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Technology, business models and network structure in the airline industry*

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Abstract

Network airlines have increasingly focused their operations on hub airports through the exploitation of connecting traffic. This has allowed them to take advantage of economies of traffic density, the existence of which is beyond dispute in the airline industry. Less attention has been devoted to airlines' decisions on thin point-to-point routes, which can be served using different aircraft technologies and different business models. This paper examines, both theoretically and empirically, the impact on airlines' networks of the two major innovations in the airline industry of the last two decades: regional jet technology, and the low-cost business model. We show that, under certain circumstances, direct services on thin point-to-point routes can be viable, and that as a result airlines may be interested in diverting passengers away from the hub.

Keywords: regional jet technology; low-cost business model; point-to-point network; hub-and-spoke network

JEL Classification Numbers: L13; L2; L93

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1 Introduction

The air transportation industry has witnessed a number of changes since the deregulation of the sector during the 1980s in the US and during the 1990s in Europe. These changes include, among others, the reorganization of routes into hub-and-spoke (HS) networks and the irruption of both regional jet aircraft and low-cost carriers.

Network airlines have increasingly focused their operations on hub airports through the exploitation of connecting traffic, which has allowed them to take advantage of the economies of traffic density that characterize the airline industry. Several papers have examined optimal choices of airlines in HS networks. Less attention has been devoted to airlines' decisions on thin point-to-point (PP) routes, which can be served using different aircraft technologies (i.e., turboprops, regional jets and mainline jets) and different business models (i.e., using either the main brand or a low-cost subsidiary).

The concentration of traffic by network airlines in their respective hub airports may imply that many travelers who do not live in hub cities do not enjoy direct services on many thin routes. This is particularly true when airlines only use mainline jets. In addition, the presence of low-cost carriers may not improve the situation if these airlines provide air services on dense routes. Therefore, it is important to study the ways in which airlines choose their combination of aircraft type and business model on PP routes, and the implications of these choices for network structure.

This paper examines the impact on airlines' decisions regarding thin PP routes of the two major innovations in the airline industry of the last two decades. First, the emergence of regional jets constitutes an important technological innovation because these aircraft can provide high-frequency services on relatively long routes. Second, the emergence of a low-cost business model (either new independent low-cost carriers, or low-cost subsidiaries of network carriers) represents an important managerial innovation, making it possible to offer seats at lower fares (with lower flight frequency). We study whether these innovations may lead to profitable PP air services on thin routes that are relatively long, since traditionally very short-haul routes have been served efficiently by airlines with turboprop aircraft, and dense long-haul PP routes are typically served by network airlines using their main brands and mainline jets.

By means of a theoretical model based on certain empirical facts, we investigate the strategic decision of a carrier in a position to set up a new PP connection instead of serving this market through a hub airport. The model studies the optimal traffic division when either a regional jet technology or a low-cost business model becomes available. If regional jet technology is available, when would the airline decide to offer a new regional jet connection? Equivalently, when would the airline decide to establish a new low-cost PP connection (for instance by means of a subsidiary low-cost carrier)? The theoretical model predicts that a network airline may find it profitable to offer services on PP routes with regional jets for sufficiently short distances. This service would be aimed at business travelers, since the smaller size of regional jet aircraft may allow airlines to increase service quality (i.e., flight frequency) at higher fares. Additionally, a network airline may find it profitable to provide flights on PP routes with a low-cost subsidiary for longer distances to serve leisure travelers who are more fare-sensitive. Both results still hold true considering only thin routes.

We test the implications of the theoretical model with an empirical analysis based on data for the major network airlines in the United States (US) and the European Union (EU). These data have been obtained from RDC aviation (capstats statistics) for 2009. The results of the empirical analysis show that route distance determines the type of aircraft used, and that regional jets are widely used on thin routes with a high proportion of business travelers. Interestingly, regional jets are more used by the main European carriers and by some American carriers on thin PP routes than on hub-to-spoke routes. Finally, European airlines tend to use low-cost subsidiaries on PP routes that are thin, relatively long, and have a high proportion of leisure travelers. Therefore, our analysis suggests that the emergence of the regional jet technology and the low-cost business model has created incentives for airlines to increase their offer of PP services on relatively thin routes. This phenomenon has acted as a brake on the prominent *hubbing* network strategy followed by major airlines since the deregulation of the sector, and it has important implications at the regional level.

Even though the research question raised in this paper seems especially relevant, to the best of our knowledge previous studies have not approached the issue from a global perspective. Brueckner and Pai (2009) argue that regional jets may have important advantages over mainline jets and turboprops; compared with mainline jets, they have smaller capacity with a relatively long range and similar cruising speed and comfort, and compared with turboprops, they have similarly small capacity but longer range, more comfort, and less noise. These advantages may be important in the development of services on thin PP routes that are too long for turboprops and too thin to obtain commercially viable frequency with mainline jets. Testing what they called the "new route hypothesis" through an analysis of data on new routes started by four major US carriers since 1996, Brueckner and Pai (2009) found no empirical evidence for it and concluded that regional jets are mostly used to feed hubs. Similarly, studying the case of Continental Airlines (focusing on its hubs in Cleveland and Houston), Dresner *et al.* (2002)

found that regional jets are mainly used on new HS routes (longer than routes served with turboprops), and appear to increase demand on denser routes where they replace turboprops. Regarding the provision of air services by low-cost carriers, the existing literature finds that the entry of a low-cost carrier on a route exerts downward pressure on fares.[1] Looking at the type of routes served by low-cost carriers, the paper by Boguslaski *et al.* (2004) found that Southwest tends to provide services on dense routes.[2] Therefore, our results seem to differ from this literature since we find that both regional-jet and low-cost connections are associated with thin PP routes.

The plan of the paper is as follows. Some descriptive data on PP routes operated by the main American and European airlines are provided in Section 2. Then, a theoretical model analyzing the optimal traffic division in a simple network is presented in Section 3. Section 4 proposes a model to test the theoretical results empirically. Finally, a brief conclusion closes the paper. All the proofs are provided in Appendix A.

2 Some descriptive data on PP routes

We use data on American and European routes during 2009. This dataset includes the distance of each route and distinguishes between hub-and-spoke-routes (i.e., HS routes) and spoke-to-spoke routes (i.e., PP routes). Our sample includes all routes with direct flights served within continental US by the six major American network carriers and their subsidiaries, and all routes with direct flights served within the EU by the four major network airlines and their subsidiaries. Overall, the total number of observations in our sample (at the airline-route level) is 5031 for US carriers, and 1033 for EU airlines. Section 4 provides a thorough explanation of the data and the sources of information used in the econometric analysis.

Focusing on PP routes, Figs. 1 and 2 below show histograms of the distance variable for the US and the EU respectively. More precisely, we observe that the number of PP routes operated by US carriers is high for routes up to 1200 miles, whereas the number of PP routes operated by EU carriers is relatively high for routes up to 600 miles. It must be taken into account that the number of observations for EU airlines is lower than that of US airlines and that the mean route distance is much longer in US. Hence, we must use different categories of distance when analyzing which type of airlines are responsible for the high number of PP

[1] See Goolsbee and Syverson (2008), Morrison (2001) and Dresner *et al.* (1996).

[2] From a different perspective, Basso and Jara-Díaz (2006) and Kraus (2008) study the implications of network structure on aggregate costs.

routes in those distance ranges. Note also that US carriers did not have any LC subsidiaries in 2009.

–Insert Figs. 1 and 2 here–

Fig. 3 below shows that regional aircraft are the type most used by the main American carriers up to a route distance of 900 miles. In fact, US major airlines mainly serve PP routes in the distance range 300-900 miles with RJs, and RJs are still widely used on routes in the distance range 900-1200 miles. Turboprops are widely used on routes shorter than 300 miles. Mainline jets are obviously the dominant type of aircraft on routes longer than 1200 miles. The upshot of this exploratory examination of data is that the high number of PP routes in the distance range of 300-1200 (and particularly in the distance range 300-900 miles), may be related to the advantages that US airlines have gained from using RJs.

–Insert Fig. 3 here–

Finally, Fig. 4 shows that RJs are the aircraft most frequently used by the main European carriers up to a route distance of 600 miles, especially the distance range 300-600 miles. Turboprops are also widely used on routes shorter than 300 miles. Interestingly, the use of mainline jets with an LC subsidiary is the dominant model on routes longer than 600 miles. Thus, these data provide some evidence that the relatively high number of PP routes in the distance range 300-600 miles has to do with the use of RJs. Furthermore, the viability of PP routes on routes longer than 600 miles seems to be associated (in many cases) with the use of LC subsidiaries.

–Insert Fig. 4 here–

The theoretical and empirical analyses below explore this evidence further, with the purpose of understanding the impact of both RJ technology and the LC business model on airline network structure in the US and the EU.

3 The theoretical model

We consider a monopoly model based on the analysis of Brueckner and Pai (2009) to study the impact of regional jet aircraft. The main novelties of our analysis are: the extension of the model to consider new low-cost PP connections, the explicit consideration of PP routes as thin routes, and the introduction of the distance between endpoints as an important element conditioning airlines' choices. As explained below, following Bilotkach *et al.* (2010), route distance is introduced in the model by means of a distance-dependent cost function. Since airlines use different aircraft and business models depending on the characteristics of each city-pair market (and route distance is an important element), we identify the optimal network choice for different distance ranges. This also provides us with some predictions to test in the econometric analysis in Section 4.

We assume the simplest possible network with three cities (A, B and H) and three city-pair markets (AH, BH and AB) as shown in Fig. 5.[3]

−Insert Fig. 5 here−

AH and BH are "local" markets, which are always served nonstop, and market AB can be served either directly or indirectly with a one-stop trip via hub H, depending on the airline's network choice. The distance of routes AH and BH is assumed to be constant and equal to 1, whereas the distance of route AB is given by d, with $d \in (0, \infty)$. The magnitude of d is an important factor influencing the airline's network choice.

As in Brueckner (2004), utility for a consumer traveling by air is given by $consumption + travel\ benefit -$ *schedule delay disutility*. *Consumption* is $y-p$ where y denotes income and p is the airline's fare. $Travel\ benefit$ is denoted by b. Letting T denote the time circumference of the circle, consumer utility then depends on expected schedule delay (defined as the difference between the preferred and actual departure times), which equals $T/4f$, where f is number of (evenly spaced) flights operated by the airline. The *schedule delay disutility* is equal to a disutility parameter $\delta > 0$ times the expected schedule delay expression from above, thus equaling $\delta T/4f = \gamma/f$, where $\gamma \equiv \delta T/4$. Hence, utility from air travel is $u_{air} = y-p+b-\gamma/f$.

As in Brueckner and Pai (2009), we assume that the airline is a perfectly discriminating monopolist able to extract all surplus from the consumer. Letting u_o denote the utility of the outside option (which might represent an alternative transport mode such as automobile, train or ship or not traveling at all), surplus extraction implies $u_{air} = u_o$ and thus $p = z-\gamma/f$, where $z \equiv y + b - u_o$ is constant. Note that an increase in f reduces the *schedule delay disutility*, allowing the airline to raise p. Additionally, we suppose that connecting passengers incur an extra time cost at the hub. Let us denote this layover time disutility by μ, which enters as a negative shift factor in the utility of connecting passengers since they dislike waiting, and thus $p = z - \mu - \gamma/f$ for connecting passengers.

[3] The same network is considered in Oum *et al.* (1995), Brueckner (2004), Flores-Fillol (2009) and Brueckner and Pai (2009) since it is the simplest possible structure allowing for comparisons between hub-and-spoke (HS) and fully-connected (FC) configurations.

To address the question at hand, this setup is expanded to admit two types of consumers: H-types (business travelers) and L-types (leisure travelers). With respect to the L-types, the H-types have higher income, higher layover-time disutility and a stronger aversion to schedule delay, i.e., $z_H > z_L$, $\mu_H > \mu_L$ and $\gamma_H > \gamma_L$.

Fares charged by the perfectly discriminating monopolist to AB passengers depend on their type and routing. Denoting d and c superscripts direct and connecting services, AB fares are

$$p_H^d = z_H - \gamma_H / f^d, \tag{1}$$

$$p_H^c = z_H - \mu_H - \gamma_H / f^c, \tag{2}$$

$$p_L^d = z_L - \gamma_L / f^d, \tag{3}$$

$$p_L^c = z_L - \mu_L - \gamma_L / f^c, \tag{4}$$

where f^d and f^c are the flight frequencies for the two routings,[4] and type-H fares respond more than type-L to changes in flight frequency since $\gamma_H > \gamma_L$.

Turning our attention to local passengers in markets AH and BH, we assume that there is a share λ of type-H passengers and a share $1 - \lambda$ of type-L passengers. Therefore

$$\widetilde{p} = \widetilde{z} - \widetilde{\gamma} / f^c, \tag{5}$$

with $\widetilde{z} = \lambda z_H + (1 - \lambda) z_L$ and $\widetilde{\gamma} = \lambda \gamma_H + (1 - \lambda) \gamma_L$.

Passenger population size in market AB is normalized to unity, whereas population in markets AH and BH is given by N, with $N > 1$ since local spoke-to-hub markets (and hub-to-spoke markets) are normally denser than spoke-to-spoke markets. Thus, the route AB can be considered as a thin route, and we will study the profitability of new PP air services on this route. In market AB, we assume that there is a share δ of type-H passengers and a share $1-\delta$ of type-L passengers. Further, the shares of H-types and L-types flying direct are θ_H and θ_L, respectively. Therefore the direct traffic on route AB and the connecting traffic on routes AH and BH are given by

$$q^d = \delta\theta_H + (1 - \delta)\theta_L, \tag{6}$$

$$q^c = N + 1 - q^d. \tag{7}$$

Naturally, as θ_H and/or θ_L increase, q^d also increases while q^c decreases. The number of flight departures on route AB is given by $f^d = q^d / n^d$, where n^d is the *number of passengers*

[4]As argued in Flores-Fillol (2010), connecting passengers care about schedule delay on both routes and thus the relevant frequency for these passengers is $min\{f_{AH}^c, f_{BH}^c\}$. In the symmetrical case $f_{AH}^c = f_{BH}^c = f^c$, the *schedule delay disutility* is equal to γ_H / f^c for H-types and γ_L / f^c for L-types.

per flight on route AB. Both aircraft size and load factor determine the number of passengers per flight, which is given by $n^d = l^d s^d$, where s^d stands for aircraft size and $l^d \in [0,1]$ for load factor. Equivalently, flight frequency on routes AH and BH is $f^c = q^c/n^c$, with $n^c = l^c s^c$ being the number of passengers per flight on each of these routes.[5]

Substituting these expressions for f on Eqs. (1)-(5), revenue is

$$\begin{aligned} R \;=\; & \underbrace{2N\left(\widetilde{z}-\frac{\widetilde{\gamma}n^c}{q^c}\right)}_{local}+\underbrace{\theta_H\delta\left(z_H-\frac{\gamma_H n^d}{q^d}\right)}_{direct\ H\text{-}types}+\underbrace{\theta_L(1-\delta)\left(z_L-\frac{\gamma_L n^d}{q^d}\right)}_{direct\ L\text{-}types}+ \\ & \underbrace{+(1-\theta_H)\delta\left(z_H-\frac{\gamma_H n^c}{q^c}\right)}_{connecting\ H\text{-}types}+\underbrace{(1-\theta_L)(1-\delta)\left(z_L-\frac{\gamma_L n^c}{q^c}\right)}_{connecting\ L\text{-}types}, \end{aligned} \tag{8}$$

where the 2 factor arises because there are two local markets, i.e., AH and BH.

Similarly to Bilotkach *et al.* (2010), a *flight's operating cost* on route AB is given by $\omega(d) + \tau^d n^d$, where the parameter τ^d is the marginal cost per seat of serving the passenger on the ground and in the air, and the function $\omega(d)$ stands for the cost of frequency (or cost per departure), which captures the aircraft fixed cost (including landing and navigation fees, renting gates, airport maintenance and the cost of fuel). The function $\omega(d)$ is assumed to be continuously differentiable with respect to $d > 0$ with $\omega'(d) > 0$ because fuel consumption increases with distance. Note that cost per passenger, which can be written $\omega(d)/n^d + \tau^d$, visibly decreases with n^d capturing the presence of economies of traffic density (i.e., economies from serving a larger number of passengers on a certain route), the existence of which is beyond dispute in the airline industry.[6] In other words, having a larger traffic density on a certain route reduces the impact on the cost associated with higher frequency. Further, to generate determinate results, $\omega(d)$ is assumed to be linear, i.e., $\omega(d) = \omega d$ with a positive marginal cost per departure $\omega > 0$.[7] Therefore, the airline's total cost from operating on route AB is $C^d = f^d\left[\omega d + \tau n^d\right]$ and, using $f^d = q^d/n^d$, we obtain $C^d = q^d\left(\frac{\omega d}{n^d} + \tau^d\right)$. Proceeding analogously for routes AH and BH, we obtain $C^c = q^c\left(\frac{\omega}{n^c} + \tau^c\right)$ since distance of routes AH

[5] We extend the approach in the existing literature, which typically assumes 100% load factor (see Brueckner, 2004; Brueckner and Flores-Fillol, 2007; Flores-Fillol, 2009; Brueckner and Pai, 2009; Flores-Fillol, 2010; and Bilotkach *et al.*, 2010).

[6] Empirical studies confirming presence of economies of traffic density in the airline industry include Caves *et al.* (1984), Brueckner and Spiller (1994) and Berry *et al.* (2006).

[7] Since fuel consumption is higher during landing and take off operations, $\omega''(d) < 0$ might be a natural assumption. Assuming a concave function of the type $\omega(d) = \omega d^r$ with $r \in (0,1)$ would have no qualitative effect on our results; the critical distances that will be computed would simply need to be raised to the power $1/r$.

and BH is assumed to be constant and equal to 1. Therefore, the *airline's total cost* from operating all routes is

$$C = \underbrace{2q^c\left(\frac{\omega}{n^c} + \tau^c\right)}_{C^c} + \underbrace{q^d\left(\frac{\omega d}{n^d} + \tau^d\right)}_{C^d}. \tag{9}$$

Quite naturally, as d increases and the triangle in Fig. 5 flattens, direct connections between cities A and B become less profitable. The airline's objective is to maximize profits, which are given by $\pi = R - C$.

As in Brueckner and Pai (2009), we assume that airline's only choice variables are θ_H and θ_L, i.e., the division of H-type and L-type traffic between direct and connecting service (note that q^c and q^d depend on θ_H and θ_L). On the one hand, we observe that $\pi(\theta_H, \theta_L)$ is a strictly convex function of θ_H for γ_H sufficiently large with respect to γ_L,[8] so that the optimal θ_H is a corner solution, equal to either 0 or 1. On the other hand, it can be checked that $\pi(\theta_H, \theta_L)$ is a strictly concave function of θ_L, meaning that the optimal θ_L lies in the interval $[0, 1]$.

Starting from a situation in which the airline operates a hub-and-spoke network (i.e., AB passengers make a one-stop trip via hub H and $q^d = 0$), in the two following subsections we will consider other simple divisions of traffic between direct and connecting traffic when either a regional jet (RJ) or a low-cost (LC) direct connection between A and B is established by the airline. Even though the AB market is relatively thin (as compared to local markets, which are denser),[9] the airline may be interested in sending either H-types or L-types direct (or both). The result $(\theta_H, \theta_L) = (0, 0)$ represents a hub-and-spoke (HS) network, and $(1, 1)$ denotes a fully-connected (FC) network. Finally, passenger segmentation occurs when only one type of passengers flies direct: $(1, 0)$ occurs when only H-types fly direct, and $(0, 1)$ occurs when only L-types fly direct.

3.1 The emergence of RJ technology

RJ technology is characterized by a lower aircraft size and a higher marginal cost per seat. Let us consider an airline that operates a HS network (i.e., there is no direct service between A and B). In this situation, when a RJ technology becomes available, the emergence of a new direct service on route AB to carry type-H passengers seems natural, since the lower aircraft

[8] As in Brueckner and Pai (2009), strict convexity requires $\gamma_H > 2\tilde{\gamma}$ or, equivalently, $\gamma_H(1-2\lambda) > 2\gamma_L(1-\lambda)$. This condition requires γ_H sufficiently large with respect to γ_L and $\lambda < 1/2$, i.e., there are more L-types than H-types among local passengers. Computations are available upon request.

[9] Remember that passenger population size in market AB is normalized to unity, whereas population in markets AH and BH is given by N, with $N > 1$.

size implies a higher flight frequency (because $f^d = q^d/n^d$, with $n^d = l^d s^d$) and H-types are more sensitive to schedule delay. Therefore, assuming that load factor remains the same in the three routes of the network (i.e., $l^d = l^c$), then $n^d < n^c$ and $\tau^d > \tau^c$. Hence, as pointed out in Brueckner and Pai (2009), for the outcome $(\theta_H, \theta_L) = (1, 0)$ to be optimal, the following conditions need to be met

$$\frac{\partial \pi(1,0)}{\partial \theta_L} < 0, \tag{10}$$

$$\pi(1,0) - \pi(0,0) > 0, \tag{11}$$

$$\frac{\partial \pi(0,0)}{\partial \theta_L} < 0, \tag{12}$$

where Eqs. (10) and (11) ensure that there is no incentive to either increase θ_L or reduce θ_H (remember that $\theta_H = \{0, 1\}$), and Eq. (12) is needed to rule out $\pi(1,0) < \pi(0, \theta_L)$ for $\theta_L \in [0, 1]$.

Carrying out the needed computations, Eq. (10) becomes

$$\Omega \equiv (1-\delta)\left[\mu_L + 2\tau^c - \tau^d + \omega\left(\frac{2}{n^c} - \frac{d}{n^d}\right) + n^d \frac{\gamma_H - \gamma_L}{\delta} - N n^c \frac{2\widetilde{\gamma} - \gamma_L}{(N+1-\delta)^2}\right], \tag{13}$$

which shows the gains and losses for the airline from increasing θ_L (i.e., sending more L-types direct). On the one hand, the airline saves the connecting discount to compensate for layover time disutility (μ_L) and the costs corresponding to routes AH and BH: the passenger cost ($2\tau^c$) and the cost of frequency ($\frac{2\omega}{n^c}$). Note that the cost of frequency decreases in s^c (since $n^c = l^c s^c$) because there is a negative relationship between flight frequency and aircraft size. On the other hand, it incurs the costs associated to the new direct service on route AB: the passenger cost (τ^d) and the cost of frequency ($\frac{\omega d}{n^d}$), which increases with distance since longer routes are more costly to serve. The two last terms capture the gain of sending more L-types direct as aircraft size is larger on route AB and smaller on routes AH and BH. Thus, there is an advantage associated to larger aircraft, which implies lower flight frequency and lower fares, since L-types are fare-sensitive.

Equivalently, Eq. (11) reduces to

$$\Phi \equiv \delta\left[\mu_H + 2\tau^c - \tau^d + \omega\left(\frac{2}{n^c} - \frac{d}{n^d}\right) - n^d \frac{\gamma_H}{\delta} + n^c \frac{(1-\delta)(\gamma_H - \gamma_L) + N(\gamma_H - 2\widetilde{\gamma})}{(1+N)(1+N-\delta)}\right], \tag{14}$$

which indicates that the gain from sending all the H-types direct increases with their layover time disutility (μ_H) and with the costs corresponding to routes AH and BH ($2\tau^c + \frac{2\omega}{n^c}$). In contrast, the airline incurs the costs associated to the new direct service on route AB ($\tau^d + \frac{\omega d}{n^d}$). The negative effect $n^d \frac{\gamma_H}{\delta}$ shows that the benefit from shifting all the H-types to direct service decreases with aircraft size and thus increases with frequency, capturing the advantage in terms of schedule delay stemming from a higher flight frequency and a smaller aircraft size. The last positive term, which increases with n^c and thus decreasing with f^c, captures the fact that sending all the H-types direct is more beneficial if the service quality (i.e. flight frequency) of the connecting service is poor.

Finally, Eq. (12) yields this condition

$$\Lambda \equiv (1-\delta)\left[\mu_L + 2\tau^c - \tau^d + \omega\left(\frac{2}{n^c} - \frac{d}{n^d}\right) - n^c \frac{\delta\left(\gamma_H - \gamma_L\right) - N\left(2\widetilde{\gamma} - \gamma_L\right)}{(1+N)^2}\right], \tag{15}$$

which has a similar interpretation as Eq. (13), except for the last term that has a more complex intuitive explanation.

At this point, as in Brueckner and Pai (2009), we can analyze the emergence of a direct connection to serve H-type passengers. We consider an initial situation in which all aircraft are mainline jets with similar characteristics, i.e., $n^d = n^c$ and $\tau^d = \tau^c$. In this situation, it seems reasonable to assume that it is optimal for the airline to operate a HS network, so that $\theta_H^* = \theta_L^* = 0$. For this situation to hold, the inequalities $\Omega, \Phi, \Lambda < 0$ need to be satisfied. We therefore consider the adoption of a new RJ technology, so that the airline sends the H-types direct on route AB by implementing a new business model characterized by lower aircraft size (and thus higher flight frequency) and higher cost per passenger. Therefore, we can define $\Delta n^d = n^d - n^c < 0$ and $\Delta\tau^d = \tau^d - \tau^c > 0$. In this situation, the expressions Ω and Λ remain negative since they decrease in τ^d and increase in n^d, and only Φ may change sign. More precisely, Φ will become positive when

$$-\delta\Delta\tau^d - \frac{\delta\omega d}{\Delta n^d} - \gamma_H \Delta n^d > 0, \tag{16}$$

where the first and the second terms have a negative impact, whereas the third term has a positive effect. When Φ reverses its sign from negative to positive, then $\theta_H^* = 1$, $\theta_L^* = 0$ becomes an optimal decision. On the one hand, a higher cost associated to route AB and a longer distance between cities A and B make the emergence of a direct connection to serve H-types more difficult. On the other hand, type-H passengers' aversion to schedule delay makes a new direct connection easier.

3.2 The emergence of a LC business model

Compared to the standard HS business model (using mainline jets), the LC business model is characterized by a higher load factor and a lower marginal cost per seat. As before, let us consider an airline that initially operates a HS network (i.e., there is no direct service between A and B). In this situation, the airline can set up a new LC direct connection.[10] Although the airline could set up a subsidiary LC carrier on route AB, it may also create its own LC direct connection offering less frequency at lower fares, since market AB is thinner than local markets.[11] In this framework, the emergence of a new direct service to carry type-L passengers seems natural, since the higher load factor implies a lower flight frequency and thus a lower fare (because $p_L^d = z_L - \gamma_L/f^d$) and L-types are less sensitive to schedule delay and more fare-sensitive. Since the airline uses similar mainline jets on all routes, aircraft size is also the same (i.e., $s^d = s^c$), then $n^d > n^c$ and $\tau^d < \tau^c$. Although these two considerations are favorable to the adoption of a LC business model, there is still a trade-off since setting up a new direct connection implies a new cost element, as shown in Eq. (9). For the outcome $(\theta_H, \theta_L) = (0, 1)$ to be optimal, the following conditions need to be observed

$$-\frac{\partial \pi(0,1)}{\partial \theta_L} < 0, \tag{17}$$

$$\pi(1,1) - \pi(0,1) < 0, \tag{18}$$

$$-\frac{\partial \pi(1,1)}{\partial \theta_L} < 0, \tag{19}$$

where Eqs. (17) and (18) ensure that there is no incentive either to decrease θ_L or to raise θ_H (remember that $\theta_H = \{0, 1\}$), and Eq. (19) is needed to rule out $\pi(0,1) < \pi(1, \theta_L)$ for $\theta_L \in [0,1]$. Carrying out the necessary computations, Eq. (10) becomes

$$\Psi \equiv (1-\delta)\left[-\mu_L - 2\tau^c + \tau^d - \omega\left(\frac{2}{n^c} - \frac{d}{n^d}\right) + n^c \frac{\delta\left(\gamma_H - \gamma_L\right) + N\left(2\widetilde{\gamma} - \gamma_L\right)}{\left(N+\delta\right)^2}\right], \tag{20}$$

which shows the gains and losses for the airline from decreasing θ_L (i.e., sending fewer L-types direct). On the one hand, the airline incurs the connecting discount to compensate for layover time disutility (μ_L) for those passengers who switch from the direct to the connecting service. Additionally, the airline incurs the passenger cost ($2\tau^c$) and the frequency cost ($\frac{2\omega}{n^c}$) associated to routes AH and BH, whereas it saves the passenger cost (τ^d) and the frequency cost ($\frac{\omega d}{n^d}$) associated to the direct service on route AB. Finally, the last term captures the fact that savings from sending fewer L-types direct increase with load factor of connecting aircraft,

[10] The managerial operations that a carrier needs to carry out to implement a LC business model on route AB remain beyond the scope of this paper.

[11] If the airline itself creates a direct LC connection, it could be argued that the assumption of the lower marginal cost per seat on route AB may not be realistic. This assumption can easily be relaxed since it is not needed to obtain the results that follow.

capturing the cost advantage in terms of economies of traffic density stemming from larger aircraft size (and lower frequency), which leads to lower fares.

Equivalently, Eq. (18) reduces to

$$\Gamma \equiv \delta\left[\mu_H + 2\tau^c - \tau^d + \omega\left(\frac{2}{n^c} - \frac{d}{n^d}\right) - n^d\left(\gamma_H - \gamma_L\right) + n^c\frac{\gamma_H - 2\widetilde{\gamma}}{N+\delta}\right], \tag{21}$$

which indicates that the gain from sending all the H-types direct logically increases with their layover time disutility (μ_H) and with the costs corresponding to routes AH and BH ($2\tau^c + \frac{2\omega}{n^c}$). In contrast, the airline incurs the costs associated to the direct service on route AB ($\tau^d + \frac{\omega d}{n^d}$). The last two terms show the preference of H-types for service quality (i.e., flight frequency). Thus, the higher the load factor on route AB (which increases n^d), the lower the frequency and the higher the cost for H-types to fly direct. Equivalently, the higher the load factor on routes AH and BH (which increases n^c), the lower the frequency and the higher the savings from switching to a direct connection.

Finally, Eq. (19) yields this condition

$$\Upsilon \equiv (1-\delta)\left[-\mu_L - 2\tau^c + \tau^d - \omega\left(\frac{2}{n^c} - \frac{d}{n^d}\right) - \delta n^d\left(\gamma_H - \gamma_L\right) + n^c\frac{2\widetilde{\gamma} - \gamma_L}{N}\right], \tag{22}$$

which has a similar interpretation to Eq. (20).

At this point, we can analyze the emergence of a direct connection to serve L-type passengers. We consider an initial situation in which all routes have similar characteristics, i.e., $n^d = n^c$ and $\tau^d = \tau^c$. In this situation, the optimal division of passengers is $(\theta_H^*, \theta_L^*) = (0, \theta_L^*)$ with $\theta_L^* \in [0,1)$, so that the airline operates a HS network where all H-types and at least some L-types fly connecting, where θ_L^* approaches 0 as the distance between A and B increases.[12] To sustain this distribution of passengers, we need to observe $\Psi, \Upsilon > 0$, so that $\theta_L = 1$ is not optimal, meaning that (at least) some L-types travel connecting through the hub. Concerning H-types, the airline will send them connecting when $\Sigma \equiv \pi(1,\theta_L) - \pi(0,\theta_L) < 0$ with $\theta_L \in [0,1]$. Note that Γ is a particular case of Σ with $\theta_L = 1$ (the expression for Σ is given in Appendix A) and thus $\Sigma < 0$ implies $\Gamma < 0$. Therefore, $\Psi, \Upsilon > 0$ and $\Sigma < 0$ are assumed to hold. In this framework, the airline adopts a new LC business model on route AB by setting up a new low-cost connection, so that the airline can operate higher load-factor aircraft with a lower cost per passenger on direct flights between cities A and B, i.e., $\Delta n^d = n^d - n^c > 0$ and $\Delta\tau^d = \tau^d - \tau^c < 0$. The negative impact of this new business model on

[12]Since $\pi(\theta_H, \theta_L)$ is a strictly concave function of θ_L, although the result $\theta_L^* = 0$ is a possibility, the only statement that can be made is that $\theta_L^* \in [0,1)$.

Ψ and Υ is unambiguous and $\Psi, \Upsilon > 0$ will occur if Δn^d and $\Delta\tau^d$ are sufficiently important. Finally, the expression Σ (and Γ) remains negative (i.e., H-types still fly connecting) as long as $-\Delta\tau^d - \frac{\omega d}{\Delta n^d} - \frac{\gamma_H - \gamma_L}{\delta + \theta_L(1-\delta)}\Delta n^d < 0$, where the first and the second terms have a positive impact, whereas the third term has a negative effect.

3.3 The effect of distance

After studying the setting in which either a RJ or a LC direct connection may arise, our attention now shifts to the effect of distance between endpoints on PP routes because airlines may use different aircraft and business models depending on the characteristics of each city-pair market (and route distance is an important element). We discern distance intervals in which a new PP connection can optimally arise, analyzing the differences between the two types of connection (either RJ or LC).

3.3.1 RJ technology

Focusing on the effect of distance, from $\Omega < 0$ and $\Lambda < 0$ we can derive two lower bounds, i.e., $d > d_\Omega$ and $d > d_\Lambda$. In the same way, from $\Phi > 0$, we can obtain the upper bound $d < d_\Phi$ (note that d_Ω, d_Λ and d_Φ can be trivially computed and are provided in Appendix A).[13] Therefore, the following lemma can be stated.

Lemma 1 *Focusing on the effect of distance between endpoints A and B, for a sufficiently low n^d relative to n^c, the optimal division of passengers is*
i) $(\theta_H^*, \theta_L^*) = (1, 0)$, for $d \in (\max\{d_\Omega, d_\Lambda, 0\}, d_\Phi)$, and
ii) $(\theta_H^*, \theta_L^*) = (0, 0)$, for $d > d_\Phi$.

The condition requiring a sufficiently low n^d relative to n^c (i.e., RJs are sufficiently small as compared to mainline jets) ensures that $d_\Phi > \max\{d_\Omega, d_\Lambda\}$. The result in Lemma 1($i$) suggests that the airline would segregate passengers for moderately short distances, by sending H-types direct and L-types connecting. Thus, a network airline may find it profitable to offer services on PP routes with RJs (for business travelers) for sufficiently short distances, since the smaller size of RJ aircraft may allow airlines to increase service quality (i.e., flight frequency) at higher fares. We will see in the empirical analysis that this strategy seems to be followed by the main

[13] As mentioned in footnote 6, a more realistic modeling of the cost per departure would be $\omega(d) = \omega d^r$ with $r \in (0, 1)$. This assumption would have no qualitative effect on our results; the critical distances d_Ω, d_Λ and d_Φ would simply need to be raised to the power $1/r$.

European carriers and by some American carriers. As we observed in Figs. 3 and 4 in Section 2, regional aircraft are the aircraft most frequently used by the main American carriers up to a route distance of 900 miles (although RJs are still widely used on routes in the distance range 900-1200 miles), whereas RJs are the type most used by the main European carriers up to a route distance of 600 miles. Naturally, as captured in Lemma 1(ii), sending passengers direct becomes less profitable as distance increases, and the airline operates in a HS manner for sufficiently long distances.

In addition, whenever $\max\{d_\Omega, d_\Lambda\} > 0$, it could happen that $d \in (0, \max\{d_\Omega, d_\Lambda\})$ for short distances. In this case, both high and low types may fly direct, as captured in the following corollary.

Corollary 1 *When $d_\Omega > 0$ and $d \in (0, \min\{d_\Omega, d_\Sigma\})$, then the optimal division of passengers is $(\theta_H^*, \theta_L^*) = (1, \theta_L^*)$ with $\theta_L^* \in (0, 1]$.*

The condition $d < d_\Sigma$, which implies $\pi(1, \theta_L) > \pi(0, \theta_L)$ for $\theta_L \in [0, 1]$, ensures that all H-types still fly direct (the bound d_Σ is explained in Appendix A); and $d < d_\Omega$, which implies $\frac{\partial \pi(1,0)}{\partial \theta_L} > 0$, guarantees that the airline sends (at least) some L-type passengers direct.[14]

Therefore, the result in the corollary above states that the airline would send all H-types and a certain number of L-types direct for short distances, because connecting becomes increasingly inefficient. Although the existence of alternative transportation modes for very short distances makes this result unlikely, it is a plausible outcome for viable short air routes.[15]

3.3.2 LC business model

Focusing on the effect of distance, from $\Gamma < 0$, $\Psi < 0$ and $\Upsilon < 0$, we can derive the lower bound $d > d_\Gamma$ and the upper bounds $d < d_\Psi$ and $d < d_\Upsilon$ (note that d_Γ, d_Ψ and d_Υ can be trivially computed and are provided in Appendix A). Therefore, the following lemma can be stated.

Lemma 2 *Focusing on the effect of distance between endpoints A and B, for a sufficiently high n^d relative to n^c, the optimal division of passengers is*

[14] Note that the condition $d < d_\Lambda$ (which implies $\frac{\partial \pi(0,0)}{\partial \theta_L} > 0$) is no longer needed with $d < d_\Sigma$ (which implies $\pi(1, \theta_L) > \pi(0, \theta_L)$ for $\theta_L \in [0, 1]$).

[15] Although the turboprop technology is still used for very short routes (as we will see in the empirical analysis), our theoretical analysis focuses only on the use of RJs on routes initially served with mainline jets, to have a more tractable setting.

i) $(\theta_H^*, \theta_L^*) = (1,1)$*, for* $d < d_\Gamma$*, and*
ii) $(\theta_H^*, \theta_L^*) = (0,1)$*, for* $d \in (d_\Gamma, \min\{d_\Psi, d_\Upsilon\})$*.*

The condition requiring a sufficiently low n^d relative to n^c (i.e., the load factor in the LC flights on route AB is sufficiently high as compared to the load factor in regular flights on routes AH and BH) ensures that $\min\{d_\Psi, d_\Upsilon\} > d_\Gamma$. When a LC business model is set up on route AB, the result in Lemma 2(i) suggests that the airline would send all passengers direct for short distances. For longer distances, the airline would segregate passengers sending only L-types direct, as captured in Lemma 2(ii). We will see in the empirical analysis that this strategy seems to be followed by the main European airlines. As we observed in Fig. 4 in Section 2, the viability of the European PP routes longer than 600 miles seems to be associated with the use of LC subsidiaries. Naturally, as distance increases, sending passengers direct becomes less profitable and airlines end up adopting HS networks for sufficiently long distances, as captured in the following corollary.

Corollary 2 *When* $d > \max\{d_\Psi, d_\Sigma\}$*, then the optimal division of passengers is* $(\theta_H^*, \theta_L^*) = (0, \theta_L^*)$ *with* $\theta_L^* \in [0,1)$*.*

The condition $d > d_\Sigma$, which implies $\pi(1,\theta_L) < \pi(0,\theta_L)$ for $\theta_L \in [0,1]$, ensures that all H-types still fly connecting (the bound d_Σ is explained in Appendix A); and $d > d_\Psi$ implies $-\frac{\partial \pi(0,1)}{\partial \theta_L} > 0$, so that the airline sends (at least) some L-type passengers connecting.[16]

Therefore, the result in the corollary above states that, for sufficiently long distances, the airline would send all H-types and a certain number of L-types connecting, adopting a hub-and-spoke network structure. Quite naturally, as distance increases, direct flights become less profitable.

3.4 Discussion

Considering an environment in which both a RJ technology may be available and a LC business model can be adopted by airlines on thin routes, we can contemplate a numerical example where the previous results arise (since the solutions are complex). Given the stylized nature of the model, parameter choices are necessarily arbitrary and the analysis is not exhaustive. However, it reveals some interesting insights which are in line with the empirical evidence. Let $z_L = 5$, $\gamma_L = 0.1$, $\mu_L = 2.7$, $z_H = 15$, $\gamma_H = 2$ and $\mu_H = 8.8$, so that income, schedule-delay and

[16]Note that the condition $d > d_\Upsilon$ (which implies $-\frac{\partial \pi(1,1)}{\partial \theta_L} > 0$) is no longer needed with $d > d_\Sigma$ (which implies $\pi(1,\theta_L) < \pi(0,\theta_L)$ for $\theta_L \in [0,1]$).

connection disutilities are much higher for the H-types. Let $\delta = 0.5$, so that AB passengers are composed by both H and L-types in equal parts. However $\lambda = 0.45$ indicates that H-types are relatively scarce among local passengers (remember that a sufficient condition for strict convexity of $\pi(\theta_H, \theta_L)$ with respect to θ_H is $\lambda < 1/2$). Let $N = 1.3$ (remember that $N > 1$ is assumed), indicating that local spoke-to-hub markets (i.e., markets AH and BH) are normally denser than spoke-to-spoke markets (i.e., market AB). The marginal cost per departure is $\omega = 4$, which is larger than the marginal cost per passenger on hub-to-spoke routes, which is given by $\tau^c = 3$. Logically, the condition $\tau^d_{LC} < \tau^c < \tau^d_{RJ}$ is observed, with $\tau^d_{LC} = 0.6$ and $\tau^d_{RJ} = 6$ (where subscripts denote the type of PP connection between endpoints A and B). Finally, the number of passengers per flight on routes AH and BH is given by $n^c = 5$, and the condition $n^d_{RJ} < n^c < n^d_{LC}$ is respected, with $n^d_{RJ} = 1.35$ and $n^d_{LC} = 6.5$, since RJ aircraft are smaller and the load factor is higher when a low cost business model is implemented. Given this parameter constellation, the optimal choice of θ_H and θ_L depends on the value of d, in a way made clear in Fig. 6 below

–Insert Fig. 6 here–

The critical values of d that determine the different relevant regions are $d_\Omega = 1.96$, $d_\Phi = 2.12$, $d_\Gamma = 6.01$ and $d_\Psi = 7.48$ (Appendix B explains why these are the critical values of d), and the equilibrium in network structure depends crucially on the type of PP connection adopted on route AB (either RJ or LC). With the parameter values chosen above, we can compute the profit obtained by the airline for different values of θ_H and θ_L. More precisely, we will consider the cases $\theta_H, \theta_L = \{0, 1\}$, i.e., assuming that the airline has to send all passengers of the same type through the same routing. This is not a strong assumption since, looking at Fig. 6 above, one can observe that the optimal values of θ_H and θ_L are either 0 or 1 in all cases except in the following two regions. First, the region $d < d_\Omega$ when a RJ model is adopted and $(\theta^*_H, \theta^*_L) = (1, \theta^*_L)$ with $\theta^*_L \in (0, 1]$, with $\theta^*_L \to 0$ as d decreases, so that a FC network arises for a sufficiently small distance between A and B. Second, the region $d > d_\Psi$ when a LC model is adopted and $(\theta^*_H, \theta^*_L) = (0, \theta^*_L)$ with $\theta^*_L \in [0, 1)$, with $\theta^*_L \to 0$ as d increases, so that a HS network arises for a sufficiently long distance between A and B. Table 1 below presents the value of $\pi(0, 0)$, $\pi(1, 0)$, $\pi(0, 1)$ and $\pi(1, 1)$ for some particular values of d in the different regions shown in Fig. 6. The values in Table 1 confirm the results shown in Fig. 6 above.[17]

–Insert Table 1 here–

As we can see, the choice of θ_H and θ_L gives rise to a certain network structure, where shorter distances between endpoints A and B support FC structures and higher levels of d favor HS network configurations. Interestingly, for $d \in (d_\Phi, d_\Gamma)$, the HS network is the outcome when RJ technology is available and the FC network is the outcome when airlines implement a LC business model. As a consequence, we can conclude that adopting either a RJ model or a LC model on certain PP routes can significantly affect airlines' network structure.

Additionally, focusing on the cases in which there is passenger segmentation (i.e., $(\theta_H^*, \theta_L^*) = (1, 0)$ when a RJ model is adopted, and $(\theta_H^*, \theta_L^*) = (0, 1)$ when a LC model is adopted), we observe that $(1, 0)$ arises for shorter distances than $(0, 1)$. This result is also confirmed by the empirical evidence, as will be shown in the next section.

4 The empirical model

In this section we conduct an empirical analysis to examine the type of aircraft and the business model chosen by the main American and European network carriers. First, we explain the criterion for the selection of the sample of routes and describe the variables used in the empirical analysis. Then, we examine data and estimate equations to identify how route features (distance, demand, proportion of business and leisure travelers) influence aircraft technology and business models.

4.1 Data

As we mentioned above, our data are based on routes from both the US and the EU in 2009. Data on airline supply on each route both for the US and the EU (frequencies, type of aircraft and total number of seats) have been obtained from RDC aviation (capstats statistics) and data on distance of the route are from the Official Airlines Guide (OAG) and the webflyer web site.[18]

[17] Note that when a RJ model is adopted in the region $d < d_\Omega$, then $\pi(1,0) > \pi(1,1)$ is possible for values of d close to d_Ω (the optimal result is $(\theta_H^*, \theta_L^*) = (1, \theta_L^*)$ with $\theta_L^* \in (0, 1]$). In addition, when a LC model is adopted in the region $d > d_\Psi$, then $\pi(0,0) < \pi(0,1)$ is possible for values of d close to d_Ψ (the optimal result is $(\theta_H^*, \theta_L^*) = (0, \theta_L^*)$ with $\theta_L^* \in [0, 1)$).

[18] See *http://webflyer.com.*

Our sample includes all routes with direct flights served within continental US by the six major American network carriers (American Airlines, Continental, Delta, Northwest, United Airlines and US Airways)[19] and their subsidiaries, and all routes with direct flights served within the EU (EU of 27 countries + Switzerland and Norway) by the four major network airlines (Air France, British Airways, Iberia and Lufthansa) and their subsidiaries. Altogether, at the airline-route level, we have 5031 observations for US carriers, and 1033 for EU airlines.[20]

We account for routes with different market structures, including monopoly and oligopoly routes. Monopoly routes represent 54% of observations for US carriers, and 53% of observations for EU airlines, where monopoly routes are defined as those routes where the dominant airline has a market share larger than 90% in terms of total annual seats.[21]

Note that we do not treat airlines' services in different directions on a given route as separate observations because this would miss the fact that airline supply must be exactly or nearly identical in both directions of the route. So we consider the link that has the origin in the largest airport. For example, on the route Saint Louis-Akron-Saint Louis, we consider the link Saint Louis-Akron but not the link Akron-Saint Louis.

Regarding the type of aircraft, the most used turboprops in our sample are the following: ATR 42/72, British Aerospace ATP, De Havilland DHC-8, Embraer 120, Fairchild Dornier 328, Fokker 50, Saab 340/2000. The most used regional jets (RJs) are: Avro RJ 70/85/100, Bae 146, Canadian Regional Jet, Embraer RJ 135/140/145/270/175/190/195, Fokker 70/100. Finally, the most used mainline jets in our sample are the following: Airbus 318/319/320/321, Boeing 717/737/757, and MD 80/90.

Note that network airlines can provide regional services either directly or by means of a subsidiary or partner airline.[22] On routes where regional aircraft are dominant, we cannot determine whether the provision of air services is undertaken by a regional carrier that is a subsidiary of the network airline, or by an independent regional carrier that has signed a

[19] The Delta-Northwest merger was not completed until early 2010. Hence, we prefer to treat Delta and Northwest as separate airlines regarding their choice of aircraft.

[20] Since data for some explanatory variables are not available for the American carriers, the sample used in the regressions is reduced to 4895 observations.

[21] We exclude data for airlines that offer fewer than 52 frequencies per year on a particular route: operations with less than one flight per week should not be considered as scheduled.

[22] Decisions of this type are beyond the scope of this paper. Forbes and Lederman (2009) examine the conditions in which the major airlines in the US prefer to provide regional air services either using vertically integrated carriers or through contracts with independent regional carriers. They find that major airlines are likely to rely on trusted regional subsidiaries on those routes where schedule disruptions are costly and likely to occur.

contract with the network airline. This occurs because our dataset always allocates these regional flights to the network carrier.

In addition to the type of aircraft being used, we are also interested in the business model implemented by the airline: either full-service or low-cost (LC) service. This analysis focuses on European airlines because the American network carriers did not have any LC subsidiaries in 2009. Among the European airlines, we have Transavia (LC subsidiary of Air France), Vueling (LC subsidiary of Iberia), and Germanwings and Bmi Baby (LC subsidiaries of Lufthansa).

Regarding the US airline aircraft choice, 6% of the observations refer to turboprops, 52% to RJs and 42% to mainline jets. Among European airlines, 10% of the observations refer to turboprops, 35% to RJs, 24% to mainline jets with LC subsidiaries and 31% to mainline jets with the main brand.

We consider the following hub airports for US carriers: Dallas (DFW), New York (JFK), Miami (MIA) and Chicago (ORD) for American Airlines; Cleveland (CLE), Houston (IAH) and New York (EWR) for Continental; Atlanta (ATL), Cincinnatti (CVG), New York (JFK) and Salt Lake City (SLC) for Delta; Detroit (DTW), Memphis (MEM) and Minneapolis (MSP) for Northwest; Chicago (ORD), Denver (DEN), Los Angeles (LAX), San Francisco (SFO) and Washington Dulles (IAD) for United Airlines; and Charlotte (CLT), Philadephia (PHX) and Phoenix (PHX) for US Airways. We consider the following hubs for European airlines: Amsterdam (AMS) and Paris (CDG and ORY) for Air France; London (LHR) for British Airways; Madrid (MAD) for Iberia; and Frankfurt (FRA), Munich (MUC) and Zurich (ZRH) for Lufthansa. The observations of airlines operating in their hubs represent 41% for US carriers and 47% for European carriers.[23]

Data on population and Gross Domestic Product per Capita (GDPC) of American endpoints refer to the Metropolitan Statistical Area (MSA) and the information has been obtained from the US census. Some routes located in Micropolitan Statistical Areas are excluded from the empirical analysis because of the difficulties in obtaining sound comparable data. In the case of the EU, these data refer to the NUTS 3 level (the statistical unit used by Eurostat), provided by Cambridge Econometrics (European Regional Database publication). We are aware that MSAs in the US and NUTS 3, as defined by Eurostat, are not strictly comparable. Hence, it is difficult to make joint estimations using the whole sample of routes that include airlines from both the US and the EU.

[23] Note that network carriers (and their regional subsidiaries) may exploit some connecting traffic in other airports that are not their main hubs. Hence, our analysis of PP routes may also include routes with a modest proportion of connecting passengers.

Las Vegas (LAS), Orlando (MCO) and Spokane (GEG) are considered as tourist destinations in the US. In the EU, all airports located in the following islands are considered as tourist destinations: the Balearic and Canary Islands (Spain), Sardinia and Sicily (Italy), Corsica (France), and many Greek islands,[24] and also the airports of Alicante (ALC), Faro (FAO), Malaga (AGP) and Nice (NCE).

Finally, we built an airport access variable that measures the distance between the airport and the city center using Google Maps. In most cases, the identity of the relevant cities was self-evident. For airports located between cities, we calculated the distance from the airport to the closest city with more than $100,000$ inhabitants.

4.1.1 Descriptive data for the US

Table 2 below shows data on the US airlines considered in this analysis. As can be seen, there is a high diversity in their network of routes. Delta, Northwest and US Airways have an extensive network, offering services on a high number of monopoly routes and on many routes that do not have any of their hubs as endpoints. Interestingly, these airlines often choose RJs to serve city-pair routes. Continental and United focus their operations on their main hubs and their use of RJs is less intensive, although it is still the aircraft type most used by Continental. Finally, American Airlines mainly operates with mainline jets.

–Insert Table 2 here–

Table 3 shows some characteristics of the routes served by the major US airlines in relation to the type of aircraft used. It can be seen that RJs are used on longer routes than turboprops but on shorter routes than mainline jets. Additionally, regional aircraft are used on thinner routes (with lower numbers of seats) than mainline jets. Overall, RJs are widely used by US airlines.

–Insert Table 3 here–

4.1.2 Descriptive data for the EU

Table 4 shows data on European airlines. As in the case of US airlines, we also see a high diversity in the route networks. British Airways provides services on a relatively low number of European routes, most of them in competition with other airlines. The vast majority of its routes are served with mainline jets and it does not have a LC subsidiary. Less than half of the

[24] Details available from the authors on request.

routes have the hub as an endpoint. Air France and Lufthansa have a much more extensive network of routes in Europe and they quite often use either RJs or LC subsidiaries to offer services. However, Air France focuses its operations more on its hubs and also on monopoly routes. Finally, Iberia has similar characteristics to Lufthansa but provides services on a lower number of routes.

–Insert Table 4 here–

Table 5 shows some supply characteristics of the routes where the European airlines considered offer services. Interestingly, the LC subsidiaries are used on the longest routes. Additionally, the use of mainline jets with the main brand seems to be focused particularly on dense routes. Overall, it can be seen that RJs and LC subsidiaries are widely used by European airlines.

–Insert Table 5 here–

4.2 Analysis

The theoretical framework raises several questions that may be addressed in an empirical analysis. We expect very short-haul routes to be served by turboprops, while long haul PP routes may be served by mainline jets if dense enough.

The relevance of our analysis lies in identifying the type of routes in which major airlines are more likely to use either RJs or LC subsidiaries. The question at hand is whether these technical and managerial innovations in the airline industry can lead to profitable direct air services on thin PP routes.

The theoretical analysis shows that airlines on spoke-to-spoke routes may use RJs for sufficiently short distances (though longer than with turboprops) to serve business travelers, and a LC business model for longer distances to serve leisure travelers.

Therefore, we want to address the following questions in the empirical analysis to test the results obtained in the theoretical part. The first is whether RJs are mainly used to feed hubs or to provide services on thin PP routes. The second is to check whether RJs are widely used on routes with a high proportion of business travelers, and whether LC subsidiaries are widely used on routes with a high proportion of leisure travelers. Finally, a crucial point in our analysis is to examine the effect of distance on the aircraft type and business model adopted by airlines, in both the US and the EU.

The US network carriers had no LC subsidiaries in 2009, but these subsidiaries play a prominent role in Europe. Therefore, our analysis of LC subsidiaries is confined to European airlines. There are at least three reasons for this important difference between the US and the EU. First, the national interests of the former flag carriers in Europe make them operate in non-hub national airports to prevent competition in the home market. Second, Europe has a higher number of airports that specialize in leisure travelers. Finally, it could be argued that LC carriers in the US have experienced a certain *upmarket* movement that bring them closer to the network carriers. In this context, setting up a new subsidiary LC carrier would be inadvisable for American network carriers.[25]

4.2.1 The emergence of a RJ technology

To examine airlines' aircraft choices, we estimate the following equation for the airline i offering services on route k

$$Type\_of\_aircraft_{ik} = \alpha + \beta_1 Distance_k + \beta_2 Population_k + \beta_3 Population_k^2 + \beta_4 GDPC_k + \\ + \beta_5 D_k^{tourism} + \beta_6 Dist\_to\_city\_center_k + \beta_7 D_k^{monopoly} + \beta_8 D_{ik}^{hub} + \varepsilon_k. \tag{23}$$

Note that different types of aircraft may be used on the same route. Hence, we need to compute the market share of all aircraft used by airlines from the same category (turboprops, RJs or mainline jets) in terms of the total number of seats offered on the route. The dependent variable for the type of aircraft used is then constructed. This variable takes the value zero for routes where RJs have the largest market share (which will be the reference case); it takes the value one for routes where the turboprops have the largest market share, and it takes the value two for routes where mainline jets have the largest market share. Note that typically the market share of the category of aircraft that is dominant is well above 50%. We consider the following variables as exogenous explanatory variables of the type of aircraft used by airlines.

1. $Distance_k$: Number of kilometers in the case of European routes and number of miles in the case of American routes flown to link the endpoints of the route.

2. $Population_k$: Weighted average of population at the origin and destination regions of the route. We also include the square of the population as an explanatory variable because

[25] Graham and Vowles (2006) and Morrell (2005) undertake a broad examination of the establishment of LC subsidiaries by network carriers, but fail to find indisputable evidence of the success of this strategy. In the US, it seems that the difficulties in effectively separating network operations from those of the LC subsidiary may lead to a cannibalization and dilution of the main brand. Furthermore, network carriers may find it difficult to differentiate the pay scales of employees due to union activism.

the effect of this variable is concentrated around the median values of its statistical distribution.[26]

3. $GDPC_k$: Weighted average of Gross Domestic Product per capita at the origin and destination regions of the route. Weights are based on population.

4. $D_k^{tourism}$: Dummy variable that takes the value one for routes in which at least one of the endpoints is a major tourist destination.

5. $Dist\_to\_city\_center_k$: The sum of the distances between the origin and the destination city-center and the respective airports.

6. $D_k^{monopoly}$: Dummy variable that takes the value one on routes where one airline has a market share larger than 90% in terms of total annual seats.

7. D_{ik}^{hub}: Dummy variable that takes the value one on routes in which at least one of the endpoints is a hub airport.

We include airline fixed effects in the regression. We consider the airline with the highest number of observations as the reference, i.e., Delta for the US sample and Air France/KLM for the EU sample.

The cost superiority of mainline jets in relation to RJs increases with distance, while on very short-haul routes turboprops are less costly than RJs. Thus, as route distance increases, we can expect RJs to be used less than mainline jets and more than turboprops. The longer range of RJs with respect to turboprops yields a clear prediction on the expected effect of the distance variable. However, the expected results for the rest of explanatory variables in the choice of RJs in relation to turboprops are not clear a priori.

Demand should be higher in more populated and richer endpoints. Additionally, monopoly routes should generally be thinner than routes where several airlines offer air services. As compared to mainline jets, we expect RJs to be used more on both monopoly routes and thinner routes, i.e., routes with less populated endpoints.

Note that the variable $GDPC_k$ may capture two different effects. On the one hand, demand should be higher in richer endpoints but, on the other hand, the proportion of business travelers may also be higher.

[26] The same could be argued for the distance variable, but the square of distance is highly insignificant when we include it in the regressions. As a consequence, this variable is not considered.

In this regard, our analysis also tries to identify routes with a higher proportion of leisure travelers. These routes are the ones with a tourist destination as endpoint and the ones with airports further away from the city center. The relatively higher frequency of RJs makes them particularly convenient for business travelers, so that we expect RJs (in relation to mainline jets) to be used less on tourist routes with a higher proportion of leisure travelers.

Finally the dummy variable for hub airports allows us to determine whether RJs are more likely to be used either to feed hubs or to provide services on PP routes. Recall that hub-to-spoke routes may be generally denser than spoke-to-spoke routes.

The estimation is made using a multinomial logit in which the use of RJs is the reference case. When we consider the move from RJs to another type of aircraft (i.e., either turboprops or mainline jets), note that a higher value of the corresponding explanatory variable would mean that the use of RJs will be more (less) likely if the sign of the coefficient associated to this variable is negative (positive).

Tables 6 and 7 show the results of the estimation of the aircraft choice for the main American and European airlines. Table 6 shows the coefficients estimated and their respective standard errors. Table 7 shows the predicted change in the probability for an outcome to take place (i.e., the use of RJs in relation either to turboprops or to mainline jets) as each independent variable changes from its minimum to its maximum value (i.e., from 0 to 1 for discrete variables) while all other independent variables are held constant at their mean values. The results in Table 6 report the statistical significance of the considered relationships, while the results in Table 7 report the quantitative impact of each explanatory variable.

–Insert Tables 6 and 7 here–

First, we compare the use of RJs as compared to mainline jets. Looking at the effect of distance between endpoints, RJs are used more on shorter routes, as expected. The impact of the variable of distance is really important: the predicted increase in the probability of using mainline jets in relation to RJs as distance shifts from its minimum to its maximum value is about 95% in the case of American airlines and 85% in the case of European airlines.

Additionally, we find that RJs are more likely to be used on thinner routes than mainline jets. Our results show that mainline jets are used more than RJs on routes with more populated and richer endpoints (although the variable of GDP per capita is not statistically significant in the case of European airlines). In contrast, mainline jets are less used on monopoly routes. The predicted change in probabilities is quite high for all these variables and similar for US and EU airlines. Only the effect of population on the predicted change in probabilities seems to be clearly higher in the case of European airlines.

Interestingly, RJs seem to be more used on routes with a higher proportion of business travelers. We make this conclusion in view of the fact that RJs are less used than mainline jets on tourist routes and on routes where airports are further from the city-center. The predicted change in probabilities is also high for both variables, especially for US airlines.

Finally, European airlines use RJs more on spoke-to-spoke routes (i.e., PP routes) than on hub-to-spoke routes. Although we do not find statistical differences between hub-to-spoke routes and spoke-to-spoke routes considering US airlines as a whole, this result can be qualified by analyzing each carrier independently and focusing on airline-specific effects. Results from regressions for each airline show that these differences are generally related with the magnitude of the effect but not with its direction or its statistical significance. An important exception is the result of the dummy variable for hub-to-spoke routes (i.e., D_{ik}^{hub}) for US airlines. Table 8 explores this effect, showing the results of this variable for each American airline.[27] The data in Table 8 suggest that several US airlines use RJs more on spoke-to-spoke routes than on hub-to-spoke routes as is the case for European airlines.

–Insert Table 8 here–

Shifting our attention to the analysis of the use of RJs with respect to turboprops, as expected, we can derive only one strong inference: turboprops are used more than RJs on shorter routes. The predicted decrease in the use turboprops with respect to RJs when distance shifts from its minimum to its maximum value is about 44% in the case of US airlines and 60% in the case of European ones. Recall that the main advantage of RJs over turboprops is that they can be used on longer routes. As we have shown above, turboprops are used only on routes shorter than 300 miles, while RJs predominate on routes up to 900 miles in the US and on routes up to 600 miles in the EU. In the same vein, the mean distance of routes covered mainly by turboprops is between two and three times lower than the mean distance of routes covered mainly by RJs. From a statistical point of view, there are other variables that are significant, such as the dummies for monopoly routes and tourist endpoints. However, the impact of these variables in terms of the change in the predicted probabilities is very small (almost zero).

Looking at our previous theoretical results, we observe that the result $(\theta_H^*, \theta_L^*) = (1, 0)$, i.e., only business passengers travel direct, is confirmed empirically. Our empirical results show that RJs are mostly used by business travelers for intermediate-distance routes, and are

[27]The full report of the estimates of airline specific regressions is available upon request from the authors.

mostly used on PP routes (for EU carriers and several US carriers). Consequently, new direct connections may be related to the advent of RJ technology. In terms of Brueckner and Pai (2009), the "new route hypothesis" based on RJ direct connections seems plausible.

4.2.2 The emergence of a LC business model

Here we focus our attention on routes where mainline jets are used. Our interest here is to examine when an airline is more likely to choose to operate the route with a LC subsidiary instead of the main brand. Recall that this analysis focuses only on European airlines. We estimate the following equation for an airline i offering services on route k

$$\begin{aligned} D^{LC\_subsidiary} &= \alpha + \beta_1 Distance_k + \beta_2 Population_k + \beta_3 GDPC_k + \beta_4 D_k^{tourism} + \\ &+ \beta_5 Dist\_to\_city\_center_k + \beta_6 D_k^{monopoly} + \beta_7 D_{ik}^{hub} + \varepsilon_k, \end{aligned} \tag{24}$$

where the dependent variable is dichotomous and takes the value one on routes where airlines offer services through a LC subsidiary. We use the same explanatory variables as in equation (23).[28]

A priori, it is not clear whether the LC subsidiary is used more than the main brand either on longer or on shorter routes. However, following the theoretical analysis, the expected result is that the LC subsidiary may be widely used on thin PP routes with a high proportion of leisure travelers and relatively long distances. Thus, we expect LC subsidiaries to be used more on spoke-to-spoke routes (than on hub-to-spoke routes), on monopoly routes, on routes with poorer and less populated endpoints, and on routes with a high proportion of leisure travelers, i.e., routes from/to tourist destinations and routes with airports further away from the city center.

The estimation is made using the logit technique. A higher value of the coefficient associated to an explanatory variable means that the LC subsidiary is more (less) likely to be used if the sign of this coefficient is positive (negative). Table 9 below shows the results of the estimation of equation (24).

–Insert Table 9 here–

The results above confirm our hypotheses. Indeed, all the coefficients are statistically significant and have the expected sign, except the one corresponding to the variable of the

[28] We exclude the observations of British Airways in the regression because this airline did not have a LC subsidiary in the period considered. Given the reduced number of observations in this regression, we consider that airline fixed effects are inappropriate. The low number of observations also advises against including the square of population as explanatory variable. In any case, this latter variable is highly insignificant when included in the regression.

distance from the airport to the city center, which is not statistically significant. The impact in terms of change in the predicted probabilities is also high for all the significant variables.

Importantly, the coefficient associated to the variable of distance is positive and statistically significant, so we find evidence that the LC subsidiary is used more than the main brand on longer routes. For a network airline, the predicted increase in the probability of using a LC subsidiary instead of the main brain as route distance shifts from its minimum to its maximum value is about 72%.

Furthermore, the LC subsidiary is used more on spoke-to-spoke routes because the coefficient associated to the dummy variable for hub routes is negative and statistically significant. This result may be expected because network airlines concentrate connecting traffic in their hubs. The predicted decrease in the probability of using LC subsidiaries when routes have a hub as endpoint is about 76%.

The LC subsidiary is more likely to be used on monopoly routes and on routes with poorer and less populated endpoints. Therefore, we conclude that LC subsidiaries are used more on thinner routes. The predicted change in the probability of using LC subsidiaries is notable for all these variables.

Finally, it seems that the LC subsidiary is more likely to be used on routes with a high proportion of leisure travelers because the coefficient associated to the dummy variable for tourist routes is positive and statistically significant. The predicted increase in the probability of using LC subsidiaries when routes have a tourist major destination as an endpoint is about 24%.

These results corroborate our theoretical results, and the optimal passenger division $(\theta_H^*, \theta_L^*) = (0, 1)$, i.e., only leisure passengers travel direct, is confirmed. Therefore, LC subsidiaries are mostly used to carry leisure travelers on relatively long and thin PP routes. Consequently, new direct connections may be related to the emergence of this new business model.

5 Concluding remarks

Airlines may benefit from concentrating operations in their hub airports through the exploitation of density economies and a higher level of connectivity. However, adopting a HS network configuration may have negative consequences, such as congestion, lower competition due to airport dominance (by the *hubbing* airline) and lower service quality for citizens living in cities far from hub airports.

This paper shows that, under certain circumstances, airlines may also have incentives to divert passengers away from the hub. Our main contribution is the analysis of the impact of two major innovations in the airline industry in the provision of air services on PP routes (out of the hub): RJ technology, and the LC business model.

We find that RJ technology and the LC business model are intensively used on thin PP routes. More precisely, our main findings can be summarized as follows. On the one hand, a network airline will find it profitable to offer services on thin PP routes with RJ for sufficiently short distances (but longer distances than with turboprops). This direct connection will be addressed mostly to business travelers, since the smaller size of RJ aircraft may allow airlines to increase service quality (i.e., flight frequency) at higher fares. Naturally, sending passengers direct becomes less profitable as distance increases, and the airline will operate in a HS manner for sufficiently long distances. In the latter case, carriers use RJ aircraft to feed their hubs. On the other hand, a network carrier will be interested in serving a thin PP route by means of a subsidiary LC carrier for sufficiently long distances. This direct connection will be used mainly by leisure travelers who are more fare-sensitive. In this case, flight frequency is also lower.

The research question raised in this paper is especially relevant, because setting up new RJ or LC direct connections may have very different implications in terms of network structure, fares and flight frequency. In addition, the regional impact of the different airline network configurations may also differ widely. Policy makers and airport operators should assess which type of airline networks they want to foster in their sphere of influence. If they wish to promote direct connections away from the hub, they should use tools such as airport charges (both the level and the relation with the weight of the aircraft), investment in capacities, and marketing of the cities where the airports are located.

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Figures and Tables

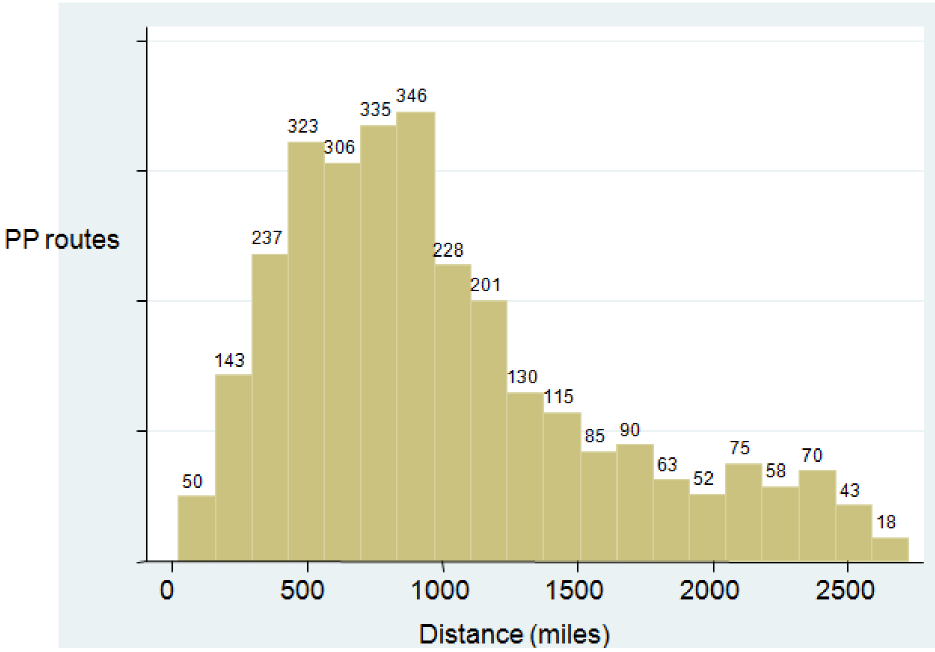

Fig. 1: Histogram of the variable of distance (PP routes – US)

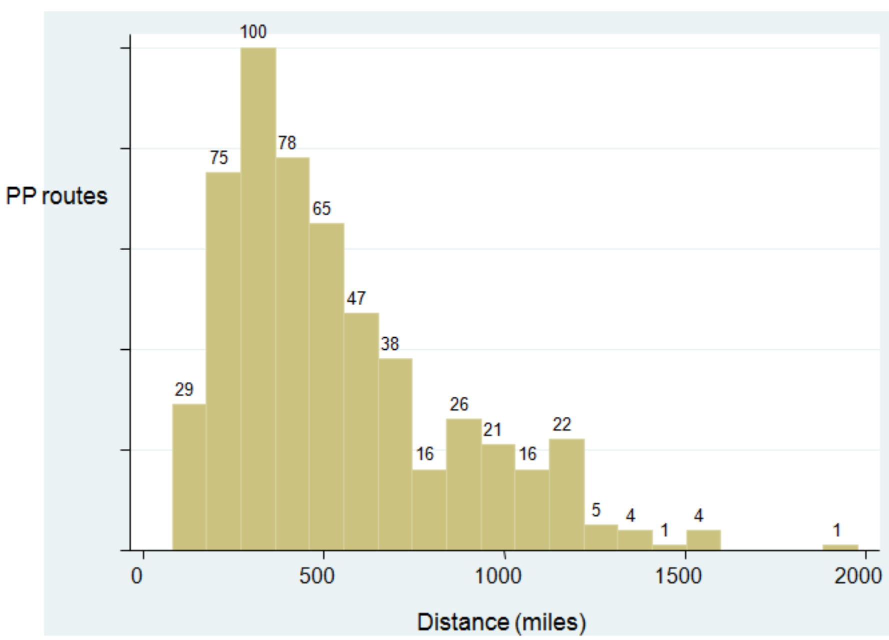

Fig. 2: Histogram of the variable of distance (PP routes – EU)

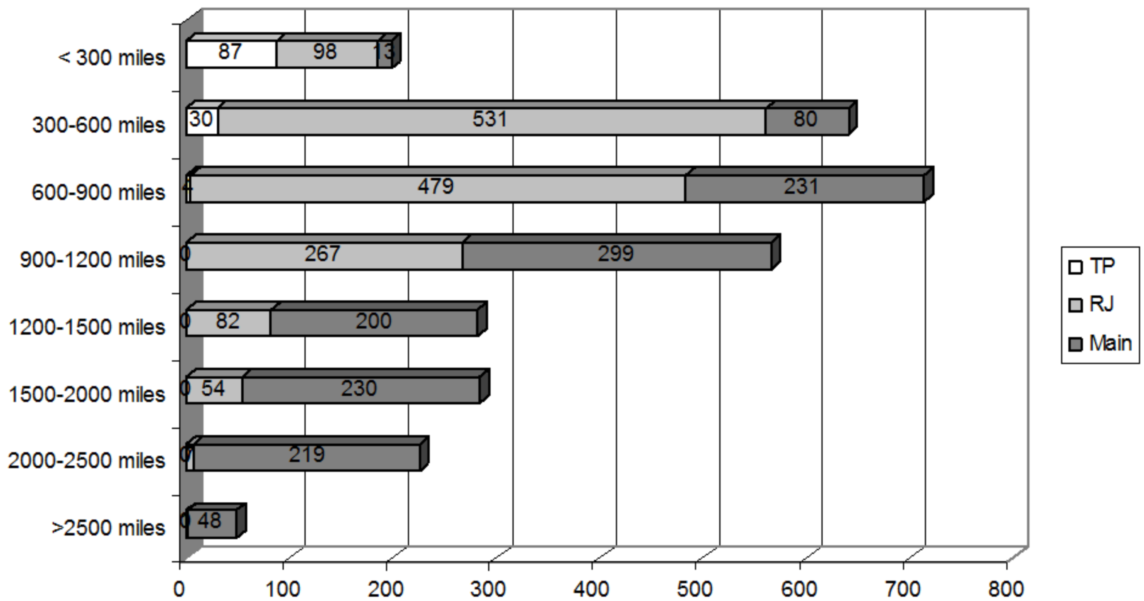

Fig. 3: Aircraft technology by distance (PP routes - US)

Note 1: Data refer to the number of routes where each considered type of aircraft is dominant.

Note 2: TP are turboprops, RJ are regional jets and Main are mainline jets.

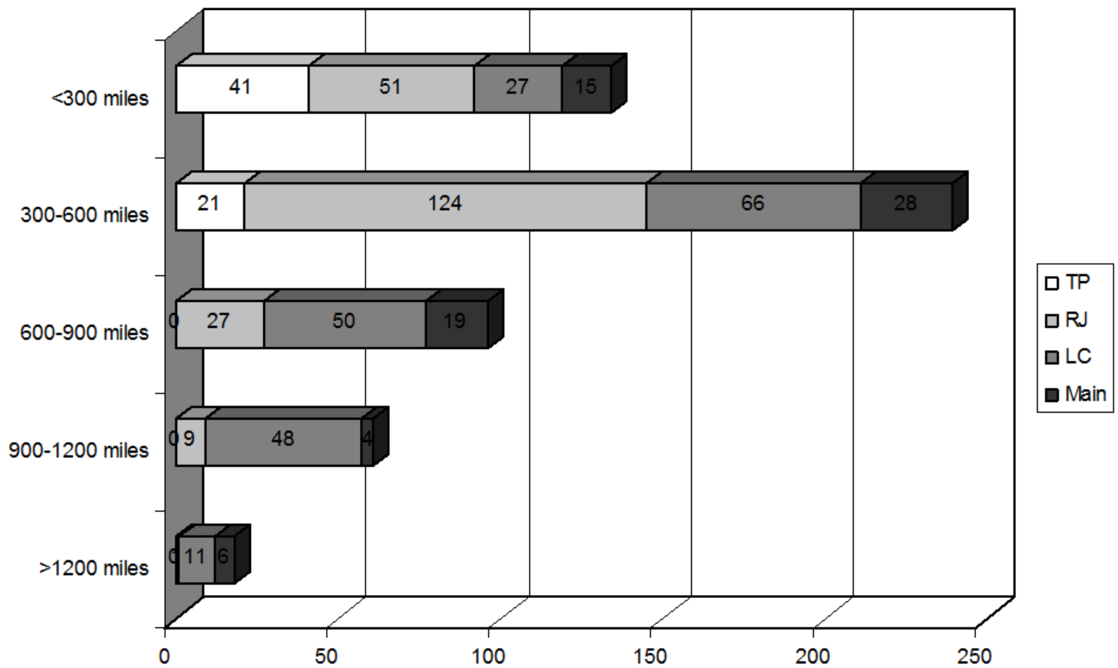

Fig. 4: Aircraft technology and business model by distance (PP routes - EU)

Note 1: Data refer to the number of routes where each considered type of aircraft and business model is dominant.

Note 2: TP are turboprops, RJ are regional jets, LC are mainline jets with a low-cost subsidiary and Main are mainline jets with the main brand.

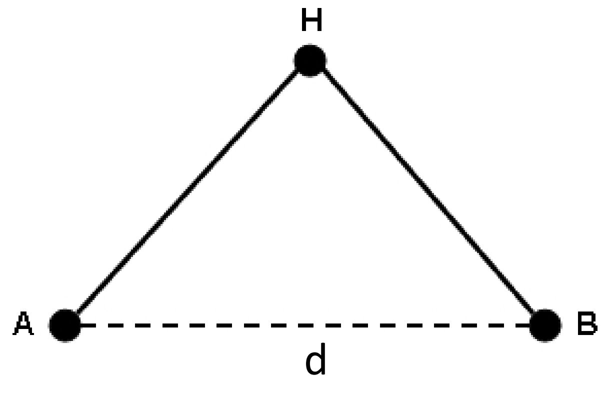

Fig. 5: Network

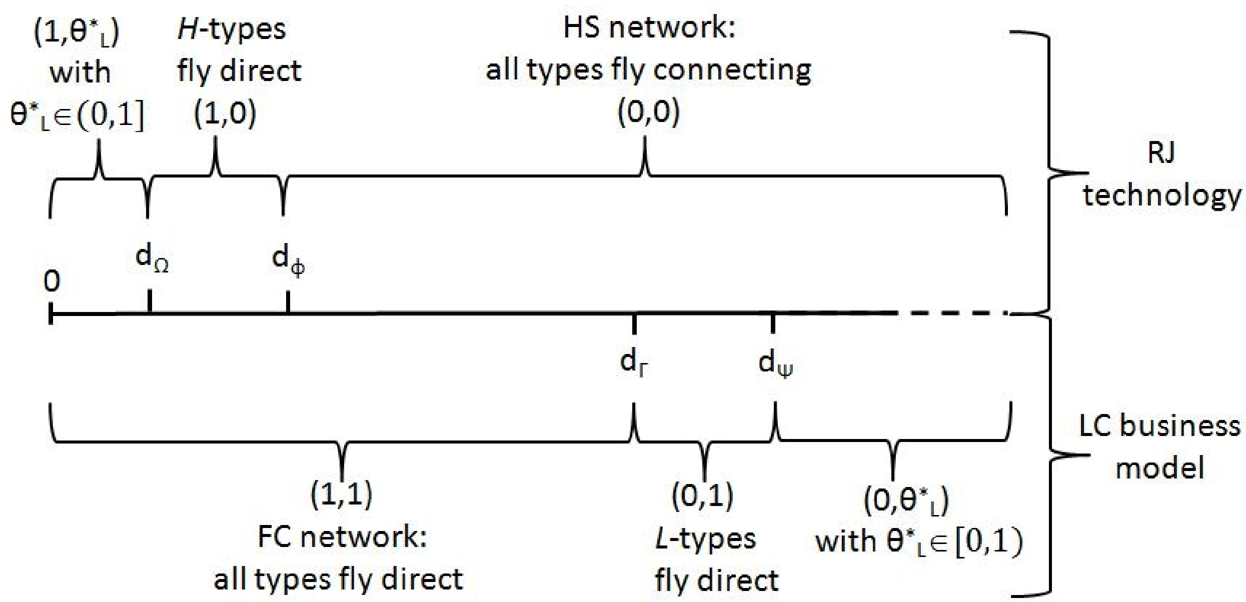

Fig. 6: Optimal network choice

Table 1: Example of network choice when RJ and LC models are available on route AB

	$d = 0.5$ ($d < d_\Omega$)		$d = 2$ ($d \in (d_\Omega, d_\Phi)$)		$d = 4$ ($d \in (d_\Phi, d_\Gamma)$)		$d = 7$ ($d \in (d_\Gamma, d_\Psi)$)		$d = 8$ ($d > d_\Psi$)	
	RJ	LC	RJ	LC	RJ	LC	RJ	LC	RJ	LC
$\pi(0,0)$	3.79	3.79	3.79	3.79	<u>3.79</u>	3.79	<u>3.79</u>	3.79	<u>3.79</u>	<u>3.79</u>
$\pi(1,0)$	6.19	-0.82	<u>3.97</u>	-1.28	1.01	-1.90	-3.44	-2.82	-4.92	-3.13
$\pi(0,1)$	3.07	5.84	0.85	5.38	-2.12	4.76	-6.56	<u>3.84</u>	-8.04	3.53
$\pi(1,1)$	<u>6.37</u>	<u>7.54</u>	1.93	<u>6.61</u>	-4.00	<u>5.38</u>	-12.89	3.54	-15.85	2.92

Note: $d_\Omega = 1.96$, $d_\Phi = 2.12$, $d_\Gamma = 6.01$ and $d_\Psi = 7.48$.

Table 2: Some data about US airlines

Routes	American	Continental	Delta	Northwest	United	US Airways
All	823	276	1242	1122	567	1001
Monopoly	325	177	722	796	225	485
From hub	304	252	445	370	423	268
With RJs	182	127	799	739	221	538
With turboprops	11	57	14	79	74	66
With mainline jets	630	92	429	304	272	397

Table 3: Supply characteristics by type of aircraft used (US carriers)

	Turboprops	RJs	Mainline jets
Total observations	301	2606	2124
Mean distance (miles)	221	661	1299
Total seats	55742	81465	247077
Total departures	1186	1027	1778
Mean aircraft size	40.18	75.39	139.87

Table 4: Some data about EU airlines

Routes	Lufthansa	Iberia	British Airways	Air France/KLM
All	382	217	87	347
Monopoly	184	108	22	237
From hub	161	78	40	206
With RJs	126	82	10	141
With turboprops	28	21	3	55
With mainline jets main brand	116	46	74	85
With mainline jets low-cost	112	68	0	66

Table 5: Supply characteristics by type of aircraft used (EU carriers)

	Turboprops	RJs	Mainline jets main brand	Mainline jets low-cost
Total observations	103	359	321	246
Mean distance (kms)	393	715	972	1209
Total seats	60306	85953	372842	103026
Total departures	951	1060	2573	700
Mean aircraft size	54.57	66.06	141.07	148.12

Table 6: Results of estimates of the aircraft choice (mlogit) - US sample

	US sample ($N = 4895$)		EU sample ($N = 1033$)	
	Dependent variable: RJ=0, turboprop=1	Dependent variable: RJ=0, mainline jet=1	Dependent variable: RJ=0, turboprop=1	Dependent variable: RJ=0, mainline jet=1
$Distance_k$	-0.0098 (0.0006)***	0.0025 (0.00009)***	-0.006 (0.0006)***	0.0015 (0.00017)***
$Population_k$	-3.29e-07 (9.30e-08)***	7.85e-08 (3.67e-08)**	0.00023 (0.00020)	0.00037 (0.00013)***
$Population_k^2$	2.02e14 (4.62e-15)***	-6.07e-15 (1.89e-15)***	-1.44e-08 (1.84e-08)	-2.63e-08 (1.09e-08)**
$GDPC_k$	8.14e-06 (0.00002)	0.00003 (0.00001)***	0.003 (0.005)	0.002 (0.002)
$D_k^{tourism}$	1.91 (0.55)***	2.08 (0.28)***	0.86 (0.37)**	0.92 (0.26)***
$Dist\_to\_city\_center_k$	-0.04 (0.017)**	0.02 (0.003)***	-0.011 (0011)	0.015 (0.005)***
$D_k^{monopoly}$	2.04 (0.32)***	-1.06 (0.08)***	0.91 (0.32)***	-0.81 (0.16)***
D_{ik}^{hub}	-0.30 (0.21)	0.06 (0.09)	-0.064 (0.37)	0.38 (0.18)**
$D_{American}$	1.42 (0.51)***	1.62 (0.12)***	–	–
$D_{Continental}$	2.97 (0.38)***	0.11 (0.19)	–	–
$D_{Northwest}$	1.60 (0.37)***	−0.34 (0.12)***	–	–
D_{United}	3.82 (0.42)***	0.006 (0.15)	–	–
$D_{US\ Airways}$	1.69 (0.37)***	-0.05 (0.11)	–	–
$D_{British\ Airways}$	–	–	0.21 (0.96)	0.96 (0.40)**
$D_{Lufthansa}$	–	–	-0.35 (0 : 35)	0.78 (0.20)**
D_{Iberia}	–	–	-0.45 (0 : 38)	-0.12 (0.24)
$Constant$	-0.94 (0.80)	-3.82 (0.36)***	0.69 (0.97)	-2.84 (0.61)***
R^2	0.41		0.25	
$F(joint\ sig.)$	1683.68***		322.99***	

Note 1: Standard errors in parenthesis (robust to heteroscedasticity).

Note 2: Statistical significance at 1% (***), 5% (**), 10% (*).

Table 7: Change in the predicted probabilities

	US sample ($N = 4895$)		EU sample ($N = 1033$)	
	Dependent variable: RJ=0, turboprop=1	Dependent variable: RJ=0, mainline jet=1	Dependent variable: RJ=0, turboprop=1	Dependent variable: RJ=0, mainline jet=1
$Distance_k$	-44.66%	95.74%	-60.52%	84.61%
$Population_k$	-0.045%	35.37%	0.26%	66.71%
$GDPC_k$	0.0010%	19.82%	0.32%	13.17%
$D_k^{tourism}$	0.006%	43.72%	0.23%	19.17%
$Dist\_to\_city\_center_k$	-0.02%	42.18%	1.73%	37.34%
$D_k^{monopoly}$	0.023%	-25.70%	1.15%	-19.38%
D_{ik}^{hub}	-0.0026%	1.60%	0.31%	9.04%

Table 8: Results from regressions for the variable D_{ik}^{hub} - US sample

	Coefficient	Change in the predicted probabilities
Delta ($N = 1214$)	0.14 (0.16)	3.27%
American ($N = 808$)	-0.18 (0.37)	-0.20%
Continental ($N = 268$)	1.68 (0.89)***	30.61%
Northwest ($N = 1085$)	0.83 (0.20)***	15.27%
United ($N = 528$)	4.52 (0.85)***	-58.72%
US Airways ($N = 992$)	1.19 (0.24)***	28.68%

Note 1: Standard errors in parenthesis (robust to heteroscedasticity).

Note 2: Statistical significance at 1% (***), 5% (**), 10% (*).

Table 9: Results of estimates of the business model (logit) – EU routes with mainline jets ($N = 493$)

	Dependent variable RJ=0, turboprop=1	
	Coefficient	Change in the predicted probabilities
$Distance_k$	0.0013 (0.00029)***	72.67%
$Population_k$	-0.00017 (0.00005)***	43.71%
$GDPC_k$	-0.013 (0.0046)***	59.77%
$D_k^{tourism}$	1.001 (0.45)**	24.08%
$Dist\_to\_city\_center_k$	-0.005 (0.009)	-12.09%
$D_k^{monopoly}$	2.27 (0.37)***	51.08%
D_{ik}^{hub}	-4.02 (0.42)***	76.36%
$Constant$	2.40 (0.87)***	–
R^2	0.58	
$F(joint\ sig.)$	114.40***	

Note 1: Standard errors in parenthesis (robust to heteroscedasticity).

Note 2: Statistical significance at 1% (***), 5% (**), 10% (*).

A Appendix: Proofs

Proof of Lemma 1.
From Eqs. (13), (14) and (15), we obtain the following threshold values for distance

$$d_\Omega = \tfrac{n^d}{\omega}\left[\mu_L + 2\tau^c - \tau^d + \tfrac{2\omega}{n^c} + n^d \tfrac{\gamma_H - \gamma_L}{\delta} - N n^c \tfrac{2\widetilde{\gamma} - \gamma_L}{(N+1-\delta)^2}\right], \tag{A1}$$

$$d_\Phi = \tfrac{n^d}{\omega}\left[\mu_H + 2\tau^c - \tau^d + \tfrac{2\omega}{n^c} - n^d \tfrac{\gamma_H}{\delta} + n^c \tfrac{(1-\delta)(\gamma_H - \gamma_L) + N(\gamma_H - 2\widetilde{\gamma})}{(1+N)(1+N-\delta)}\right], \tag{A2}$$

$$d_\Lambda = \tfrac{n^d}{\omega}\left[\mu_L + 2\tau^c - \tau^d + \tfrac{2\omega}{n^c} - n^c \tfrac{\delta(\gamma_H - \gamma_L) - N(2\widetilde{\gamma} - \gamma_L)}{(1+N)^2}\right], \tag{A3}$$

where $\Omega, \Lambda < 0$ imply $d > d_\Omega, d_\Lambda$, and $\Phi > 0$ implies $d < d_\Phi$. Therefore, $(\theta_H^*, \theta_L^*) = (1, 0)$ arises for $d \in (\max\{d_\Omega, d_\Lambda, 0\}, d_\Phi)$. We assume that this interval is non-empty, a condition that is guaranteed for a sufficiently small n^d relative to n^c (i.e., RJs need to be sufficiently small as compared to mainline jets).[29] Finally, since $\Phi < 0$ implies $d > d_\Phi$, then $(\theta_H^*, \theta_L^*) = (0, 0)$ arises for $d > d_\Phi$. ■

Proof of Corollary 1.
This corollary explains the requirements that must hold to sustain the optimal distribution of passengers $(\theta_H^*, \theta_L^*) = (1, \theta_L^*)$ with $\theta_L^* \in (0, 1]$. To have (at least) some L-types traveling direct, i.e., $\theta_L^* \in (0, 1]$, we need $\min\{d_\Omega, d_\Lambda\} > 0$ and $d \in (0, \min\{d_\Omega, d_\Lambda\})$. In addition, $d < d_\Phi$ ensures $\pi(1, 0) > \pi(0, 0)$, but it does not guarantee to observe $\theta_H^* = 1$ for any θ_L^*. At this point, let us define $\Sigma \equiv \pi(1, \theta_L) - \pi(0, \theta_L) > 0$, where

$$\Sigma \equiv \delta\left[\mu_H + 2\tau^c - \tau^d + \omega\left(\tfrac{2}{n^c} - \tfrac{d}{n^d}\right) - n^d \tfrac{\gamma_H - \gamma_L}{\delta + \theta_L(1-\delta)} + n^c \tfrac{(1-\delta)(1-\theta_L)(\gamma_H - \gamma_L) + N(\gamma_H - 2\widetilde{\gamma})}{[N + (1-\delta)(1-\theta_L)][1 + N - (1-\delta)\theta_L]}\right]. \tag{A4}$$

Therefore $d < d_\Sigma$ implies $\Sigma \equiv \pi(1, \theta_L) - \pi(0, \theta_L) > 0$ for any $\theta_L \in [0, 1]$, ensuring that all H-types still fly direct, where

$$d_\Sigma = \tfrac{n^d}{\omega}\left[\mu_H + 2\tau^c - \tau^d + \tfrac{2\omega}{n^c} - n^d \tfrac{\gamma_H - \gamma_L}{\delta + \theta_L(1-\delta)} + n^c \tfrac{(1-\delta)(1-\theta_L)(\gamma_H - \gamma_L) + N(\gamma_H - 2\widetilde{\gamma})}{[N + (1-\delta)(1-\theta_L)][1 + N - (1-\delta)\theta_L]}\right]. \tag{A5}$$

Finally, imposing $d < d_\Omega$ (which implies $\frac{\partial \pi(1,0)}{\partial \theta_L} > 0$) is sufficient to guarantee that the airline sends (at least) some L-type passengers direct (and the condition $d < d_\Lambda$ is not needed anymore). In conclusion, $d < \min\{d_\Omega, d_\Sigma\}$ sustains the optimal division of passengers $(\theta_H^*, \theta_L^*) = (1, \theta_L^*)$ with $\theta_L^* \in (0, 1]$. Note that $d_\Omega < d_\Sigma$ is satisfied for a sufficiently small n^d relative to n^c.

Note that, from the expression for $\Sigma \equiv \pi(1, \theta_L) - \pi(0, \theta_L)$ above, we cannot recover $\Phi \equiv$

[29] Computations available from the autors on request.

$\pi(1,0)-\pi(0,0)$ by setting $\theta_L=0$ (observe the element that multiplies n^d in the expressions for Φ and Σ). The reason is that there is a discontinuity in $\pi(0,\theta_L)$ between $\theta_L=0$ and $\theta_L>0$ because $\theta_L=0$ implies dismantling the direct route between cities A and B and sending all passengers through the hub (i.e., adopting a HS network). ■

Proof of Lemma 2.

From Eqs. (20), (21) and (22), we obtain the following threshold values for distance

$$d_\Psi=\frac{n^d}{\omega}\left[\mu_L+2\tau^c-\tau^d+\frac{2\omega}{n^c}-n^c\frac{\delta(\gamma_H-\gamma_L)+N(2\widetilde{\gamma}-\gamma_L)}{(N+\delta)^2}\right], \tag{A6}$$

$$d_\Gamma=\frac{n^d}{\omega}\left[\mu_H+2\tau^c-\tau^d+\frac{2\omega}{n^c}-n^d\left(\gamma_H-\gamma_L\right)+n^c\frac{\gamma_H-2\widetilde{\gamma}}{N+\delta}\right], \tag{A7}$$

$$d_\Upsilon=\frac{n^d}{\omega}\left[\mu_L+2\tau^c-\tau^d+\frac{2\omega}{n^c}+\delta n^d\left(\gamma_H-\gamma_L\right)-n^c\frac{2\widetilde{\gamma}-\gamma_L}{N}\right], \tag{A8}$$

where $\Psi,\Upsilon<0$ imply $d<d_\Psi,d_\Upsilon$, and $\Gamma<0$ implies $d>d_\Gamma$. Therefore, $(\theta_H^*,\theta_L^*)=(0,1)$ for $d\in(d_\Gamma,\min\{d_\Psi,d_\Upsilon\})$. We assume that this interval is non-empty, a condition that is guaranteed for a sufficiently large n^d relative to n^c (i.e., the load factor in the low-cost flights on route AB is sufficiently high as compared to the load factor in regular flights on routes AH and BH).[30] Finally, when $\Gamma>0$ then $d<d_\Gamma$ and $(\theta_H^*,\theta_L^*)=(1,1)$. ■

Proof of Corollary 2.

This corollary explains the requirements that must hold to sustain the optimal distribution of passengers $(\theta_H^*,\theta_L^*)=(0,\theta_L^*)$ with $\theta_L^*\in[0,1)$. To have (at least) some L-types traveling connecting, i.e., $\theta_L^*\in[0,1)$, we need $d>\max\{d_\Psi,d_\Upsilon\}$. However, this condition does not guarantee that all H-types still fly connecting (i.e., $\theta_H^*=0$), which requires $\Sigma<0$ or, equivalently, $d>d_\Sigma$ (the expressions for Σ and d_Σ are given in the proof of Corollary 1). Therefore, $d>\max\{d_\Psi,d_\Sigma\}$ sustains the optimal division of passengers $(\theta_H^*,\theta_L^*)=(0,\theta_L^*)$ with $\theta_L^*\in[0,1)$. Note that $d_\Psi>d_\Sigma$ for a sufficiently large n^d relative to n^c. ■

B Appendix: Details on the numerical analysis

These are the values for all the critical values of distance: $d_\Lambda=1.90$, $d_\Omega=1.96$, $d_\Phi=2.12$, $d_\Gamma=6.01$, $d_\Psi=7.48$ and $d_\Upsilon=14.48$. Finally let us denote d_Σ^{RJ} and d_Σ^{LC} the values of d_Σ, depending on the type of PP connection between endpoints A and B. Note that d_Σ^{RJ} and d_Σ^{LC} are functions of θ_L. On the one hand, d_Σ^{RJ} is a concave function that takes values between

[30] Computations available from the autors on request.

2.21 (when $\theta_L = 0$) and 2.74 (when $\theta_L = 0.85$). On the other hand, d_{Σ}^{LC} is an increasing and concave function that takes values between -12.37 (when $\theta_L = 0$) and 6.01 (when $\theta_L = 1$).

There are a number of restrictions that must hold to carry out this numerical analysis. Lemma 1 states that $(\theta_H^*, \theta_L^*) = (1, 0)$ arises for $d \in (\max\{d_\Omega, d_\Lambda, 0\}, d_\Phi)$ and, since $d_\Omega > d_\Lambda$, the relevant value is d_Ω. Looking at Lemma 2, $(\theta_H^*, \theta_L^*) = (0, 1)$ arises for $d \in (d_\Gamma, \min\{d_\Psi, d_\Upsilon\})$ and, since $d_\Psi < d_\Upsilon$, the relevant value is d_Ψ. Following Corollary 1, $(\theta_H^*, \theta_L^*) = (1, \theta_L^*)$ with $\theta_L^* \in (0, 1]$ is observed when $d_\Omega > 0$ and $d \in \left(0, \min\left\{d_\Omega, d_\Sigma^{RJ}\right\}\right)$ and, since $d_\Omega < d_\Sigma^{RJ}$ holds for any $\theta_L \in [0, 1]$, the relevant value is d_Ω. Finally, looking at Corollary 2, $(\theta_H^*, \theta_L^*) = (0, \theta_L^*)$ with $\theta_L^* \in [0, 1)$ occurs when $d > \max\left\{d_\Psi, d_\Sigma^{LC}\right\}$ and, since $d_\Psi > d_\Sigma^{LC}$ holds for any $\theta_L \in [0, 1]$, the relevant value is d_Ψ. ■

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