstract

In this paper, we outline and test an explanatory framework drawing on stochastic actor-based modeling to understand changes in the outline of European air transport networks between 2003 and 2009. Stochastic actor-based models show their capabilities to estimate and test the effect of exogenous and endogenous drivers on network changes in this application to the air transport network. Our results reveal that endogenous structural effects, such as transitivity triads, indirect relations and betweenness effects impact the development of the European air transport network in the period under investigation. In addition, exogenous nodal and dyadic covariates also play a role, with above all the enlargement of the European Common Aviation Area having benefitted its new members to open more air routes between them. The emergence of major low-cost airline-focused airports also significantly contributed to these changes. We conclude by outlining some avenues for further research.

4.1 Introduction

The deregulation of the air transport industry in Europe through the implementation of three subsequent deregulation ‘packages’ has greatly affected and transformed the entire sector. As a consequence, over the last decades air transport networks in Europe have undergone major changes in terms of structure, capacity, demand and scale.

The structure of European airport network has evolved into a complex, multi-layered network consisting of hub-and-spoke and point-to-point networks (Malighetti et al., 2009). This mixed structure consists of a number of *overlapping* networks, but also and perhaps above all of a number of *parallel* networks (De Neufville, 2004). Ryanair, for instance, which is known to operate a point-to-point network, offers service between London, Brussels and Frankfurt via London/Stansted, Brussels/Charleroi, and Frankfurt/Hahn rather than through London/Heathrow, Brussels/Zaventem and Frankfurt/Main. In addition, air transport services tend to shift towards second ranked cities due to changes in global production and the use of smaller long-haul aircraft (O'Connor and Fuellhart, 2013; O'Connor, 2003). The deconcentration of air transport networks may imply opportunities for secondary airports, and pose challenges for large hub airports.

Changing structures have coincided with network expansion. Burghouwt and Hakfoort (2001) found that the total seat capacity of European airport network has grown by 59% between 1990 and 1998, while the growth of intercontinental traffic and intra-European traffic has surpassed 70%. Fan (2006), examining intra-European flights between 1996 and 2004 found that the number of cities served increased by 40% (from 94 to 135), while the number of city-pairs surged by 91% (from 224 to 428). Air travel in Europe continues to grow at a rapid rate, as Eurocontrol forecasts there will be 14.4 million yearly flights in Europe by 2035, which would be 50% more than in 2012 at a growth rate of 1.8% per year (EUROCONTROL, 2013).

These overall figures clearly indicate that the European airport network continues to experience both growth and change. However, to date relatively little attention has been paid to the factors *driving* the changes in European air transport networks. Exceptions are the studies by Burghouwt and Hakfoort (2001) and Fan (2006). In Burghouwt and Hakfoort (2001), the authors investigate how the capacity of the European airport network changed over the period 1990-1998 at the airport and the route level. Although their distinction between airport and route level change overcomes the drawbacks of previous empirical studies in that the nature of

change is better revealed, the study remains descriptive, thus largely ignoring the interdependence between airport (nodal) and route (dyadic) attributes. Fan (2006) provides more evidence on the evolution of inter-city air transport connectivity in Europe, showing for instance that network growth is mostly attributable to the rising importance of low-cost carriers. His analysis, however, does not explore other factors that may be driving the evolution of air transport networks in Europe.

Taken together, it is clear that our understanding of the spatial-temporal development of European air transport networks can be enhanced by addressing the mechanisms of change and growth in a more comprehensive way. The objective of this paper is to explore and interpret the factors *driving* changes in European airport networks. To this end, we apply a stochastic actor-based modeling (SABM) framework. To our knowledge, this is the first time that SABM is applied in a longitudinal analysis of air transport networks. Reviewing recent theoretical and empirical research suggests that SABM has indeed the potential to shed light on the processes underlying network dynamics (Andrew, 2009; Buchmann and Pyka, 2013; Ingold and Fischer, 2014; Kinne, 2013; Liu et al., 2013c). The main advantages of applying SABM to examine network dynamics are that (1) the modeling framework encompasses a wide variety of endogenous and exogenous effects on network change, and (2) allows evaluating these effects in the spirit of statistical inference (i.e. by providing parameter estimates that allow for the formal testing of hypotheses regarding potential drivers of network change).

The remainder of this paper is structured as follows. In the next section (4.2), we discuss the conceptual parallels between the analysis of air transport structures and (social) network analysis in which SABM was developed. This is essential as one of the basic assumptions of SABM is that actors control and change their outgoing ties based on their and others' attributes, their roles in the network and their interactions throughout the rest of the network (Snijders et al., 2010): unless it can be established that this assumption holds in the case of air transport networks, applying SABM would be a mere statistical exercise without much formative remit. The following sections outline the collection of longitudinal network data (4.3) and the methodological core of SABM (4.4). We then specify the SABM framework applied in this research by introducing the endogenous network and the exogenous actor and dyadic attributes used in the modeling (4.5), after which we discuss the main results of our analysis (4.6). In the final section (4.7), we present our main conclusions and outline some avenues for further research.

4.2 Air transport networks as ‘social networks’?

4.2.1 Airports as ‘actors’ in air transport networks

SABM has been developed in the domain of social network analysis, where ‘networks’ most commonly consist of interacting individuals who have the ability to exercise influence or (some degree of) control over their interactions. For SABM to be meaningful in other contexts, a discussion of how nodes or actors are able to exercise such influence is needed. In the present context, this entails a discussion of how airports can be considered as ‘actors’ in the development of airport transport networks. Of central importance in this discussion is the observation that the roles played by airports in the air transport value chain has changed over the last decades, as evidenced by their shifting operational objectives and their changing relationships with carriers, passengers and other airports.

Since the mid-1980, there has been a gradual shift in the ownership structures and operational objectives of airports. In (admittedly overly) general terms, before the mid-1980s airports tended to be government-owned, and primarily (or merely) seen as “logistic medium” to serve regional and/or macroeconomic development. From the mid-1980s on, however, the neoliberal ‘logic’ of privatization and commercialization has forced airports to function as “multipoint service-provider firms”²⁶ (Jarach, 2001) which focus on maximizing profitability by improving productive efficiency and competitiveness (Oum et al., 2006). Although this shift has been varied in its concrete operationalization, and has unfolded very unevenly in space and time, it seems fair to state that this is an overarching shift that has led airports to get more proactively involved as an *actor* in the air transport business by seeking interactions with the other key participants or ‘actors’ in air transport networks: carriers, passengers and other airports.

4.2.2 Airport - carrier relationship

Traditionally, airports and carriers worked together in a more or less stable supplier-customer relationship, whereby airports strived to attract a large number of carriers and provide them with infrastructure-related public services (e.g., air traffic control, ground-handling and other aviation-related activities). However, deregulation and liberalization have altered this. The most conspicuous examples of this changing relationship can, of course, be found in the advent and

²⁶ Under this concept, an airport becomes a commercial hub, in which a bundle of diversified service propositions and products are offered to an enlarged category of target customers.

proliferation of low-cost carriers (LCCs) and the increased competitive pressures on legacy or full-service carriers (FSCs). With FSCs increasingly being vulnerable to potential bankruptcy, for instance, there was the danger of spillover effects in that this could also bring down their hub airports. For instance, the bankruptcies of Aloha Airlines, Skybus Airlines, and ATA Airlines in 2008 cost Oakland International Airport over \$2 million in annual revenue due to losses in gate leases and landing fees (Waite, 2009). Meanwhile, LCCs have stimulated rapid growth at smaller airports. For example, the traffic at London Stansted languished at around 5 million per year in its first decade (De Neufville, 2004), but it became the fastest growing major international airport in the world and saw a substantial passenger growth of 25.6% in 2000 (Francis et al., 2004) after being selected as a major base for Ryanair's operations. These dramatic changes have forced all airports to reexamine their relationship with carriers, with the former proactively and defensively participating in air transport business (Albers et al., 2005). Redondi et al. (2011), for instance, recently suggested that airports increasingly recommend new routes to carriers to improve their own network connectivity.

In addition to the (shifting) operational relationships between airports and carriers, their interaction is also shaped by the wider socio-economic context and unfolding liberalization of the airline market. First, even though it is airlines that realize the opening or closure of routes, their decisions regarding the anticipated profitability are influenced by the socio-economic context (e.g., the economic power measured by GDP, population and other indicators) of the cities or catchment areas in which airports are located. And second, only in relatively liberalized markets carriers can freely choose to open or close a route: when shaping (de)regulation policies, government and airport operators consider the overall geographies of air transport aggregated by airports (Van De Vijver et al., 2014), and these geographies are not solely or always directly shaped by individual carriers. From this perspective, airports implicitly co-determine the opening or closure of routes.

4.2.3 Airport - passenger relationship

Paralleling the changing ownership structure of airports and their shifting relations with carriers, airports also seek to transform their associations with passengers from an indirect airport - airline - passenger relationship to a more direct airport - passenger relationship (Francis et al., 2004). The most straightforward example is that some airports now try to sell tickets to passengers themselves, thus confronting airlines, tour operators and travel agents who

historically controlled this business (Jarach, 2001). A very visible example of the changed role of airports in their relation with passengers has been Stansted's "Create your own connection" project, which helps passengers to 'self-hub' by taking advantage of its enormous potential for indirect connections (Malighetti et al., 2008). As independent, profit-seeking players in the air transport market they also tend to place more and more emphasis on passenger revenues that are not strictly air transport-related, such as spending in the terminals and car parks.

4.2.4 Airport - airport relationship

The relation between airports has transformed from being relatively independent entities into a closer relationship with cooperation and competition coexisting. On the one hand, cooperation can be expressed as opening a route between two airports to increase each other's accessibility. Connection modes (i.e., direct or indirect) can be varied between different levels of airports (i.e., 'hierarchy' of airports) emerging from (regional) economic development and individual airline network strategies (Burghouwt, 2007; Zhang et al., 2013). For instance, large hub airports tend to attract more direct connections than non-hub airports by reducing waiting time, routing and other related factors (Burghouwt and de Wit, 2005), while small airports in Europe strive to connect to a hub airport to indirectly reach more destinations or attract LCC services to have direct connections (Pels, 2008). On the other hand, and contrary to the conventional view that airports were monopoly providers of services to both airlines and passengers, airport markets in Europe are increasingly competitive in nature. In particular, they are likely to compete to each other in terms of local markets, connecting traffic, destinations and even cargo traffic (Tretheway and Kincaid, 2010). In particular, it is worth noting that secondary airports in Europe have shown to be intense competition for the major airports (Forsyth, 2010).

This overview suggests that airports are no longer the passive bystanders they used to be: they are increasingly becoming major actors in the air transport networks. Indeed, the underlying logic of profit-maximization and revenue-generation leads them to *actively alter and manipulate* their relations with other major actors in the airline business (carriers, passengers, and each other). Although clear not exactly the same as individuals managing their position in inter-personal (social) networks, we believe the resemblance is strong enough to explore the potential of methods devised in the context of social network analysis to explore the networks connecting airports. In particular, we focus on the application of a modeling framework that allows understanding how networks change over time: SABM.

4.3 Data collection

In this section, we introduce the data collection based on the requirements of SABM in terms of the number of observation moments, the number of actors, and the total number of changes between consecutive observations.

We examine changes in the European air transport network between 2003 and 2009. This seven-year timespan guarantees the assumption of SABM that the total number of changes between two observations should not be too high or too low, as shown in table 4.1 and discussed below. If the total number of changes between consecutive observations is too high, this may violate the assumption that the network changes gradually. If, in turn, the total number of changes is too small, then SABM cannot provide enough information for estimating the parameters (Snijders et al., 2010)²⁷.

In terms of collection of actor (airport) information, we first confine the geographical scope of our research as countries that signed European Common Aviation Area (ECAA) agreements before 2009. This includes all 27 EU members, alongside Norway, Iceland, Switzerland, Albania, Bosnia and Herzegovina, Croatia, Kosovo, Macedonia, Moldova, Montenegro and Serbia. In this ECAA, we selected the 120 airports serving more than 150,000 passengers in 2009 (i.e., the total number of the local origin, destination and transit passengers)²⁸. Figure 4.1 shows the location of airports used in this study. Unsurprisingly, countries with a higher gross domestic product (GDP), a larger population, and a wider geographical extent tend to have more airports in the framework.

²⁷ Even though the air transport industry experienced the single largest 21st century decline between the two observation points of 2003 and 2009 due to the SARS epidemic and economic downturn (MacDonald, 2011), SABM seems capable of capturing the network change mechanisms between the two observations.

²⁸ This paper only considers airports where their located cities have a high global network connectivity (GNC) index (Neal, 2012). Some tourist destinations in Italy or Spain may, therefore, not be included in the analysis.

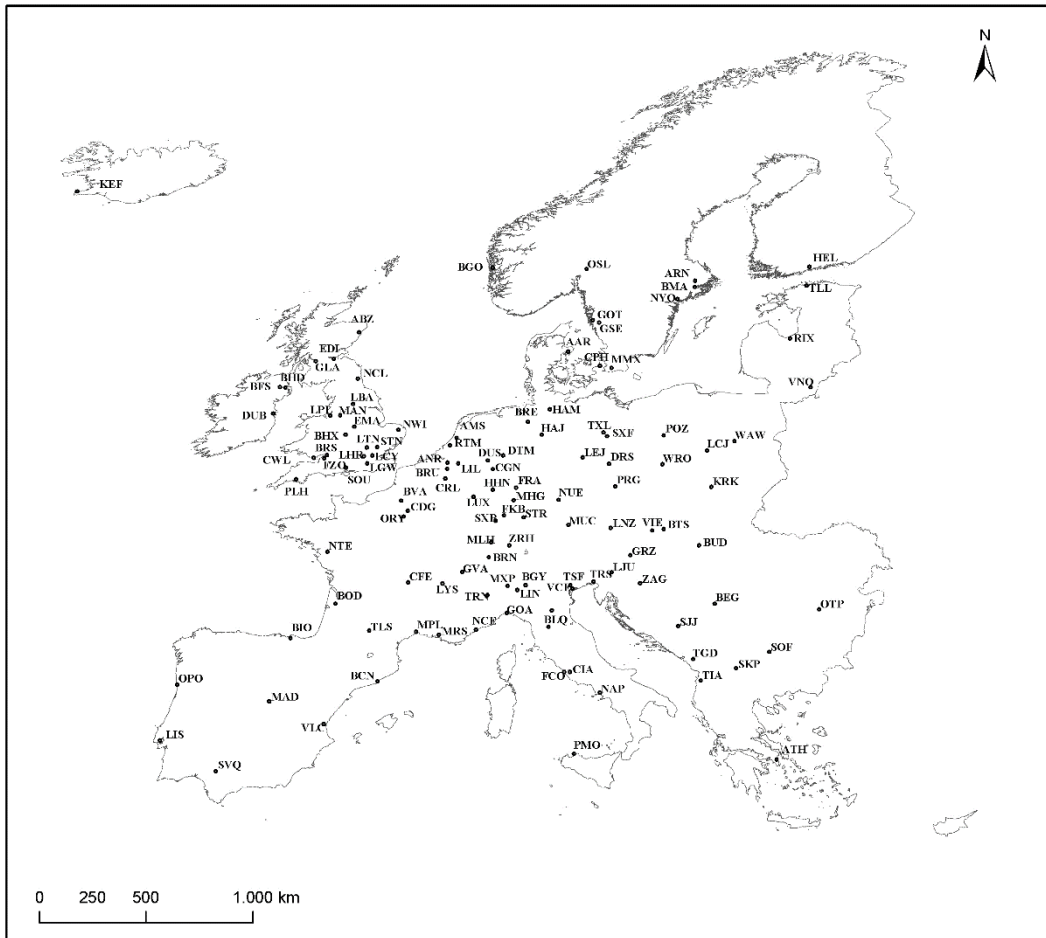


Figure 4.1 Location of airports in Europe

Drawing on this airport list, we constructed the network data that serves as the dependent variable in the model: two binary adjacency matrices representing the presence or absence of direct connections between airport pairs. The European air transport network in this analysis is a binary, non-directed and one-mode network. To achieve this, we collected data at the route level from Sabre Airline Solutions' Airport Data Intelligence (ADI), which contains information on actual connection between two airports (i.e., an airport pair directly connected by a commercial carrier). In order to obtain meaningful entries, we deleted routes with less than 100 passengers per year.

To obtain meaningful estimation results, SABM also provide quantitative indicators to measure the total number of tie changes between two consecutive observations. The Jaccard index is used to guarantee the gradual change of the networks, which is calculated as $N_{11}/(N_{11} + N_{01} + N_{10})$, where N_{11} , N_{01} and N_{10} are the number of maintained ties, new ties

and broken ties. Drawing on experience with the SABMs, the value of the Jaccard index should preferably be above 0.3 (Snijders et al., 2010). Table 4.1 shows that our data results in a Jaccard index of 0.573, which implies that the underlying network-formation process can be modeled through SABM. Over the period from 2003 to 2009, the majority of the possible routes start by being absent and ended up so ($0 \rightarrow 0$). About 18 percent significant connections remained unchanged, while 9 percent and 4 percent of routes were opened or canceled, respectively. The density of the network increased slightly and the average degree likewise also saw growth during the study period.

Table 4.1 Descriptive network statistics and tie changes between the two periods

Statistic	2003	2009
Nodes	120	120
Density	0.216	0.268
Average degree	25.717	31.917
Existing ties	1543	1915
Changes	2003 \rightarrow 2009	
Jaccard index	0.573	
No tie: $0 \rightarrow 0$	4941 (69%)	
New tie: $0 \rightarrow 1$	656 (9%)	
Broken tie: $1 \rightarrow 0$	284 (4%)	
Maintained tie: $1 \rightarrow 1$	1259 (18%)	

4.4 Stochastic actor-based models

This paper employs stochastic actor-based models (SABMs) to examine the drivers of the air transport network change summarized in the previous section. Since their introduction for network dynamics by Snijders (1995) and his colleagues, SABMs have been widely applied in various fields, ranging from friendship networks (Cheadle et al., 2013) to inter-organizational networks (Liu et al., 2013a; Liu et al., 2013c; Van de Bunt and Groenewegen, 2007), manufacturing networks (Buchmann and Pyka, 2013), political networks (Andrew, 2009; Kinne, 2013), and many other areas. However, to date this approach has not been applied to air transport networks, probably in part because of the high requirements in terms of availability of longitudinal network data, which has been a longstanding limitation to analyze the changes of transportation networks using statistical analysis tools (Xie and Levinson, 2009).

In the following paragraphs, we briefly summarize the basic mechanism of this approach. SABMs combine continuous time Markov models, random utility models and simulation techniques to analyze network dynamics (Van de Bunt and Groenewegen, 2007). First, the models assume that network changes are time-continuous and decompose changes into unobserved *ministeps*, in each of which an actor creates a new tie, terminates an existing tie, or does nothing at all (Fischer et al., 2012), even though network changes are only observed at two or more discrete moments in time. The process is conceptualized as a Markov process, implying that for any point in time the probability distribution of the future network, given current and past states of the network, is only a function of the current network (Snijders et al., 2010). Second, the models consider the development of a network over time to be the result of the purposeful, utility-maximizing choices of individual actors (Kinne, 2013). Actors weigh the different options for network change by considering the current network structure (*network effects*), actors' attributes (*actor covariates*) and properties of pairs of actors (*dyadic covariates*) as expressed by an objective function (Snijders et al., 2010). Third, very much as in 'conventional' statistical procedures, SABMs are capable of estimating and testing parameters in order to assess the effect of a given mechanism, while controlling for the possible simultaneous operation of other mechanisms (Snijders et al., 2010). This means that the iterative Markov chain is treated as a Monte Carlo algorithm to draw up expected values, which are then confronted with the observed values. A method of moments is then adopted to estimate parameters by minimizing the difference between the observed and expected values (Snijders, 2001). Convergence is checked by assessing deviations in the simulated network statistics from their targeted or observed values (Ruth M. Ripley et al., 2013). SABMs can thus test hypotheses as in conventional statistical models by calculating t-statistics from estimated coefficients and standard errors. Note that SABMs do not make any assumptions about whether the first observed network is in a long-term (dynamic) equilibrium and thus do not model the first observed network itself but only use it as the starting point of the simulations (Snijders et al., 2010), so that results should not be interpreted as increases or decreases over time, but simply as non-random tendencies through time (Ingold and Fischer, 2014). In other words, quite opposite results would be obtained if one models and makes inferences about the first observed network. For instance, if the first observed network shows a strong transitivity effect, this does not mean that the extent of transitivity effect in the network will increase or sustain in the future. It would be possible that no transitivity exist in the longitudinal SABM approach where the first observed network is not modeled at all.

The so-called objective function is the core of the model, and determines the probabilities of the tie changes made by the actors (Snijders et al., 2010). The dependent variables in the model are the changes in tie variables derived from the $n \times n$ adjacency matrix $x = (x_{ij})$, where n is the total number of actors, and x_{ij} is either 1 (i.e., presence of a tie) or 0 (i.e., absence of a tie). The objective function is assumed to be a linear combination of a set of network *effects*:

$$f_i(x^0, x, v, w) = \sum_k \beta_k s_{ki}(x^0, x, v, w) \quad (1)$$

Where, i is the focal actor, f_i is the value of the objective function for actor i depending on the current state x^0 , a potential future state x of the network (i.e., structural or endogenous effects), as well as on actor attributes v and dyadic attributes w (i.e. covariates or exogenous effects). The functions s_{ki} define effects that may potentially drive the changes of network from the perspective of actor i and the weights β_k are the statistical parameters that express dynamic tendencies of network evolution. If β_k equals 0, the corresponding effect plays no role in the network dynamics; if β_k is positive, there will be a higher probability that the network moves towards the direction with a high score on the corresponding network effect s_{ki} , and the converse if β_k is negative (Snijders et al., 2010).

Because we treat the European air transport network as a non-directed network, we chose to implement the actor-based ‘unilateral initiative and reciprocal confirmation’ model (Snijders, 2011; Van de Bunt and Groenewegen, 2007). In this model, one airport takes the initiative and decides to create a route to another airport based on the expected utility. The other airport then has to confirm this change, equally based on the expected utility. Note that for termination of a link this is not required (Ruth M. Ripley et al., 2013). This is a reflection of reality, as opening a new route requires mutual agreement between two airports, while termination only requires one airport to act. In the next section, we outline the different endogenous (structural) and exogenous (actor and dyadic) effects implemented in our model.

4.5 Model specification

We introduce the main effects in the objective function and the implications of the statistical parameters in the context of the air transport network. We include four endogenous network effects (i.e., density, number of distances two, betweenness and transitivity triads)²⁹ and four

²⁹ These four network effects correspond to nonstop route, one-stop route, hubbing and interconnected subgroup consisting of air transport network in practice.

exogenous effects (i.e., two actor covariates and two dyadic covariates reflecting the liberalization of air transport in Europe). The selection of the four endogenous network effects is based on the literature studying air transport networks using complex network theory whereby the classic metrics, such as degree distribution, clustering coefficient (i.e., transitivity commonly used in social sciences), length of shortest path and betweenness have been applied to explore the characteristics of air transport networks (Barrat et al., 2004; Boccaletti et al., 2014; Boccaletti et al., 2006; Ducruet and Beauguitte, 2014; Guimera and Amaral, 2004; Liu et al., 2013b; Zanin and Lillo, 2013).

4.5.1 Structural effects

Density effect

The most basic effect is defined by the density of airport i , which captures the tendency of airport i to connect to other airports during the period under investigation. As we are dealing with a non-directed network, in-degree and out-degree effects are combined into an overall degree or density effect.

$$S_{1i}(X) = \sum_j x_{ij} \quad (2)$$

A positive value for the density parameter suggests that airports tend to open more routes; a negative value for the density parameter suggests that airports tend to have fewer routes. Snijders et al. (2010) suggest that this effect should be included in all models, and basically serves as a baseline parameter that can be compared with the intercept in a conventional linear regression (Liu et al., 2013c). From a decision-theoretic perspective, this parameter can be regarded as the overall balance between benefits and costs of an actor (Snijders et al., 2010). For instance, a negative parameter could mean that the costs outweigh the benefits, and vice versa.

Transitivity closure effect

The transitivity triads effect assesses the tendency of two airports j and h to become connected if both airports share a common ‘partner’ (airport i) in the network. It is defined as the number of transitive patterns in i ’s relations.

$$S_{2i}(X) = \sum_{j < h} x_{ij} x_{ih} x_{jh} \quad (3)$$

A positive sign suggests that airports connecting to the same ‘partner’ airport are more likely to initiate a new route compared to other airports that do not have a ‘partner’ in common. For example, the more airports A directly connect that also choose to connect to airport B, the more likely airport A will connect to B directly over time. A negative sign indicates that airports connecting to the same airport are less likely to form closed triangles than other airports that do not have a ‘partner’ in common.

Number of distances two effect

Number of distances two effect (*nbrDist2*) takes into account indirect connections between actors, which is defined by the number of actors j to whom i is indirectly related through at least one intermediary node (i.e., at geodesic distance two).

$$S_{4i}(X) = \#\{x_{ij} = 0, \max_h(x_{ih}x_{hj}) > 0\} \quad (4)$$

A positive sign for this effect suggests that airports prefer to open indirect routes connecting other airports through an intermediary airport, whereas the negative *nbrDist2* effect indicates that airport A is more likely to directly connect to airport B, given that airport A’s ‘neighbor’ airport C directly connected to airport B (and regardless of any other indirect connection to airport B). Note that although both the *transitivity closure effect* and *nbrDist2 effect* pertain to the formation of triadic relationships, they differ in that the former is dependent on the number of indirect connections, whereas the latter is independent of the number of indirect connections.

Betweenness effect

The betweenness effect measures the number of pairs of actors (j, h) that are indirectly linked by actor i . A positive sign indicates the tendency that airports prefer to be in between disconnected airports and are more likely to function as ‘transfer’ centers. A negative sign suggests that airports are less likely to be in between disconnected airports over time.

$$S_{3i}(X) = \sum_{j,h} x_{hi}x_{ij}(1 - x_{hj}) \quad (5)$$

4.5.2 Actor covariates

ECAA Enlargement

Aiming at establishing a single European ‘sky’ to facilitate better air transport services for consumers, the European Commission initiated a European Common Aviation Area (ECAA). The ECAA grants its members more freedom to set prices, capacity or frequency. The fifteen Member States of the European Union (EU) plus Iceland and Norway were part of the ECAA in 2000, with Switzerland joining in 2002. During the period under investigation, the enlargement of the ECAA coupled with the extension of the EU in two rounds has resulted in significant increases in air traffic and the number of routes and carriers (Niemeier et al., 2012). In 2004, eight East European countries (i.e., Poland, Hungary, the Czech Republic, Slovakia and Slovenia and the three Baltic states of Estonia, Latvia and Lithuania) joined the EU, followed by Bulgaria and Romania in 2007. In addition, the successful negotiation with several Balkan countries (i.e., Albania, Bosnia-Herzegovina, Macedonia, Croatia, Serbia, Montenegro and Kosovo) to join the ECAA in 2006 again stimulated the development of the European aviation market. Dobruszkes (2009) found that low-cost carriers (LCCs) in Europe greatly benefited from the extension of the liberalization of the European skies to the new EU Member States, as their seats supply doubled between 2004 and 2008. The number of city-pairs connecting airports in the established member states to the new ones also showed a significant increase (i.e., from 21 in 2004 to 285 in 2008). We include a dummy variable called ‘ECAA enlargement’ to explicitly control for the contribution of the enlargement of the ECAA to the dynamics of European airport network during this period. This variable is coded as ‘1’ if an airport is located in countries that were not a part of the EU or the ECAA in 2003, and we expect a positive effect for this parameter.

LCC bases

It is known that the liberalization of air transport in Europe has led to the dramatic rise of the importance of (a new generation of) low-cost carriers. LCCs are responsible for a large portion of the dramatic increase of intra-European inter-city connectivity, and have above all impacted the connectivity of ‘smaller’ cities between 1996 and 2004. (Fan, 2006) found that, in 2004, 60% of the city-pairs exclusively serviced by LCCs were operated out of secondary and tertiary cities, while 51% did not involve a primary city at all. Dobruszkes (2006) equally found that more than half of the growth of the supply available in terms of seats was directly due to LCC operations between 1995 and 2004, benefiting both the larger, main cities (such as London, Madrid and Milan) and secondary cities whose growth and survival are largely dependent on LCCs. Collectively, these studies reveal that the emergence of LCC bases is likely to be a major

driving force in the evolution of the airport network in Europe. We control for this effect by introducing a dummy variable called ‘LCC bases’. In general, LCC bases are defined as airports with significant presence of LCCs in terms of seats or flights, combining two lists developed by Dobruszkes (2006) and the Deutsches Zentrum für Luft- und Raumfahrt (DLR) (2011), respectively³⁰.

4.5.3 Dyadic covariates

Former ECAA members – Former ECAA members

We include two exogenous dyadic covariates in our model. The variable ‘Former ECAA members – Former ECAA members’ tests the hypothesis that there is a higher propensity to create ties between the former ECAA members.

Former ECAA members – New ECAA members

The variable ‘Former ECAA members – New ECAA members’ tests the hypothesis that there is a higher propensity to open new routes between the former ECAA members and the new ECAA members as a result of the enlargement of the ECAA and the EU.

4.6 Results and discussion

4.6.1 Model tests and goodness-of-fit

As the data and model structures for actor-based models are complicated even in the simplest cases and estimating these models are time-consuming, stepwise procedures combining forward steps (where model selection starts with a simple model and effects are gradually added to the model) with backward steps (where model selection starts with a complicated model including all effects that are expected to be strong and non-significant effects are then deleted) are used to select model (Snijders et al., 2007). However, forward model selection is technically and practically preferable to backward model selection due to better convergence and faster computation time. Wald and score-type tests are applied to determine whether individual or various effects should be included in the model based on the (joint) significance of parameters

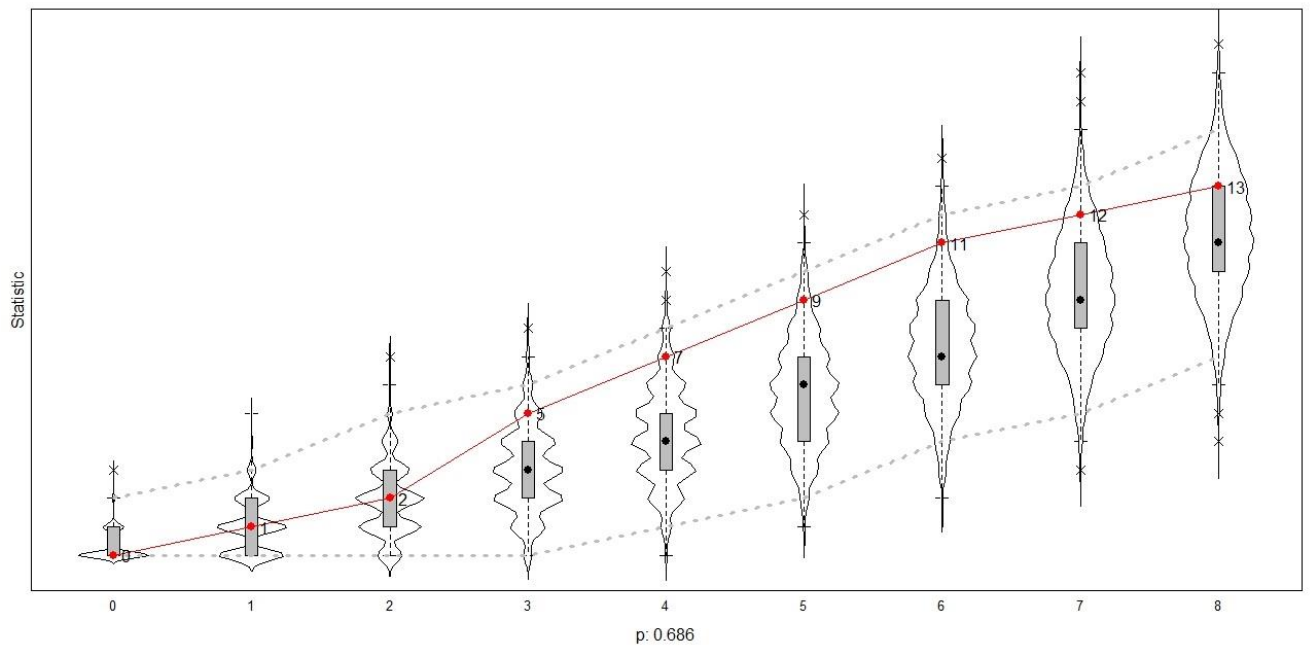
³⁰ The LCC bases included in this paper are BCN, BFS, BGY, BRS, CGN, CRL, DUB, DUS, EDI, EMA, FCO, GLA, GVA, HHN, KRK, LGW, LPL, LTN, MAD, MAN, MXP, NCE, NYO, ORY, OSL, RIX, STN, STR, SXF, VIE, VLC.

(Ruth M. Ripley et al., 2013)³¹. Moreover, we also assess the goodness-of-fit of the model by comparing degree distribution, geodesic distances distribution and the triad census of networks simulated from the estimated model with the observed networks (Liu et al., 2013c; Ruth M. Ripley et al., 2013). A satisfactory fit is achieved when the observed values are within a band which is a 90% relative frequency region calculated for the simulated values. The p-value (i.e., larger than 0.10) based on a test of Mahalanobis' distance also shows that the simulated networks can well replicate features of the observed data that are not part of the model.

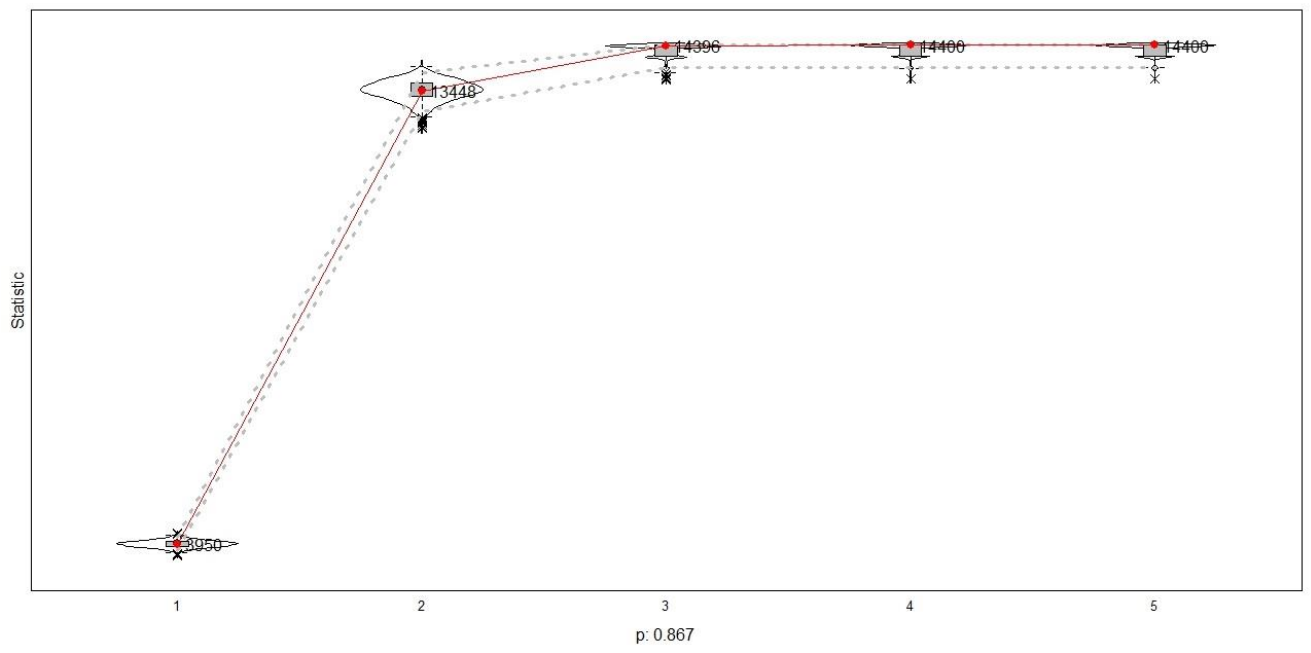
We report the results of five intermediate model specifications: model 1 is the null model only including the density effect; model 2 accounts for endogenous structural effects only; model 3 also considers the effect of ECAA enlargement, while model 4 incorporates the impacts of LCC bases; and finally, model 5 also includes the two dyadic covariates and, therefore establishes a full set of potential endogenous and exogenous effects driving the changes outline of the European air transport between 2003 and 2009. We present the parameter estimates for each of the five models in table 4.2. Simulation runs implemented in the SIENA program based on the R platform (Ruth M. Ripley et al., 2013) have been repeated 2000 times. As the t-ratios indicating the deviation of observed network data from simulated values are less than 0.1 in all five models, our results exhibit good convergence.

The significance of Score-type tests for models 2-5 suggests improvements in model fit, as new network statistics and actor and dyadic covariates are progressively added into the models. Wald-type tests for joint significance also create statistically significant values for models 2-5, meaning that the changes of the air transport network is influenced by the factors introduced in section 4.5. The violin plots in figure 4.2 show that the full model 5 is fitted well as the observed data are within the 90% band and the p-values are larger than 0.10.

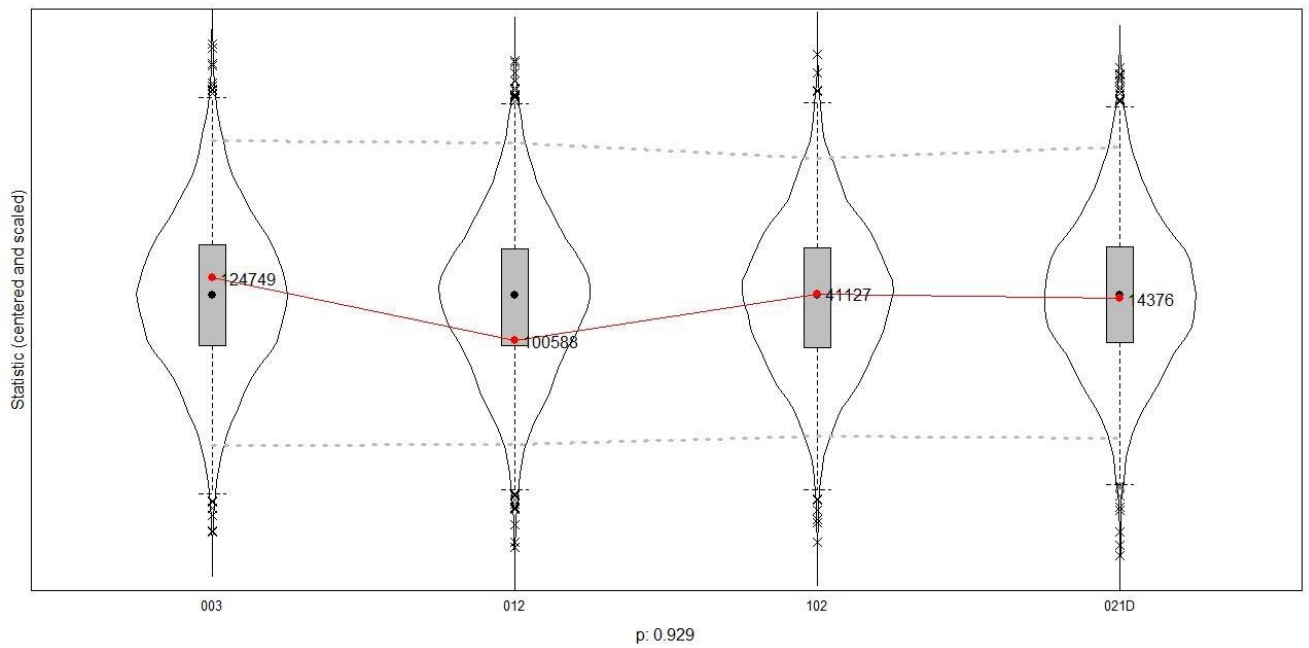
³¹ The difference between the Wald test and the score-type test is that the former is based on the parameter estimates and thereby integrates estimating and testing, whereas the latter tests a parameter without estimating it.



(a)



(b)



(c)

Figure 4.2 Goodness of Fit of Model: (a) Outdegree distribution, (b) Geodesic Distribution, (c) Triad Census

Note: The goodness of fit of the model is represented by 'violin plots' in which the red solid line shows the observed values and the box plots and 'violins' show the simulated network.

Table 4.2 Simulation results

	Model 1	Model 2	Model 3	Model 4	Model 5
Rate parameter	19.609*** (0.845)	19.871*** (0.852)	19.745*** (0.834)	18.648*** (0.733)	13.476*** (0.483)
Density	-0.706*** (0.039)	-0.844*** (0.090)	-0.958*** (0.134)	-0.710*** (0.087)	-0.693*** (0.110)
Transitive triads		0.060*** (0.003)	0.060*** (0.003)	0.053*** (0.003)	0.062*** (0.004)
Number of distances two		-0.039*** (0.009)	-0.032*** (0.009)	-0.046*** (0.010)	-0.051*** (0.014)
Betweenness		0.011*** (0.005)	0.017** (0.009)	0.006 (0.004)	0.010 (0.006)
ECAA Enlargement			0.359*** (0.093)	0.508*** (0.089)	0.472*** (0.101)
LCC bases				0.823*** (0.075)	0.949*** (0.091)
Former ECAA members – Former ECAA members					-1.104** (0.531)
Former ECAA members – New ECAA members					-0.940* (0.556)
Tests					
Score-type		2181.627*** df = 3	19.0841** * df = 1	124.695** * df=1	4.9516* df= 2
Wald		16.6*** df=3	14.9*** df=1	119*** df=1	4.925* df=2

Note: Standard errors are within parentheses. *** p < 0.01, ** p<0.05, * p<0.10

4.6.2 Parameter interpretation

For the interpretation of the numerical values of the estimated parameters, log odds ratios, which are similar to multinomial logistic regression, can be computed. The estimate for a given covariate is the log odds ratio of the respective probabilities that one actor will choose one particular tie over another, given that the only difference between the two ties is a one-unit change in the covariate of interest (Kinne, 2013; Snijders et al., 2010). Exponentiating the estimates thus yields odds ratios.

For each model, the *rate parameter* represents the frequency or the expected average number of opportunities of tie changes by each actor per micro time step. For instance, model 5 suggests that the expected number of changes of network ties for an airport is about 14.

Model 1 is the null model and only includes the basic density effect. The *density* effect benchmarks the overall tendency for airports to launch new routes. The significant and negative *density* parameter indicates that airports had a low propensity to make (random) connections to other airports in this period - a probability of 33% [$e^{-0.706}/(e^{-0.706} + 1)$]. The *density* effect is significant and negative in all five models.

Conditional on the density effect in model 1, model 2 includes three other endogenous network parameters (i.e., three triadic closure effects: transitive triplets, number of actors at distance two and betweenness). The positive *transitive triplets* effect postulates that more intermediaries will add proportionately to the tendency to transitive closure (Snijders et al., 2010). Numerically, if a potential route *ij* closes one more triad than an alternative route, then, ceteris paribus, the odds of the route *ij* being created is greater by a factor of 1.062 ($e^{0.060}$), or about 6.2%. European airports tend to form cohesive and interconnected triadic subgroups for several reasons. First, hub airports have the tendency to form “trunk traffic triplet” to lower costs on inter-hub routes (O’Kelly, 1998; O’Kelly, 2014; O’Kelly et al., 2014). Second, connecting with other hub airports can also improve the accessibility to the rest of their network. In particular, if the dominant carriers of those hubs have incentives to join in strategic alliances, then the inter-hub routes can benefit from higher frequencies and better coordination of time schedules (Doganis, 2006; Zhang et al., 2014). For instance, the strategic integration of the major Austrian and Swiss airports into the ‘sub-group’ led by Frankfurt airport may contribute to the network closure (Malighetti et al., 2009). In addition, some small airports tend to connect to each other via point-to-point low-cost services, leading to a larger percentage of formation of closed triplets (Malighetti et al., 2009; Redondi et al., 2013).

Number of distances two effect takes into account indirect connections between airports. The significant and negative sign of this effect further confirms the tendency toward network closure. All other effects being equal, if airport A has one more one-stop route, the probability for airport A to open an additional direct route in the future is 49% [$e^{-0.039}/(e^{-0.039} + 1)$]. This indicates that keeping connected with the other airports, even through a one-stop route is important for airport managers to increase their airports’ connectivity, especially for small

airports located in remote areas. For instance, Burghouwt (2007) found that a substantial number of small airports that lost direct air service was partially compensated by an increase in the number of one-stop connections through other airline hubs and traffic nodes.

The significant and positive *betweenness* parameter suggests that airports have a tendency to occupy ‘broker’ positions in the network, allowing them to connect two airports that are not directly linked. If airport A has one more pair of airports that are indirectly linked by it than airport B, then *ceteris paribus*, the odds that airport A opening a new route is higher than airport B by a factor of 1.011 ($e^{0.011}$), or slightly by 1.1%. This corresponds to the practice of ‘hub-and-spoke’ network configuration by full-service carriers in Europe³². Moreover, airports with low domestic air-services, such as a number of airports located in the Czech Republic, Slovakia, Hungary, Switzerland, Lithuania and Belgium, often function as the intermediary points to connect airports of Central and Eastern Europe to Western Europe, represented by Brussels and Geneva airport (Malighetti et al., 2009).

Model 3 adds the first nodal covariate “ECAA Enlargement” into model 2 and the result confirms our expectation that the enlargement of the ECAA has benefited the new joint members to open more new air routes. All other effects being equal, being the member of the ECAA increases the odds to open a new route by 43.2% [$(e^{0.359} - 1) * 100\%$]. The significance and sign of structural effects in model 2 remains the same.

Model 4 incorporates the second nodal covariate “LCC bases,” and the result shows that the major LCC airports have tended to add a large number of new routes into their networks, overall *significantly* driving the changing structure of the European air transport network. For instance, being a LCC-airport has a higher probability by 69.5% [$e^{0.823}/(e^{0.823} + 1)$] to open a new route. The significance and sign of parameters in model 3 remains the same, except that the *betweenness* effect becomes insignificant. This can be explained by the fact that the impact of the major LCC airports on changes of European airport network is so dramatic that the effect of some airports playing bridging roles on network dynamics can be neglected. In addition, the major LCC airports were affected less than the hub airports given the recent economic crisis

³² It should be noted that *betweenness* used to define ‘hubs’ here only shows their spatial characteristics, but not the temporal properties (e.g., the adoption of the wave-system structures to coordinate inbound and outbound flights (Burghouwt and de Wit, 2005; O’Kelly, 2010)).

(Dobruszkes and Van Hamme, 2011), which may make the latter taking more conservative strategy to expand their networks.

Model 5 incorporates the two dyadic covariates into the model. The negative effects of those two dyadic covariates may largely due to the recent economic crisis and they only show marginally significant effects (i.e., the p-values are 0.04 and 0.09, respectively). Dobruszkes and Van Hamme (2011) found that most airports in Europe faced a stagnation or decline in air supply in terms of number of seats during the recent economic crisis corresponding to the decrease of demand. Opening a new route seems to be risky and difficult for airlines to adapt to the economic decline due to long negotiation time and high costs. All the other parameters for endogenous network effects and the two exogenous actor covariates maintain their significance and sign as in model 4.

4.6.3 Discussion

This section discusses how the results obtained from SABM can benefit airport operators, carriers and local governments. First, we design a toy network to illustrate how the coefficients in table 3 can be applied in practice (Figure 4.3).

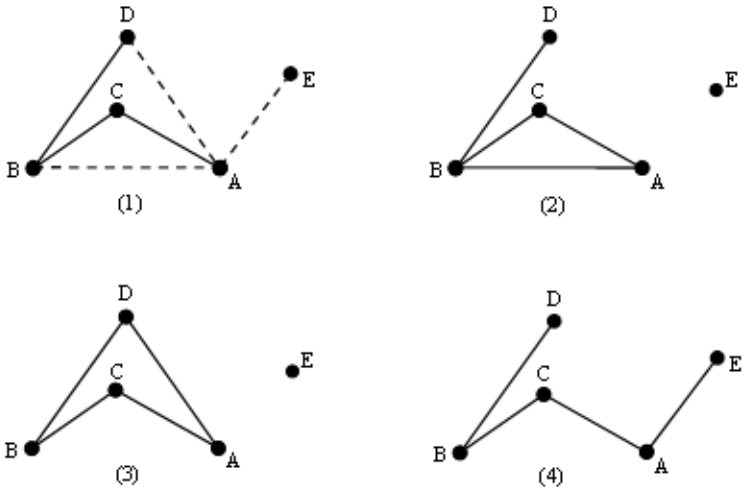


Figure 4.3 Toy network

Given the estimated coefficients, the objective function for opening a new route is³³:

³³ For simplicity, we assume that airport A neither locates in a country being a new ECAA member nor a LCC base. In this way, the objective function only includes the four network effects.

$$f_i(x) = \sum_{j,h}(-0.693x_{ij} + 0.062x_{ij}x_{ih}x_{jh} - 0.051\max_h(x_{ih}x_{hj}) + 0.01x_{hi}x_{ij}(1 - x_{hj})) \quad (6)$$

Taking airport A as an example, Figure 4.3(1) shows its initial network state. If airport A plans to enlarge its network and opens only one new route with three alternatives among airport B, D and E, then the objective function above can be used to calculate and compare the cost of opening a new route for these three cases shown in Figure 4.3 (2)-(4). For instance, the cost of connecting to airport B is: $-0.693 * 2 + 0.062 * 1 - 0.051 * 1 + 0.01 * 0 = -1.375$. Table 4.3 presents the number of network structures and cost for each case and suggests that airport A would choose to connect to B (given that B also ‘agrees’) due to less costs. This means that airport A tends to deploy a more cohesive network strategy as forming interconnected subgroup may reduce costs.

Table 4.3 Costs to airport A when considering a new route

Case	Number of Network Structures				Cost
	Degree	Transitivity Triads	NbrDist2	Betweenness	
Initial network state for airport A (1)	1	0	1	0	-0.744
Connect to airport B (2)	2	1	1	1	-1.365
Connect to airport D (3)	2	0	1	1	-1.427
Connect to airport E (4)	2	0	1	1	-1.427

Taken together, stakeholders such as airport operators, local governments and carriers can use the proposed model to assist in shaping network strategies. For airport operators, they can decide which airport to connect in the future by comparing the costs or utilities of different network ‘states’ given their existing networks. As the model allows adding exogenous actor and/or dyadic covariates, local governments can make corresponding policies based on the current results. For instance, the probability of opening a route between a former ECAA member and a new ECAA member is very low (i.e., 28% and the parameter is only marginally significant). Local governments and ECAA committees may thus consider devising more liberalized policies to encourage new entries. In addition, carriers can decide whether to take a conservative network expansion strategy or aggressive network expansion strategy based on the overall change of the air transport network. For instance, this paper finds that airports had

a low propensity to make new connections and the air transport network in Europe tend to be more cohesive and interconnected. This implies that it may be costly to open new routes. Therefore, carriers with high cost structure may consider taking a conservative network expansion strategy, but focusing on improving the efficiency of the current network.

4.7 Conclusion

To date, there has been little explicit research on the mechanisms *driving* the evolution of air transport networks. This paper has attempted to contribute to this under-researched topic by examining how stochastic actor-based modeling, a methodology drawn from the field of longitudinal social network analysis, may contribute to this stream of research. Compared to simpler forms of network analysis, SABM has four distinct advantages. First, simply measuring and comparing number of routes, density, betweenness and other network indicators at two different points in time can only show that the airport network increases or decreases in terms of these measures. However, it cannot verify whether these indicators significantly drive the changes (i.e., adding or deleting a route) of a specific network. Second, simple network analysis cannot control the influence of other factors on the network changes (i.e., the so-called “all other things being equal” effect in statistics). Third, the SABM can not only find out which factors affect network changes, but also quantify to what extent they change. Odds or binary probability can be used to interpret the results. And fourth and finally, the objective function of SABM based on the estimated parameters can help airports choose which airport to connect in the future by comparing the cost or utility of different network ‘states’.

The empirical specifics of this study were drawn from data on changes in the European air transport market (for passengers) between 2003 and 2009. Drawing on the SABM framework, we considered four endogenous structural effects (i.e., *outdegree*, *transitive triads*, *number of distances two* and *betweenness*), two exogenous actor covariates (i.e., *the ECAA enlargement* and *LCC bases*), as well as two dyadic covariates regarding the opening of new air services between former and new ECAA members.

During this period, airports in Europe showed a low tendency to open new connections. As indicated by the positive *transitive triads* effect and the negative *number of distances two* effect, the European airport network has a tendency toward network closure, implying the formation of several cohesive and interconnected triadic subgroups. This corroborates the finding of Malighetti et al. (2009) that subsystems (or modules) of high interconnectivity exist within the

European airport network. In addition, the slightly positive *betweenness* effect means that airports in Europe tend to ‘stand’ between two indirectly connected airports, corresponding to the development of ‘hubs’ in the ‘hub-and-spoke’ network configuration by full-service carriers in Europe, even though this effect is offset when controlling for the impact of growing LCC bases. The positive *transitive triplets* effect representing network closure and cohesiveness and the positive *betweenness* effect representing the opposite network concentration and sparseness provide explicit evidence that a multi-layered network in which hub-and-spoke network structure and point-to-point network structure are melted together (Dennis, 2005; Goedecking, 2010), suggesting that the trade-off game between these two types of network structures seems to continue in the future.

Moreover, the enlargement of the ECAA plays a crucial role in driving the changes of airport network in Europe and has benefited the new members to open more new air routes. The major LCC airports also significantly contribute to the changes in the European air transport network. Finally, the recent economic crisis starting from 2007 may hinder European carriers’ strategies to expand services between the former ECAA members and the new ECAA members or within each group.

Although we uncover the determinants of evolution of airport network in the pattern of statistical analysis rather than the descriptive level analysis in the previous literature, our model can be improved in the following aspects. First, more observation time points need to be collected between 2003 and 2009. For instance, we could collect data in 2005 to investigate the potential different impacts of EU enlargement or in 2007 to establish separate models for 2003 - 2007 and 2007 - 2009 to control for the influences on network changes before and after the current economic crisis. When handling data with three or more time periods, the issue whether parameters are constant across the periods should be considered. For instance, if the development of average degree does not follow a smooth curve, time-varying variables should be included or separate models should be established to capture time heterogeneity in model parameters (Snijders et al. 2010). In this way, the two dyadic covariates may reveal different results. Second, as stochastic actor-based models for non-directed networks become more and more capable of incorporating interaction terms, we could test whether the network closure is a result of inter-hub connection due to the alliance formation or the adoption of point-to-point network structure of LCCs. Third, more control variables, such as the market power of airports, could also be included to create a more profound model. Finally, SABM is currently limited to

binary network ties, so data consisting of valued ties (e.g., a continuous measure of strength of ties) had to be dichotomized for using this method. Although choosing an arbitrary cutoff value for dichotomization may affect results in general, our dataset consisting of the actual booking information of origin and destination guarantees the ‘real’ presence or absence of the ties.

Appendix

The appendix shows the mathematical expressions of stochastic actor-based model (SABM) summarized from Snijders (2011) which can be consulted by readers for detailed information. The SABM combines continuous time Markov models, random utility models and simulation techniques to analyze network dynamics (Van de Bunt and Groenewegen, 2007).

Let us assume a network consists of a set of nodes $\{1, 2, \dots, n\}$ and tie indicator variable X_{ij} which has the value 1 or 0 depending on whether there exists a tie between node i and node j . A particular realization of the network is denoted by lower case x . Observation time points are indicated by t_1, t_2, \dots, t_M with $M \geq 2$. Given a time point $t_m \leq t \leq t_{m+1}$, the current state of the network is $x = X(t)$. The actor-based network change process consists of two sub-processes, i.e., the change opportunity process and the change determination process.

First, the change opportunity process models the frequency or opportunity of tie changes by actors instead of actual change. This process is denoted as a rate function $\lambda_i(x, \alpha, \rho_m)$, where α and ρ_m are statistical parameters. The waiting time until the next opportunity for change by any actor has the exponential distribution:

$$P\{\text{Next opportunity for change after } t \text{ is before } t + \Delta t\} = 1 - \exp(-\lambda \Delta t) \quad (7)$$

where parameter $\lambda = \lambda_+(x, \alpha, \rho_m)$.

The probability that the next opportunity for change is for actor i is given by

$$P\{\text{Next opportunity for change by actor } i\} = \frac{\lambda_i(x, \alpha, \rho_m)}{\lambda_+(x, \alpha, \rho_m)} \quad (8)$$

Second, the change determination process models the precise tie changes made when an actor has the opportunity to make a change. Because we treat the European air transport network as a non-directed network, we chose to implement the actor-based ‘unilateral initiative and reciprocal confirmation’ model (Snijders, 2011; Van de Bunt and Groenewegen, 2007). In this model, one airport takes the initiative and decides to create a route to another airport based on

the expected utility. The other airport then has to confirm this change, equally based on the expected utility. Note that for termination of a link this is not required (Ruth M. Ripley et al., 2013).

Each actor i has an objective function $f_i(x, \beta)$ which determines the probability of the next tie change by this actor.

$$f_i(x, \beta) = \sum_k \beta_k s_{ki}(x) \quad (9)$$

Where, f_i is the value of the objective function for actor i depending on the current state x , a potential future state of the network (i.e., structural or endogenous effects), as well as on actor attributes and dyadic attributes (i.e. covariates or exogenous effects). The functions s_{ki} define effects that may potentially drive the changes of network from the perspective of actor i and the weights β_k are the statistical parameters that express dynamic tendencies of network evolution.

In the case of one-sided initiative, actor i selects the best possible choice. The probability of the network x changing into $x^{(\pm ij)}$ is given by:

$$p_{ij}(x, \beta) = \frac{\exp(f_i(x^{(\pm ij)}, \beta))}{\sum_{h=1}^n \exp(f_i(x^{(\pm ih)}, \beta))} \quad (10)$$

Actor j then accepts based on a binary choice based on objective function $f_j(x, \beta)$, with acceptance probability:

$$P\{j \text{ accepts tie proposal}\} = \frac{\exp(f_j(x^{(+ij)}, \beta))}{\exp(f_j(x, \beta)) + \exp(f_j(x^{(+ij)}, \beta))} \quad (11)$$

If actor i take an initiative to terminate of an existing tie, then there is need for actor j to confirm. The joint probability that the current network x changes into $x^{(\pm ij)}$ is given by:

$$p_{ij}(x, \beta) = \frac{\exp(f_i(x^{(\pm ij)}, \beta))}{\sum_{h=1}^n \exp(f_i(x^{(\pm ih)}, \beta))} \left(\frac{\exp(f_j(x^{(+ij)}, \beta))}{\exp(f_j(x, \beta)) + \exp(f_j(x^{(+ij)}, \beta))} \right)^{1-x_{ij}} \quad (12)$$

Note that the second factor functions only if $x_{ij} = 0$, which implies that $x^{(+ij)} = x^{(\pm ij)}$.

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5 TRAFFIC CHANGE AT SECONDARY AIRPORTS IN A LIBERALIZING TRANSATLANTIC MARKET, 2005-2008

Zhang, S., Derudder, B., Witlox, F., 2015. Traffic change at secondary airports in a liberalizing transatlantic market, 2005-2008. Working Paper

Abstract

The EU/US ‘open skies’ agreement (OSA) signed in April 2007 marks one of the most significant and substantial regimes of international air transport liberalization and has two stages. Stage I that took effect in 2008 removes restrictions on fares and routes, and stage II aims to address remained issues in terms of foreign ownership and cabotage rights. This paper examines the immediate impact of the Stage I of the Agreement given the available data between 2005 and 2008. As secondary airports become more important in global aviation market and only a few studies exist that examine changes at secondary airports in the context of the EU/US OSA, this paper attempts to investigate to what extent the transatlantic traffic changes at secondary airports in the European Union and the United States during the period 2005-2008. We find different trends among secondary airports: airports, such as Dusseldorf and Barcelona in the EU, and Seattle and Las Vegas in the US, show growth in terms of market presence and traffic level, whereas other secondary airports in general do not improve their role in the transatlantic market.

5.1 Introduction

Having long been one of the most regulated industries in the global economy, long-haul air transport has only become possible given a range of liberalized air service agreements, open skies treaties, regulation and deregulation of national/regional aviation markets, and traditional Bermuda-type air service agreements (Burghouwt, 2014). The EU/US ‘open skies’ agreement (OSA) signed in April 2007 marks one of the most significant and substantial regimes of international air transport liberalization and has two stages. The first stage that came into force at the end of March 2008 grants any licensed European Union (EU) carrier the right to fly between any EU airport and any United States (US) airport. In addition, it gives US carriers full fifth freedom rights between EU countries, provided that the flight originates from, or is destined for an airport in the US. However, issues in terms of imbalanced foreign ownership and cabotage rights remained in this first stage. Under the Agreement, US carriers can own 49% of the voting rights in European carriers, whereas European carriers can hold only 25% of voting rights and 49% of non-voting shares in US carriers. Although US carriers can fly into any EU country and from there onwards third EU country, EU carriers are not allowed to fly between US cities, which leads to unequal cabotage rights. In order to try to get the foreign ownership and cabotage rights, a second stage of negotiations was launched in May 2008 in order to further liberalize the transatlantic market with an aim of achieving an Open Aviation Area (OAA) by mid-2010.

Several studies have examined the impact of the EU/US OSA at the airport level and found that the liberalization effects vary from airport to airport. For instance, Humphreys and Morrell (2009) found that London Heathrow increased daily frequency by 20% after summer 2008, whereas London Gatwick lost nine flights per day mainly due to the switch of services from Gatwick to Heathrow by US carriers and British Airways. Barrett (2009) showed that Open Skies increased the number of direct routes by 3 to 10 between Dublin and the US without a compulsory stop at Shannon. Earlier research on the impact of bilateral OSAs also found that airports in highly populated regions saw traffic growth in long-haul traffic while smaller airports lost services due to reduced feeder functions (Mandel and Schnell, 2001). The review of these studies shows that only one or two airport(s) located in the EU have been investigated. As secondary airports become more important in global aviation services (Bel and Fageda, 2010; Maertens, 2010; O'Connor and Fuellhart, 2013; Weber and Williams, 2001), there can be potential for secondary airports to attract

long-haul traffic for new launched routes in a more liberalized circumstance (Sismanidou et al., 2013). It is, therefore, interesting to study to what extent passenger numbers change at secondary airports in transatlantic market, where traffic has long been concentrated in a few large airports (i.e., primary airports in this paper), against the backdrop of the EU/US OSA.

In addition, Burghouwt and Veldhuis (2006) concluded that both direct and indirect connections should be taken into account due to two reasons. First, as carriers adopting hub-and-spoke networks can benefit from economies of density and scope (Brueckner and Spiller, 1994; Caves et al., 1984), hub premium (Borenstein, 1989; Lee and Luengo-Prado, 2005) and entry deterrence (Goolsbee and Syverson, 2008), they compete for indirect traffic by improving the efficiency of schedule coordination and lower prices. Second, indirect connectivity is essential for consumer welfare. Demand on many long-haul routes is still too ‘thin’ to support any direct flight. Without these indirect connections, passengers would not reach their desired destinations. Based on an empirical case study on the market between Northwest Europe and the US, they found that the number of indirect connections increased at a higher rate than direct connectivity (i.e., 41% versus 21%) between 2003 and 2005. Redondi et al. (2011) found that hubs at the global level compete fiercely for indirect traffic and highlighted that average travel time and geographical location are important elements to improve the performance of hubs. Moreover, Valentina et al. (2014) found that the EU/US OSA had different impacts on direct and indirect flights: ‘the number of direct transatlantic connections and served airport pairs decreased and only indirect competition increased’. We thus investigate both direct and indirect markets in the analysis.

Taken together, the objective of this paper is to examine to what extent passenger numbers change at a group of secondary airports in the EU and the US after the EU/US OSA, distinguishing between direct and indirect markets. Due to data limitations, we only explore the impact of the first stage of the new Agreement and thus capture immediate changes. The studied years are 2007 (i.e., the year when the OSA was signed), 2005 (i.e., before the OSA) and 2008 (i.e., the year when the first stage of the OSA came into force). In section 5.2, we review the literature on the estimated and actual impact of the EU/US OSA on passenger numbers. Section 5.3 presents our dataset and method of classifying airports. We show changes in passenger numbers for secondary EU airports and

secondary US airports in both direct and indirect markets in section 5.4. We present our main conclusions in section 5.5, and outline areas for future research.

5.2 Impact of EU/US OSA on passenger numbers

This section reviews the literature examining the impact of fully liberalizing transatlantic market on passenger numbers. In theory, the OSA would lead to increased competition among carriers (Alves and Forte, 2015; Pels, 2009), and thus impose pressure on the participated carriers to lower costs and enhance efficiency through price cooperation and schedule coordination. The outcome of lower costs and better quality of services is that the number of passengers traveling across the transatlantic market will increase (Button, 2009). On the basis of this assumption, a number of earlier and more recent studies have estimated the impact of the OSA on passenger numbers and identified positive consequences. For instance, Gillen and Hinsch (2001) estimated that Hamburg airport would gain 149,000 new passengers of which 17,000 would be connecting passengers through the airport in a liberalized international aviation market. Brattle Group (2002) forecasted that additional transatlantic passengers would amount to between 4.1 and 11.0 million in a full and open transatlantic aviation market. Booz Allen Hamilton (2007) (an update of Brattle Group) estimated that 26 million more passengers will be carried across the EU and US over five years as a result of the OSA. In addition, Mayor and Tol (2008) predicted that passenger numbers in tourism from the US to the EU will increase by approximately 1% and 14%, depending on the magnitude of price reductions.

The literature discussed above mainly focus on the expected effects of liberalization on passenger numbers. Few studies are dedicated to conduct an empirical analysis of the actual impact of the EU-US OSA on traffic with an exception of the work done by Pitfield (2011). Focusing on routes from London airports (in particular from London Heathrow) to four major US cities (i.e., New York, Washington, Chicago and Los Angeles), Pitfield (2011) applied a number of Autoregressive Integrated Moving Average (ARIMA) models to determine the impact of the EU/US OSA on passenger numbers using data from January 1990 to March 2009. In contrast to the estimated outcomes, he found no significant impact on passenger numbers in all the cases and concluded that carriers, civil servants and governments may be overly optimistic to expect a significant change in passenger numbers after liberalization. However, as the analysis is solely based on individual case

studies, his finding cannot illustrate that other airports also experience the same situation as the London airports. This paper therefore also contributes to the empirical research on passenger effects of the EU/US OSA and provides a more comprehensive analysis by incorporating a group of primary and secondary airports.

5.3 Data

5.3.1 Dataset

The main dataset used to examine the impact of the EU/US OSA is collected through a research cooperation with Sabre Airline Solutions, and contains information drawn from Airport Data Intelligence (ADI) on actual bookings. Sabre's ADI database provides the required information for this research in terms of origin and destination airport in the EU³⁴ and the US, intermediate stops (if any), and passengers numbers at the route level in 2005, 2007 and 2008. We first define a viable direct or indirect route with at least 1% of market share in the overall direct or indirect market. Aggregating at the level of the origin airports generates 129 airports in total, 69 of which are located in the EU and 60 in the US.

Identifying secondary airports obviously requires a systematic examination of airport hierarchies, as there is no consensus in the literature as regards a classification mechanism. Ranking systems generally vary, with different indicators used in different fields (e.g., passengers and seats in air transport research *per se*, or degree, betweenness, clustering and community in research streams drawing on complex network theory), datasets, route type (i.e., direct or indirect connection), research scope (e.g., domestic, regional, international or global), dynamism (i.e., temporal aspect), and other dimensions (Burghouwt and Veldhuis, 2006; Derudder et al., 2007; Guimerà et al., 2005; Matsumoto, 2007; O'Connor, 2003; Redondi et al., 2011). As the geography of long-haul air transport in the EU is different from that of the US, classification is done separately for both regions. Different indicators are used due to the availability of data sources.

5.3.2 Identification of secondary airports in the EU

³⁴ Here, the European Union (EU) comprises its 27 members in 2007.

The EU long-haul market tends to be country-oriented before 2007 as the EU members individually signed bilateral OSAs in order to provide transatlantic services with no restriction on fares, service level, or fifth freedom operations (Button, 2009). Until 2007, EU countries such as the United Kingdom (UK), Ireland, Spain, or Greece had no OSAs with the US. We therefore proceed with the identification of secondary airports in the EU at the level of countries. In addition, countries such as The Netherlands, Belgium or Austria only have one international airport being capable of serving long-haul market and it may be difficult to establish a second international airport because of relatively small and concentrated populations. Hence, we only consider countries that have one primary airport concentrating most of its long-haul traffic alongside one or more secondary airports that may have the potential to become international gateways. The sampled countries in this research are France, Germany, Italy, Scandinavia³⁵, Spain and the UK.

The Airport Industry Connectivity Report published by Airports Council International (2014) released individual airport connectivity figures for 461 airports in 44 European countries, allowing us to benchmark the most important airports in our sampled countries. The connectivity index represented by the total connectivity units (CNU)³⁶, which is strongly correlated with economic growth and international trade, shows an airport's competitive role in global air aviation and can be used to benchmark airports. In each of the investigated countries, primary airports are defined as those that serve as hub(s) of a national carrier and have the largest CNU, whereas secondary airports are identified as those that have the second largest CNU (Table 5.1). In three countries (i.e., Germany, Italy and the UK), we further consider airports with the third largest CNU as a secondary airport because these airports also provide direct flights in the EU/US transatlantic market.

³⁵ As Copenhagen, Sweden and Norway share the same national carrier SAS airlines, we use Scandinavia to represent these three countries.

³⁶ Based on the SEO NetScan connectivity model, the total CNU measures the number and quality of direct and indirect connections by considering frequency, travel time and connecting time for every single market from perspectives of airlines, alliances, airports and passengers (Burghouwt and Redondi, 2013).

Table 5.1 Primary and secondary airports in the EU

Country	OSA date	National carrier	Primary airport (CNU _s , 2014)*	Secondary airport (CNU _s , 2014)
France	10/19/2001	Air France	CDG** (17989)	NCE (4376)
Germany	02/29/96	Lufthansa	FRA (18364) MUC (12132)	DUS (6994) TXL (6159)
Italy	11/11/1998	Alitalia	FCO (9889)	MPX (5505) VCE (3696)
Scandinavia	04/26/1995	SAS	CPH (7943)	ARN (7062)
Spain	04/30/2007	Iberia	MAD (10440)	BCN (8582)
UK	04/30/2007	British Airways	LHR (22272)	MAN (6347) LGW (3760)

Note: * The numbers shown in brackets are the total CNU_s. ** IATA codes represent the following airports: Paris Charles de Gaulle (CDG), Nice (NCE), Frankfurt (FRA), Munich (MUC), Düsseldorf (DUS), Berlin Tegel (TXL), Rome Fiumicino (FCO), Milan Malpensa (MPX), Venice (VCE), Copenhagen (CPH), Stockholm Arlanda (ARN), Madrid (MAD), Barcelona (BCN), London Heathrow (LHR), Manchester (MAN), and London Gatwick (LGW).

5.3.3 Identification of secondary airports in the US

For the identification of secondary US airports, we first single out 19 airports in the US based on whether they have significant presence (i.e., market share larger than 1% in terms of direct origin passengers) in the EU-US market. Next, we use the number of international passengers, which indicates the performance of an airport in long-haul market, to proceed with classification. Data about the number of international passengers in 2007 is collected from the US Department of Transportation, which publishes historical data about non-stop international passengers at US airports using their T-100 Segment Data (U.S. Department of Transportation, 2008).

We classified the identified US airports into two categories based on their ranks in terms of international passenger volumes. More specifically, the top 10 airports that function as international gateways are considered as primary airports, and secondary airports are those that rank just behind the identified primary airports (Table 5.2).

Table 5.2 Primary and secondary airports in the US

Primary Airport*	International Passengers (000s, 2007)	Rank	Secondary Airport	International Passengers (000s, 2007)	Rank
JFK	21,201	1	DTW	3,788	11
LAX	16,840	2	BOS	3,664	13
MIA	15,192	3	PHL	3,603	14
ORD	11,384	4	SEA	2,546	17
EWR	10,539	5	MSP	2,429	18
ATL	8,897	6	MCO	2,145	19
SFO	8,597	7	LAS	2,141	20
IAH	7,403	8	CLT	2,106	21
IAD	5,818	9	DEN	2,088	22
DFW	4,804	10			

Note: * IATA codes represent the following airports: New York John F. Kennedy (JFK), Los Angeles (LAX), Miami (MIA), Chicago O’Hare (ORD), Newark Liberty (EWR), Atlanta (ATL), San Francisco (SFO), Washington Dulles (IAD), Dallas-Fort Worth (DFW), Houston George Bush (IAH), Detroit (DTW), Boston (BOS), Philadelphia (PHL), Seattle (SEA), Minneapolis-Saint Paul (MSP), Orlando (MCO), Las Vegas (LAS), Charlotte (CLT), Denver (DEN), Phoenix (PHX).

5.4 Changes at secondary airports in the EU and the US

In this section, we examine to what extent passenger numbers change at secondary airports in the EU and the US in the first stage of the EU/US OSA in the transatlantic market. We distinguish between direct and indirect markets and apply two indicators to measure changes in the period 2005-2008 in both markets. The first approach is to measure the ratio of origin passenger numbers at secondary airports to those at primary airports. For the secondary EU airports, primary airports in the same country are used to benchmark their importance, whereas JFK that has the largest number of passengers in both markets is used to evaluate the performance of the identified secondary airports in the US³⁷. This indicator reflects the market presence of secondary airports in the transatlantic

³⁷ We scrutinize the passenger number changes at primary US airports and find that: (i) Even though EWR showed a higher growth rate than JFK between 2005 and 2007 (i.e., 39% versus 21%), this has not been enough to significantly narrow the gap as the number of passenger at JFK is still 1.8 times larger than that at EWR in 2007. (ii) Other primary airports have much less passenger numbers than JFK and EWR and do not show substantial increase in the period 2005-2008. JFK can, therefore, be used to benchmark secondary US airports.

market. The second approach is to calculate the percentage change in the origin passenger numbers of secondary airports. Furthermore, we also examine types of indirect connections of the secondary airports in order to explain changes in the indirect markets. As long-haul indirect connections can be significantly affected by location and quality of hubs (Burghouwt and Veldhuis, 2006), we distinguish types of indirect connections based on the location of hubs that transfer passengers from secondary airports in one continent to the other side of the continent. For the secondary EU airports, three types of indirect connections are identified based on whether hubs locate in the same country as secondary airports, in the EU, or in the US, respectively. While two types of indirect connections from the secondary US airports are detected based on whether hubs locate in the EU or in the US, respectively.

5.4.1 Changes at secondary airports in the EU

In the direct market, the secondary EU airports in different countries reveal different trends (Table 5.3 in Appendix). First, although primary airports in all of the investigated EU countries still play a predominant role in the transatlantic market in 2008, secondary airports, such as DUS and BCN, become more important. The surge in traffic at DUS can be largely attributed to the entry of Air Berlin after acquiring LTU International – a former Inclusive Tour Charter carrier basing at DUS, and the improvement of services by Lufthansa that has established DUS as a tertiary hub to handle the ‘spilled’ long-haul traffic from its primary hub at FRA and secondary hub at MUC (Burghouwt, 2014). Meanwhile the dramatic growth of BCN is likely to have benefited from the OSA as Spain previously had no bilateral OAS with the US.

Second, LGW witnesses decreased market presence comparing to its primary airport LHR. Humphreys and Morrell (2009) argued that LHR was more attractive than LGW due to the larger catchment area and the stronger hubbing practice at the former airport, even though LHR had serious delay problem due to the capacity limitation. Therefore, after removing the so-called “Bermuda II constraints”, the major carriers in both UK and US quickly transferred their services from LGW to LHR to take advantage of the new Agreement. Consequently, the reduction of frequencies and aircraft size resulted in decreased market presence and traffic at LGW. Third, given the modest increase or even decrease in traffic, secondary airports, such as MXP, ARN and MAN, stagnated in their role of secondary transatlantic gateways in their countries. And finally, other secondary airports

(i.e., NCE, TXL and VCE) have low direct presence in the transatlantic market, even though the number of passenger shows some degree of increase.

In the indirect market, the gap between the secondary EU airports and their countries' primary airports is, in general, narrower than that in the direct market (Table 5.4 in Appendix). In particular, following the new Agreement, BCN surpasses MAD and sustains growth of indirect traffic in 2008. The market presence and the number of passengers also continuously increased at DUS, TXL, and MXP. However, not every airport becomes more connected. Two airports in the UK report dramatic reduction in market presence and demand, similar to their performance in the direct market. Other airports, such as NCE, VCE and ARN do not have substantial growth in terms of market importance and traffic levels.

Analysis of changes in the share of the three types of indirect connections (i.e., indirect connections from secondary EU airports via primary hubs in the same country, via hubs located in the EU and in the US) highlights heterogeneous situations of the secondary EU airports. We identify and designate four distinctive types of hub-connection strategies (Figure 5.1). First, some secondary airports tend to bypass their countries' primary hubs and seek connections to other EU hubs or to a lesser degree to US hubs due to the lack of strong hubs in their own country, especially in the transatlantic market. Examples are ARN, MXP and VCE. Second, contrasting the primary-hub-bypassers, secondary airports, such as NCE and TXL, function as traffic feeders to their strong primary hubs. Third, we observe that BCN and DUS have mixed connections through hubs located in all three places, but reveal substantial growth in indirect traffic through US hubs due to the new entry of the US carriers. We term this type of situation as 'US hub - inclined'. Finally, two airports in the UK are more attractive to US carriers to feed their own hubs due to their geographical advantages. The case of BCN and DUS suggests that feeding hubs in different geographical locations can improve the performance of secondary airports in the indirect market as the transatlantic market becomes more liberalized.

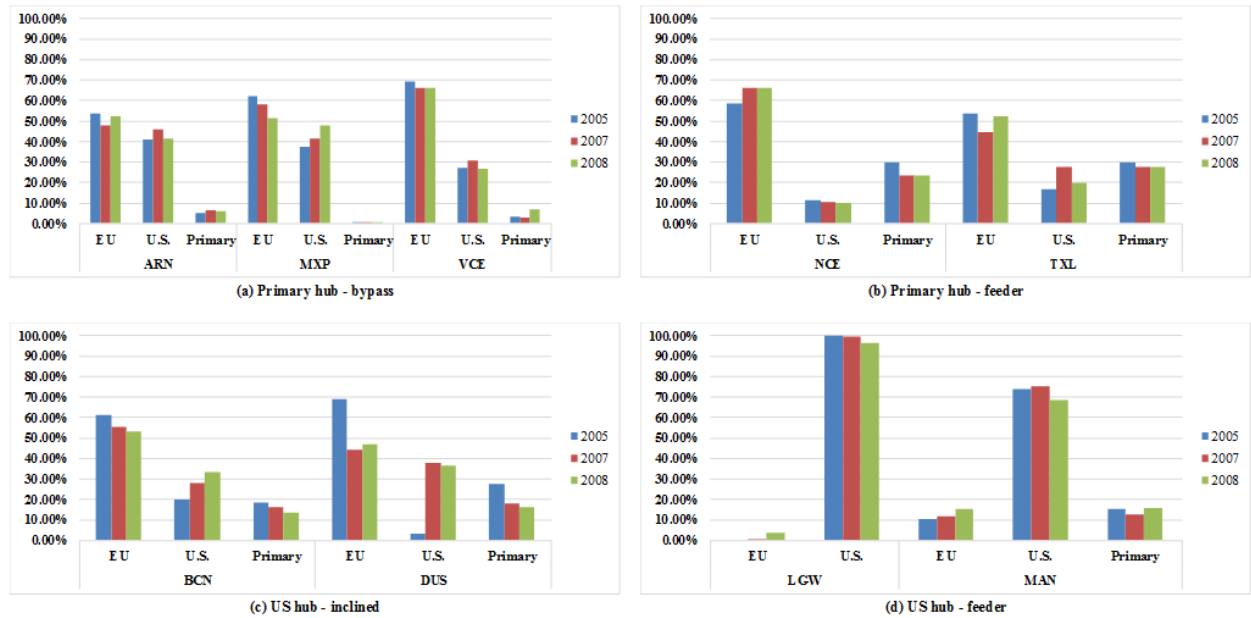


Figure 5.1 Hub-connection patterns of the secondary EU airports in indirect market

Note: The vertical axis shows the share of each type of indirect connection in terms of passenger numbers.

Taken together, the first stage of the EU/US OSA has mixed impact on secondary airports in the EU. Growth is observed at DUS and BCN in both direct and indirect markets, whereas little or even negative impacts are observed at other secondary EU airports.

5.4.2 Changes at secondary airports in the US

In the direct market, the secondary US airports have been constrained in the shadow of their primary counterparts and overall do not substantially increase their role in the transatlantic market in 2008 (Table 5.5 in Appendix). First, there was a very large difference, in the relative terms, between JFK and the investigated secondary airports in 2005 with the exception of BOS and MCO. After the first stage of the EU/US OSA, only two airports slightly improve their market presence (i.e., SEA and LAS). BOS and MCO show decreased importance, whereas other airports have nearly no change in passenger ratios. Second, in terms of percentage changes in passenger numbers, growth is experienced at four airports (i.e., SEA, DTW, MSP, and DEN) between 2007 and 2008, whereas other airports decline. During the period 2005-2008, the largest increase is at SEA where major

carriers opened several new routes to connect their or others' primary hubs, such as SEA-CDG by Air France, SEA-FRA by Lufthansa, and SEA-LHR by Northwest. However, such growth rate is still too limited to significantly alter SEA's market presence as its traffic only accounts for less than 5% of that at JFK in 2008.

Analyzing changes in the indirect market for the secondary US airports resembles the picture in the direct market. We observe reduced or marginally increased service levels in terms of the relative importance in market presence and passenger numbers at most airports (Table 5.6). An exception is LAS, which displays a small degree of improvement in serving the transatlantic market during 2005-2008. Its passenger ratio as compared to JFK increased from around 30% in 2005 to 35% in 2008 and its passenger numbers increased around 18% in the first stage of the new Agreement.

We further examine the pattern of indirect connections at the secondary US airports as regards the geographical location of hubs. Figure 5.2 shows three distinguished types of hub-connection strategies. First, some airports mainly feed hubs located in the EU (i.e., BOS, DTW and PHL). The decrease of indirect passenger numbers at these airports may be attributed to reduced performance of hubs in the EU to coordinate flights between direct transatlantic and intra-EU segments³⁸. Second, airports such as DEN, LAS and PHX provide more feeder traffic to hubs in the US than those in the EU given their strong focus on the domestic market. The observed reduction in indirect traffic at some of these airports (i.e., CLT, DEN and PHX) is partially due to the contraction of the US domestic market (Valentina et al., 2014). In addition, MSP and SEA have experienced increased share of indirect connections via EU hubs during the periods under investigation. As reflected by the airports functioning as the 'EU-hub feeder', deteriorated coordination capability of European hubs leads to decline on indirect passenger numbers at MSP and SEA.

³⁸ Due to a lack of data on scheduling, we cannot verify this explanation. However, examining the hub-connection pattern of indirect routes originating from secondary airports provides evidence that geographical location of hubs plays a role in redistributing traffic, and thus influences changes of indirect passenger numbers at secondary airports. As the attractiveness of an indirect flight depends on prices and network quality (e.g., frequency, waiting time at hubs and routing factor) (Veldhuis, 1997), future research can attempt to collect the related data to investigate schedule coordination of carriers at hubs.

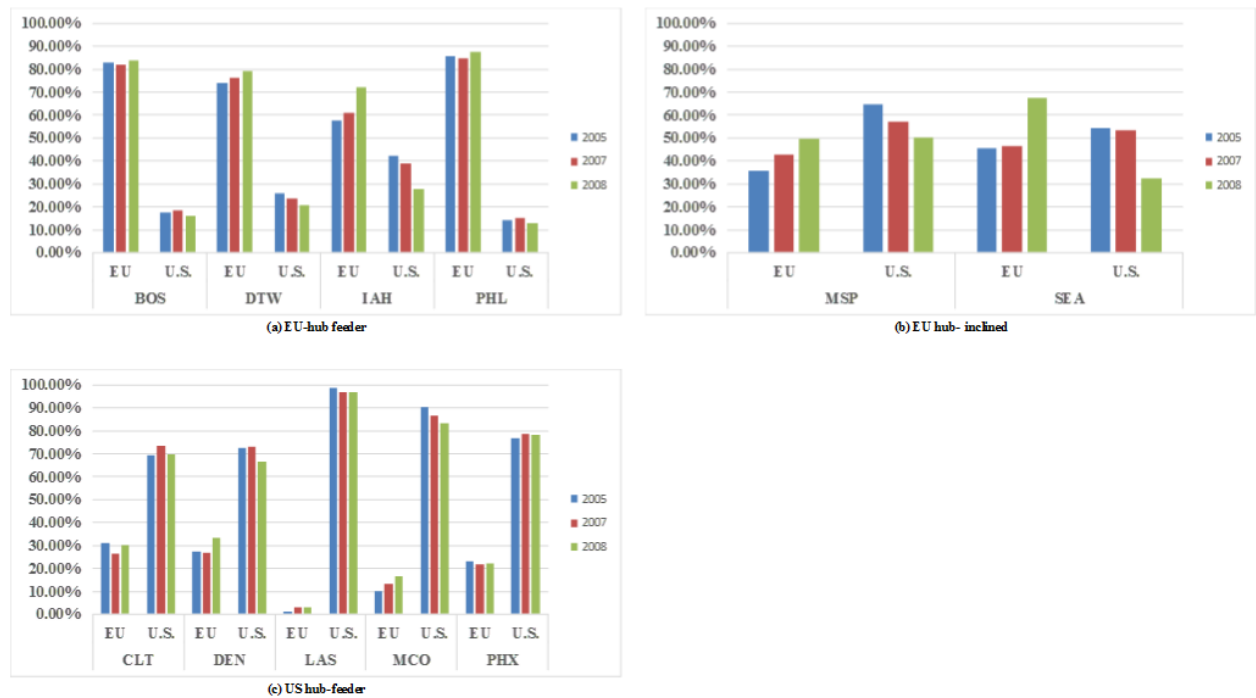


Figure 5.2 Hub-connection patterns of the secondary US airports in indirect market

Note: The vertical axis shows the share of each type of indirect connection in terms of passenger numbers.

The analysis in both direct and indirect market reveals that the secondary US airports under investigation, in general terms, show small or little growth in terms of market presence and traffic level during the period 2005-2008. We solely observe major growth figures at SEA in direct market and LAS in indirect markets.

5.5 Conclusions

The purpose of this paper is to examine passenger number changes in transatlantic market at a group of secondary airports in the EU and the US against the backdrop of the first stage of the EU/US OSA by distinguishing between direct and indirect markets. The results reveal variant trends between secondary airports. A few airports show growth in terms of market presence and traffic level, as illustrated by Dusseldorf and Barcelona in the EU, and Seattle and Las Vegas in the US. However, the significant decline of passenger numbers at London Gatwick can be directly attributed to the influence of the Agreement as shown by the swift transfer of air services to London Heathrow

by major carriers. It is noticeable that although both Spain and the UK have no bilateral OSAs with the US before 2007, their secondary airports (i.e., Barcelona and Gatwick) seem to be affected differently after ‘open skies’. Other investigated secondary airports in general do not improve their role in providing transatlantic air services, reflecting that air services concentrating on primary airports is still a relevant feature in transatlantic market. In addition, changes at secondary airports in indirect transatlantic markets can be interpreted by different patterns of connections via hubs located in different regions.

It is obvious that, since its inception in 2007, the global economic crisis partially restricts carriers’ entry into the market to exploit more opportunities provided by the EU/US OSA. In particular, Dobruszkes and Van Hamme (2011) found that the crisis of air services has much more affected the US, Europe and Japan than the rest of the world during the economic crisis using data from January 2008 to January 2010. Meanwhile, several other factors may also intervene when examining the impact of the Agreement on air services. There are three considerations that should be taken into account for further research. First, although a three-year data period (i.e., 2005-2008) can capture some changes at secondary airports, data investigating the impact of the Agreement only covers one year when the first stage of the Agreement took effect due to a lack of data after 2008. As it takes at least five years for the effects of OSA to fully materialize (Alves and Forte, 2015), data for longer time periods needs to be collected. Second, we find that changes at secondary airports in indirect transatlantic markets can be interpreted by different patterns of connections via hubs located in different regions (i.e., EU and US). However, a hub’s performance is determined by not only its regional location but also its capacity to coordinate schedules (Redondi et al., 2011). Future research can investigate how total travel time including waiting time at hubs affects the indirect connection at secondary airports. In addition, there are many potential factors other than ‘open skies’ that may affect changes at secondary airports, such as carrier strategies, international tourism and a city’s role in city networks, as well as the economic cycle. This calls for establishing time series models as suggested by Pitfield (2009) to estimate the impact of the ‘open skies’ agreement by controlling for these intervening variables.

Appendix

Table 5.3 Changes at the secondary EU airports in direct market, 05-08

Country	Airport	Passenger Number			Passenger Ratio (%)			Percentage Change (%)	
		2005	2007	2008	2005	2007	2008	2005-2007	2007-2008
France	CDG	865,657	1,062,758	975,251	100	100	100	22.77	-8.23
	NCE	25,861	18,941	24,019	2.99	1.78	2.46	-26.76	26.81
Germany	FRA	527,258	767,265	694,944	100	100	100	45.52	-9.43
	DUS	24,544	55,123	142,813	4.66	7.18	20.55	124.59	159.08
	TXL	18,138	29,205	41,560	3.44	3.81	5.98	61.02	42.30
	MUC	105,961	149,677	177,582	100	100	100	41.26	18.64
	DUS	24,544	55,123	142,813	23.16	36.83	80.42	124.59	159.08
	TXL	18,138	29,205	41,560	17.12	19.51	23.40	61.02	42.30
Italy	FCO	190,597	199,984	316,348	100	100	100	4.93	58.19
	MPX	93,294	131,401	153,688	48.95	65.71	48.58	40.85	16.96
	VCE	25,602	25,249	27,531	13.43	12.63	8.70	-1.38	9.04
Scandinavia	CPH	70,047	90,262	69,530	100	100	100	28.86	-22.97
	ARN	70,322	51,015	65,319	100.39	56.52	93.94	-27.46	28.04
Spain	MAD	154,027	245,500	221,535	100	100	100	59.39	-9.76
	BCN	16,908	51,023	86,783	10.98	20.78	39.17	201.77	70.09
UK	LHR	2,692,706	2,937,552	2,804,011	100	100	100	9.09	-4.55
	MAN	289,369	415,111	372,732	10.75	14.13	13.29	43.45	-10.21
	LGW	877,030	1,070,548	728,472	32.57	36.44	25.98	22.07	-31.95

Table 5.4 Changes at the secondary EU airports in indirect market, 05-08

Country	Airport	Passenger Number			Passenger Ratio (%)			Passenger Change (%)	
		2005	2007	2008	2005	2007	2008	2005-2007	2007-2008
France	CDG	600,161	565,600	555,162	100	100	100	-5.76	-1.85
	NCE	87,615	93,971	89,579	14.60	16.61	16.14	7.25	-4.67
Germany	FRA	555,807	455,261	435,185	100	100	100	-18.09	-4.41
	DUS	100,011	110,506	128,960	17.99	24.27	29.63	10.49	16.70
	TXL	128,824	132,214	147,858	23.18	29.04	33.98	2.63	11.83
	MUC	249,837	228,664	234,878	100	100	100	-8.47	2.72
	DUS	100,011	110,506	128,960	40.03	48.33	54.91	10.49	16.70
	TXL	128,824	132,214	147,858	51.56	57.82	62.95	2.63	11.83
Italy	FCO	496,089	536,357	419,268	100	100	100	8.12	-21.83
	MXP	171,792	180,165	224,447	34.63	33.59	53.53	4.87	24.58
	VCE	120,077	146,723	134,477	24.20	27.36	32.07	22.19	-8.35
Scandinavia	CPH	183,984	207,831	242,658	100	100	100	12.96	16.76
	ARN	165,754	172,066	191,280	90.09	82.79	78.83	3.81	11.17
Spain	MAD	225,368	233,646	229,009	100	100	100	3.67	-1.98
	BCN	202,904	264,091	272,934	90.03	113.03	119.18	30.16	3.35
UK	LHR	586,476	501,565	656,964	100	100	100	-14.48	30.98
	MAN	354,221	293,992	313,477	60.40	58.61	47.72	-17.00	6.63
	LGW	446,090	360,992	219,366	76.06	71.97	33.39	-19.08	-39.23

Table 5.5 Changes at the secondary US airports in direct market, 05-08

Airport	Passenger Number			Passenger Ratio (%)			Percentage Change (%)	
	2005	2007	2008	2005	2007	2008	2005-2007	2007-2008
JFK	2,082,768	2,511,760	2,494,264	100	100	100	20.60	-0.70
DTW	109,158	96,781	136,549	5.24	3.85	5.47	-11.34	41.09
BOS	379,489	407,313	391,875	18.22	16.22	15.71	7.33	-3.79
PHL	153,288	195,443	182,310	7.36	7.78	7.31	27.50	-6.72
SEA	46,855	81,346	120,492	2.25	3.24	4.83	73.61	48.12
MSP	31,491	33,072	45,786	1.51	1.32	1.84	5.02	38.44
MCO	455,634	437,948	394,829	21.88	17.44	15.83	-3.88	-9.85
LAS	106,170	183,926	165,185	5.10	7.32	6.62	73.24	-10.19
CLT	21,049	46,775	29,518	1.01	1.86	1.18	122.22	-36.89
DEN	47,992	46,260	56,259	2.30	1.84	2.26	-3.61	21.61
PHX	31,222	31,746	29,232	1.50	1.26	1.17	1.68	-7.92

Table 5.6 Traffic changes at the secondary US airports in indirect market, 05-08

Airport	Passenger Number			Passenger Ratio (%)			Percentage Change (%)	
	2005	2007	2008	2005	2007	2008	2005-2007	2007-2008
JFK	920,976	836,091	926,565	100	100	100	-9.22	10.82
DTW	125,239	129,081	131,407	13.60	15.44	14.18	3.07	1.80
BOS	475,588	468,180	460,279	51.64	56.00	49.68	-1.56	-1.69
PHL	110,483	96,837	87,576	12.00	11.58	9.45	-12.35	-9.56
SEA	191,011	177,911	166,798	20.74	21.28	18.00	-6.86	-6.25
MSP	126,781	121,744	108,844	13.77	14.56	11.75	-3.97	-10.60
MCO	401,767	348,478	391,219	43.62	41.68	42.22	-13.26	12.27
LAS	272,227	274,573	323,078	29.56	32.84	34.87	0.86	17.67
CLT	49,674	64,183	54,010	5.39	7.68	5.83	29.21	-15.85
DEN	190,224	176,453	152,416	20.65	21.10	16.45	-7.24	-13.62
PHX	133,434	122,752	111,256	14.49	14.68	12.01	-8.01	-9.37

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6 CONCLUSIONS: MAIN RESULTS AND FUTURE ISSUES

6.1 Introduction

The starting point of this dissertation was the identification of two significant and under-examined research areas. First, in the realm of examining determinants of airfare pricing in the airline industry, there is a lack of attention on hub markets and the associated problem of not having a concise definition of what hubs imply. As a result, the impact of route structure in hub-to-hub networks on the fare-setting may be insufficiently explored. Second, there is the limited research on the dynamics of air transport networks. This can be explained by an absence of applying suitable, advanced methodologies in network science, but also a lack of research investigating how liberalization policy may drive changes in the intercontinental markets. This dissertation has addressed both issues by putting forward four research questions, which are: (i) What factors affect the fares of full-service carriers in the US hub-to-hub markets? (ii) What factors determine price-setting of full-service carriers in European hub-to-hub markets? (iii) What factors drive changes of the European air transport network drawing on the explanatory framework of the stochastic actor-based modelling technique? (iv) To what extent does transatlantic traffic change at secondary airports in the European Union and the United States in the context of the EU/US ‘open skies’ agreement? We have answered these research questions throughout four different chapters. The purpose of this concluding chapter is to summarize and discuss our main findings, and to identify avenues for further research.

This concluding chapter is organized as follows. In the next section, we briefly review the main findings of each chapter in order to answer the above-introduced research questions. Next, we frame our findings in a broader context. To this end we use the overview scheme presented in the introductory chapter (Figure 1.1). This will help us to better analyze the route structure of an air transport network and to discuss the main factors that have significant impacts on airfares. We will also look at the network dynamics in terms of methodologies. In addition, attention will be paid to the impact of low-cost carriers. In the final section we outline a number of avenues for future research.

6.2 Overview of the main results

In Chapter 2, we defined hubs for the US full-service carriers (FSCs) using a *spatial* indicator (i.e., the relative volume of transfer passengers), and then obtained the route structure by classifying these hubs into primary and secondary hubs. Based on whether the endpoints of a route type are served as hub for one or two different carriers, we established several route structure variables that were then incorporated into an econometric model. The results show that an airport's position in the carriers' hub hierarchies influences average airfares charged by FSCs. Moreover, we also find that competition from low-cost carriers (LCCs) reduces prices charged by these FSCs. A special case is Southwest. It differs from other LCCs in that both the actual and adjoining presence of this LCC can impose a relatively larger pressure on the existing FSCs.

In Chapter 3, we explored the factors influencing the pricing behavior of full-service carriers (FSCs) in European hub-to-hub (HH) markets. A *temporal* indicator (i.e., the number of competitive indirect connections) was used to define the route structure of the examined network. Both the exploratory analysis and the econometric model showed that, in the case of alliances on routes connecting two primary hubs, airport concentration, market share inequality and competition from low-cost carriers influence average airfares charged by FSCs in European HH markets.

In Chapter 4, we attempted to bridge research on air transport networks and social networks by elaborating the roles airports play as 'actors' in their changing relationships with carriers, passengers and other airports. We also verified that stochastic actor-based models can be used to estimate and test the effect of exogenous (e.g., the emergence of major low-cost-carrier-focused airports and the enlargement of the European Common Aviation) and endogenous (e.g., degree, transitivity triads, indirect relations and betweenness effects) drivers on evolutions of the European air transport network between 2003 and 2009.

In Chapter 5, we examined how the transatlantic traffic evolves at secondary airports in the European Union (EU) and the United States (US) against the backdrop of the EU/US 'open skies' agreement during the period 2005-2008. Our preliminary analysis shows different trends among secondary airports: airports, such as Dusseldorf and Barcelona in the EU, and Seattle and Las Vegas in the US, show growth in terms of market presence and traffic level, whereas other secondary airports in general do not improve their role in the transatlantic market.

6.3 Further discussion

6.3.1 Network structure analysis

In this dissertation we have combined a spatial approach, a temporal approach, and complex network theory to define and analyze different air transport networks (Table 6.1). As these networks vary in terms of function (i.e., hubs versus ‘ordinary’ airports) and scale (i.e., the total number of airports), different indicators should be selected to answer different research questions.

Table 6.1 Overview of indicators for network analysis used in this dissertation

Indicator	Description	Category	Application Scope	Chapter Number
Transfer passengers ¹	The relative volume of transfer passengers at hubs	Spatial	Hub	2
Number of weighted indirect connections per day ²	A weighted indirect connection is defined based on the quality of the connection (e.g., flying and transfer time) at the hub and the quality of the indirect flight compared to the direct flight (e.g., routing factor)	Temporal	Hub	3
Degree ³	The number of nonstop connections of an airport	Complex network theory	Any airport	4
Transitivity triads ³	The number of transitivity triads of an airport whereby an airport’s two ‘neighbor’ airports become connected	Complex network theory	Any airport	4
Number of distances two ³	The number of airports to whom an airport is indirectly related through at least one intermediary node	Complex network theory	Any airport	4
Betweenness ³	The number of airport-pairs that are indirectly linked by an airport	Complex network theory	Any airport	4

Source: Lee and Luengo-Prado (2005)¹, Burghouwt (2007)² and Ruth M. Ripley et al. (2013)³.

Chapter 2 and 3 exclusively focused on HH networks from the perspective of carriers, and thus required a concise definition of hubs in a carrier's network system as '*the lack of homogeneity amongst hubs and any universally accepted definition can be confusing in debate, and, more importantly, can lead to a misunderstanding of what the role of any hub may be*' (Button, 2002). As these two chapters emphasize the function of hubs as switching points to reroute passengers in space and time (Derudder et al., 2007), the spatial and temporal indicators cited in Chapter 2 and 3, respectively, can thus well represent this central characteristic of hubs in a carrier's network. We used secondary literature to externally define carrier's hubs and the ensuing route structure for such HH networks due to the lack of data on the examined carriers' entire networks. As a result, this part of research can be further strengthened in two ways. First, Snijders et al. (2010) elaborated that the development of a network is determined by both endogenous variables depending only on the current network structure itself and exogenous variables depending only on externally given attributes. As shown in Table 6.1, the four indicators originating from the complex network theory (i.e., density, number of distances two, betweenness and transitivity triads) are examples of such endogenous effects, whereas the exogenous covariates can be illustrated by two spatial and temporal indicators. Put it differently, there may exist not only direct and/or indirectly connected routes but also interconnected subgroups in a HH network. Future research can thus analyze the characteristics of HH networks *per se* to better explain interrelationships among hubs. Second, mergers and acquisitions among carriers are still a fact in an increasingly consolidated US and European airline industry. For example, during 2005-2015, the US witnessed four mergers involving the six largest carriers (i.e., America West Airlines and US Airways; Northwest Airlines and Delta Airlines; Continental Airlines and United Airlines, and US Airways and American Airlines), which has led, for the time being, to three major FSCs in the domestic US airline industry. This implies that the hub hierarchy has also been altered as operational resources are rearranged and associated hub functionalities are being redefined (Ryerson and Kim, 2013). This calls for further research. One could, for example, apply the integrated complex network theory as elaborated in this dissertation to re-analyze carrier networks, and evaluate the pros and cons of these methods.

Chapter 4 introduced complex network theory in air transport networks to select the potential drivers underlying network change. Our results show that all four endogenous factors are relevant in explaining the changes of the airport network in Europe. In a recent paper, Neal (2014) compared three nested types of air transport networks by scale (route vs. origin-

destination), species (business vs. leisure) and season (summer vs. winter), and found that they share similar complex network topologies (i.e., scale-free, small-world, and modular). However, they are different in substantively important ways. For instance, although both the route and origin-destination networks are scale-free, the former is scale-free driven by efficiency in distribution networks while the latter is driven by urban population (e.g., Atlanta has a high degree in the former but low in the latter, and for New York it is the other way around). What Neal's (2014) research therefore suggests is that future research can verify whether the findings in Chapter 4 are still valid by differentiating between varieties of airport networks (e.g., short-haul vs. long-haul).

6.3.2 Main factors influencing airfares

As network management is directly linked with airfare pricing, Chapter 2 and 3 embedded route structure variables into econometric models investigating the pricing behavior of FSCs. In addition, several market structure variables and demand and cost variables, which have been shown to have significant impacts on airfares, were also incorporated and merit further discussion.

In the US market (Chapter 2), we find that the monopolistic effects on airfares are gradually weakened as hubs become less crucial in a carrier's network. Meanwhile, duopolies in routes connecting the hubs of different carriers have no or limited effects on airfares. In the European market (Chapter 3), higher fares are only found on routes where both endpoints are primary hubs for carriers within the same alliance. These results confirm that hub hierarchies characterizing route structures should be incorporated in the pricing models to better control for the inter-HH route heterogeneity. Moreover, a careful examination of these results also reveal that these variables are *de facto* the interaction term of route structure variables (i.e., primary-primary, primary-secondary and secondary-secondary) and market structure variables (e.g., routes are dominated by one carrier/alliance (monopoly) or two carriers/alliances (duopoly)). In other words, the separate route structure or market structure variables seem to have limited explanatory power in terms of pricing. One possible explanation is that these variables were taken into account as dummy variables, which may cause an endogeneity problem in the econometric models. For instance, Table 3.3 and 3.4 show that the route structure is mixed with the market structure, meaning that a route whereby both endpoints are primary airports for the same

carrier/alliance is not necessarily a monopolistic route, but can also be a duopolistic route or even an oligopolistic route. Consequently, the established econometric models may suffer from the endogeneity problem arising from omitted-variable bias. In the future, we can attempt to quantify the route structure and market structure variables, study their interactive relationships, and then compare the outcomes with their dummies counterparts to generate a more encompassing study, as was done by Evans and Kessides (1993).

In addition, other factors, such as the competition from LCCs, airport concentration, market share inequality and providing competitive one-stop alternative routings as well as control variables (e.g., current demand as represented by number of passengers, potential demand as indicated by population, traffic mix, slot-control, distance and regional tourism effect) can also have significant impacts on airfare pricing of FSCs in the HH markets. The complexity of pricing and its essential impact on profitability of carriers has made it a longstanding research topic, especially in changing market circumstances such as the proliferation of LCCs. We will systematically discuss the low-cost carrier impacts in section 6.3.4.

6.3.3 Network dynamics

The second research objective of this dissertation was to broaden our knowledge of the dynamics of air transport networks. This section provides a further discussion in terms of the methodologies that can be applied to achieve this objective. The fourth chapter innovatively explored a stochastic actor-based modeling (SABM) technique that is drawn from the field of longitudinal social network analysis to investigate the mechanisms leading to changes in networks. In our case, this involved exploring how carrier behavior can be used to explain changes in the European air transport network. We have verified the relevance of SABM in air transport networks in a conceptual and practical way.

Conceptually, we tried to answer the following question: “Can airports be considered as ‘actors’ in social networks who have the ability to exercise influence or (some degree of) control over their interactions?” In our view, the role of airports can be decomposed into a ‘physical’ and a ‘virtual’ role. A physical airport can be a multipoint service-provider firm that offers commercial services, tourist services, meeting and incentive services, logistic services and consulting services (Jarach, 2001). In terms of route and traffic development, physical airports

offer discounts and rebates on standard charges through incentives which can be significantly influenced by economic regulation, airport competition, airport ownership or characteristics of airports' catchment areas (Allroggen et al., 2013). From this perspective, airports play a relatively passive role in determining to open or end a route. However, virtual airports have become more proactively involved in the air transport business as they keep seeking interactions with carriers, passengers and other airports. First, the airport-carrier relationship has shifted to an interdependent one as illustrated by the risky status of hub airports imposed by FSCs and the improved service at secondary airports stimulated by LCCs (Francis et al., 2004; Waite, 2009). We argue that carriers and airports co-determine the dynamics of air transport networks (i.e., opening or closure of routes) in that (i) socio-economic factors of catchment areas where airports locate influence a carrier's decision to enter or exit a route; (ii) it is the entire air transport system aggregated by airports that help government and airport operators make (de)regulation policies, relying on which carriers can freely determine route entries. Second, airports attempt to 'bypass' carriers to establish direct contacts with passengers with regards to both air-transport-related businesses (e.g., tickets sale) and non-air-transport-related businesses (e.g., car parking and expenses in terminals). Third, traditionally functioning as relatively independent entities, airports have increasingly established a more closer relationship in which cooperation and competition coexist. On the one hand, airports have intended to increase each other's accessibility by opening more routes among them via direct or indirect connections (Burghouwt, 2007). On the other hand, airports appear to compete with each other in terms of local markets, connecting traffic, destinations and even cargo traffic (Tretheway and Kincaid, 2010). Taken together, airports can, therefore, be considered as 'actors' in social networks. Practically, we incorporated air transport-related variables (i.e., the enlargement of the European Common Aviation Area and the LCC-focused airports) into the models, interpreted the outcomes in the context of the air transport and proposed policy suggestions for airport operators, local governments and carriers.

In Chapter 5, we performed a descriptive analysis to examine the impact of the EU/US 'open skies' agreement on the transatlantic traffic at a group of secondary airports in the EU and US. The preliminary results show growth for some secondary airports in the long-haul sector, even though this sector has long been dominated by primary airports. Although our yearly passenger data at the route level allows us observing the changes in the demand side at the investigated airports after the first stage of the 'open skies' agreement, the results drawn from this descriptive

analysis can be improved in order to arrive at broader findings by circumventing several data and methodological difficulties. First, empirical evidence suggests that it takes at least five years for the effects of ‘open skies’ agreement to fully materialize (Alves and Forte, 2015), thus data for longer time periods needs to be collected. Second, as the global strategic alliances including virtually all the major carriers now dominate a large proportion of international air transport (Button, 2009), data at carrier and alliance levels can be helpful to investigate the impact of the new Agreement on the performance of allied carriers in terms of scheduling coordination and fare reduction (Whalen, 2007). In addition, there are many factors other than ‘open skies’, such as the economic cycle, variations in carrier competition, and other internal and external factors that may affect changes in demand and supply variables after ‘open skies’. This, therefore, calls for establishing a formal econometric model that can estimate the impact of the ‘open skies’ agreement by controlling for other intervening variables. Pitfield (2009) argues that time series models or Autoregressive Integrated Moving Average (ARIMA) models can be useful to isolate the residual impact of the ‘open skies’ agreement by seeking an intervention effect after the end of March 2008. The future work will explore the applicability of these models by collecting monthly data in terms of passenger numbers and fares at the level of routes, carriers and alliances for longer time periods.

6.3.4 The low-cost impacts

Corroborating the findings of previous research on low-cost carrier impacts (Alderighi et al., 2012; Brueckner et al., 2013; Daraban, 2007; Dresner et al., 1996; Fan, 2006), we have also captured their impacts on the airfare pricing of FSCs (Chapter 2 and 3) and on their ability to drive changes in the European air transport network (Chapter 4). We also briefly discussed the possibility of transferring the low-cost model to long-haul markets under more liberalized circumstances (Chapter 5).

In the US market (Chapter 2), we find that it is indeed necessary to distinguish between Southwest and other LCCs: both the actual and adjacent presence of Southwest in a HH route can cut FSCs’ prices by 49% and 6%, respectively, while other LCCs have no significant impact. Even though this differentiation means that the ‘Southwest copy-cats’ can still follow its model due to Southwest’s continuous profitability (Francis et al., 2006), there is also the concern that *‘it is troubling to attribute a large part of the fare reductions from airline deregulation to one*

carrier' (Morrison, 2001). In the European market, the direct presence of LCCs reduced the FSCs' prices by 9.7%, whereas no effect was found from the adjacent presence (Chapter 3). These findings suggest that policies should encourage more entries in hub markets dominated by FSCs in the US and Europe. Future research can consider the potential competition from LCCs to improve modelling in these two studies.

In modelling network dynamics in a SABM framework (Chapter 4), we established an exogenous variable (*LCC bases*) to examine whether more new routes tend to be opened by airports characterized by larger proportions of LCC services. The outcome shows that LCC-airports have a significantly higher probability of opening a new route. However, it should be noted that LCCs can easily exit an airport when negotiating successfully with another cheaper airport (Allroggen et al., 2013) or LCCs *per se* can go to demise and quickly leave the whole market.

Although we did not explicitly examine the low-cost long-haul issue in Chapter 5, the liberalization of the EU/US long-haul market would be a strong catalyst to make both FSCs and LCCs reconsider the possibility of the low-cost model in the long-haul sector. Launching low-cost long-haul services to date has been a challenging task due to difficulties to realize cost efficiency. Some services that can be minimized in short-haul markets are not as easy to be dropped in the long-haul market, such as in-flight entertainment, food, shorter seat pitch etc. Nonetheless, the costs of providing these services only account for a small proportion of the total costs, especially comparing to fuel costs, labor and central administration costs. Put differently, new long-haul LCCs may achieve cost leadership through lowering labor and central administration costs.

Despite obtaining cost advantages, there are three further significant factors influencing the success of long-haul LCCs, i.e demand, FSC's responses and the need for connecting traffic (Francis et al., 2007; Morrell, 2008). First, two types of potential demand can be substantially captured by long-haul LCCs, i.e. pure leisure markets, especially visiting friends and relatives markets and dense PTP markets with modest market share. Second, as generating new traffic is more difficult in the long-haul market than in the short-haul market, long-haul LCCs tend to diverge traffic from the established FSCs. FSCs that may respond by offering cross-subsidised low fares to deter new entrants will determine how successful long-haul LCCs are. To illustrate, at the time of writing, Lufthansa considered launching low-cost long-haul services to respond to

the fierce competition of LCCs and Middle Eastern carriers³⁹. Its performance may, to some degree, affect entries into this market. Finally, as long-haul services require high density with at least 300 seats per flight and need daily or five weekly frequencies in order to be profitable, it is important to provide feeder traffic from strong local markets. LCCs that do not operate a hub-and-spoke system may consider to explore the possibility of ‘self-hubbing’ to allow passengers arrange transfers by themselves or to seek partnerships for interline, code-sharing or even alliances.

6.4 New pillars for future research

This dissertation has broadened our understanding on the fare effects and dynamics of network structure in the air transport industry. Based on the aforementioned discussions, a variety of follow-up research questions can be put forward. We conclude by suggesting four major avenues for further research.

First, we should take a closer look at the interrelationship among hubs within hub-to-hub networks, which (i) has impacts on the configuration of multi-hub-and-spoke networks due to the rearrangement of operational resources and the redefinition of hub functionality, and (ii) better understand the mechanisms underlying network closure. For instance, would the extent of network closure over time caused by inter-hub connection due to alliance formation or multi-hub-and-poke network configuration outweigh that caused by the adoption of point-to-point network structure of LCCs, or vice versa?

Second, in the realm of airfare pricing, it is interesting to define the route structure and market structure as continuous variables, study their interactive relationships, and then compare the outcomes with their dummy counterparts to generate a more encompassing study.

Third, the framework of stochastic actor-based modelling can be further extended by (i) differentiating varieties of airport networks (e.g., short-haul vs. long-haul), (ii) collecting more observation time points to control for the potential temporal heterogeneity, (iii) incorporating more exogenous variables, (iv) exploring the possibilities of weighted network analysis.

³⁹ <http://www.ft.com/cms/s/0/8b8c38b8-076e-11e4-81c6-00144feab7de.html#axzz3UuVdRDu5>

And fourth, it would be worthwhile to study time series models to further analyze the impact of the EU/US ‘open skies’ agreements on both primary and secondary airports and to outline the opportunities and challenges for secondary airports in the process of developing their long-haul markets.

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SAMENVATTING

Prijseffecten en netwerkdynamiek in de luchtvaartindustrie: empirische studies over de Verenigde Staten en Europa

Context en doelstelling

De voortschrijdende liberalisering van de luchtvaartindustrie wordt vaak gezien als een van de voornaamste invloeden op de netwerkconfiguratie, de marktstructuur en de bedrijfsmodellen in de luchtvaartsector. Doorheen de liberaliseringstendenzen ontplooiden en intensifieerden luchtvaartmaatschappijen een 'hub-and-spoke' (HS)-strategie waarbij passagiers via een andere luchthaven moeten overstappen om hun bestemming te bereiken. Luchtvaartmaatschappijen zijn ook geleidelijk omgevormd van nationale maatschappijen naar 'full-service carriers' (FSCs) die meerdere diensten bundelen. Door de grotere concentratie van verkeer en verbindingen u hub-luchthavens verkregen de FSC's een dominante positie binnen het operationeel veld van hun hub-luchthaven, wat hen de macht verleent om hogere tarieven op te leggen voor de routes van en naar die hubs (het welgekende 'hub premium'-debat in de luchtvaartindustrie). De mate van dominantie is echter niet altijd gelijk, en varieert niet alleen binnen een individueel netwerk, maar ook tussen de verschillende netwerken van luchtvaartmaatschappijen. Deze 'hub-hiërarchie' leidt tot onderzoeksvragen over het verband tussen 'hub-to-hub' (HH) netwerken en het 'hub premium'-debat.

Tegen de achtergrond van een reeks liberaliseringsmaatregelen (zoals bijvoorbeeld drie consecutieve liberaliseringsovereenkomsten in Europa en de 'open skies'-overeenkomst tussen de Europese Unie (EU) en de Verenigde Staten) evolueren luchtvaartnetwerken in een ongekend snel tempo, en dit zowel in termen van verkeerstoename, nieuwe bestemmingen, routes en uitbreiding van de capaciteit in zowel regionale als intercontinentale markten. Toch zijn de ontwikkeling van luchthavennetwerken blootgesteld aan risico's, zoals cyclische economische crisissen. Die efemere, externe omgeving dwingt luchthavens ertoe de dynamiek van hun netwerken continu te beoordelen.

Tot op heden is er echter weinig onderzoek gewijd aan (i) de manier waarop de netwerkstructuur van invloed is op het prijsstellingsgedrag van FSCs in hun hub-markten; en (ii) het verkennen

van zowel interne en externe drijvende krachten achter de veranderingen in luchtvaartnetwerken, waarbij de veranderende rol van een luchthaven als proactieve speler in de ontwikkeling van het netwerk in acht wordt genomen.

Het algemene doel van dit proefschrift is dan ook om bij te dragen aan het lopende onderzoek naar tariefffecten en de dynamiek van de netwerkstructuur in de luchtvaartsector. We stellen vier onderzoeksvragen: (i) Welke factoren hebben invloed op de tarieven van FSC's in de hub-to-hub markten in de Verenigde Staten? (ii) Welke factoren bepalen de prijsstelling van de full-service luchtvaartmaatschappijen in de Europese hub-to-hub markten? (iii) Welke factoren veroorzaken veranderingen in het Europees luchtvervoersnetwerk vanuit het perspectief van de luchthavens (en dit aan de hand van de stochastische, actor-gebaseerde modelleertechniek)? (iv) En in hoeverre verandert het trans-Atlantisch verkeer op secundaire luchthavens in de Europese Unie en de Verenigde Staten in de context van de 'open skies'-overeenkomst tussen beide economische zones?

Overzicht van het proefschrift en de belangrijkste bevindingen

In hoofdstuk 2 definiëren we hubs voor de Amerikaanse full-service carriers (FSC's) met behulp van een *ruimtelijke* indicator (meer bepaald het relatieve volume van transferpassagiers). Op basis van de vraag of de eindpunten van een route fungeren als hubs voor één of twee verschillende luchtvaartmaatschappijen, stellen we een aantal routestructuurvariabelen op die vervolgens in een econometrisch model worden opgenomen. De resultaten tonen aan dat de positie van een luchthaven in het hiërarchisch netwerk van de hub de door de FSC's opgelegde gemiddelde vliegtarieven beïnvloedt. Bovendien stellen we ook vast dat door de concurrentie van low-cost carriers (LCC's) de FSC's worden genoodzaakt om lagere prijzen aan te nemen. Een speciaal geval is Southwest Airlines. Deze maatschappij verschilt van andere LCCs in die zin dat zowel de werkelijke als de aangrenzende aanwezigheid van deze LCC een relatief grotere druk legt op de prijsstructuur van FSC's.

In hoofdstuk 3 onderzoeken we de factoren die het prijsbeleid van FSCs in de Europese hub-to-hub (HH) markten beïnvloeden. Een *temporele* indicator (meer bepaald het aantal concurrerende indirecte verbindingen) wordt gebruikt om de routestructuur van het onderzochte netwerk te definiëren. Zowel de verkennende analyse als het econometrisch model laten zien dat, in het geval van allianties op routes tussen twee primaire hubs, luchthavenconcentraties, ongelijkheden

in marktaandeel en concurrentie tussen LCCs de gemiddelde vliegtarieven beïnvloeden die door FSC's in de Europese HH markten worden opgelegd.

In hoofdstuk 4 proberen we het onderzoek naar luchtvaartnetwerken en het domein van de sociale-netwerkanalyse netwerken samen te brengen door te onderzoeken hoe luchthavens als 'actoren' fungeren in hun veranderende relaties met luchtvaartmaatschappijen, passagiers en andere luchthavens. We tonen aan dat de stochastische, actor-gebaseerde modelleertechniek gebruikt kan worden om het effect in te schatten van exogene (bijvoorbeeld de opkomst van de op grote LCC's gerichte luchthavens en de uitbreiding van het European Common Aviation)) en endogene (bijvoorbeeld transitiviteit, indirecte relaties en 'betweenness'-effecten) krachten achter evoluties van het Europees luchtvaartnetwerk tussen 2003 en 2009.

In hoofdstuk 5 onderzoeken we hoe het trans-Atlantische luchtverkeer in de secundaire luchthavens van de Europese Unie (EU) en de Verenigde Staten (VS) tijdens de periode 2005-2008 evolueert, met de EU/VS 'open skies'-overeenkomst als context. Onze analyse toont verschillende trends onder secundaire luchthavens: luchthavens zoals Düsseldorf en Barcelona in de EU en Seattle en Las Vegas in de VS tonen een groei in termen van marktaanwezigheid en verkeersniveau, terwijl de posities in de trans-Atlantische markt van een reeks andere secundaire luchthavens niet noemenswaardig veranderen.