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Xavier Fageda
Ricardo Flores-Fillol

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Avgda. de la Universitat, 1
432004 Reus
Tel. +34 977 759 811
Fax +34 977 300 661

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

Xavier Fageda[†] and Ricardo Flores-Fillol[‡]

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Abstract

Network airlines have been increasingly focusing their operations on hub airports through the exploitation of connecting traffic, allowing them to take advantage of economies of traffic density, which are unequivocal in the airline industry. Less attention has been devoted to airlines' decisions on point-to-point thin routes, which could 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 in the last two decades: the regional jet technology and the low-cost business model. We show that, under certain circumstances, direct services on point-to-point thin routes can be viable and thus airlines may be interested in deviating passengers out of 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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[†]Department of Economic Policy, Universitat de Barcelona, Avinguda Diagonal 690, 08034 Barcelona, Spain. Tel.: +34934039721; fax: +34934024573; email: xfageda@ub.edu.

[‡]Department of Economics, Universitat Rovira i Virgili, Avinguda de la Universitat 1, 43204 Reus, Spain. Tel.: +34977759851; fax: +34977759810; email: ricardo.flores@urv.cat.

1 Introduction

The air transportation industry has witnessed a number of changes since the deregulation of the sector (that took place 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 been increasingly focusing their operations on hub airports through the exploitation of connecting traffic, allowing them to take advantage of economies of traffic density, which are unequivocal in the airline industry. In this regard, several papers have examined optimal choices of airlines in HS networks. Less attention has been devoted to airlines' decisions on point-to-point (PP) thin routes, which could 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 (not living 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 this situation if these airlines provide air services on dense routes. Thus, it is important to study the way in which airlines choose their combination of aircraft type and business model on PP routes, and the implications of these choices on network structure.

This paper examines the impact on airlines' decisions on PP thin routes of the two major innovations in the airline industry in the last two decades. First, the emergence of regional jets constitutes an important technological innovation because these aircraft may 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, allowing to offer seats at lower fares (with lower flight frequency). Thus, we study whether these innovations may lead to profitable PP air services on thin routes that are relatively long, since very short-haul routes have been traditionally 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 some empirical facts, we try to investigate the strategic decision of a carrier that may 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 become available. If the 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 low distances. This service would be oriented to 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 that are more fare sensitive. Both results still hold true considering just thin routes.

We test the implications of the theoretical model with an empirical analysis that is based on data for the major network airlines of 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 highly used on thin routes with a high proportion of business travelers. Interestingly, regional jets are more used by the main European carriers and some American carriers on PP thin 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 with a high proportion of leisure travelers. Therefore our analysis suggests that the emergence of the regional jet technology and the low-cost business model have 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 after the deregulation of the sector, and it conveys important implications at the regional level.

Even though the research question raised in this paper seems especially relevant, to the best of our knowledge, there are no previous works looking at the issue from a global perspective. Brueckner and Pai (2009) argue that regional jets may have important advantages in relation to mainline jets and turboprops. In comparison to mainline jets, regional jets have smaller capacity with a relatively long range and similar cruising speed and comfort. In comparison to turboprops, regional jets have similar small capacity but longer range, more comfort and less noise. These advantages of regional jets may be important to develop services on PP thin routes that are too long for turboprops and too small for commercially viable frequency with mainline jets. Brueckner and Pai (2009) test what they call the "new route hypothesis" through the analysis of data on new routes started for four major US carriers after 1996. However, they do not find empirical evidence of this "new route hypothesis" and they conclude that regional jets are mostly used to feed hubs. In a similar way, Dresner *et al.* (2002) study the case

Continental Airlines (focusing on its hubs in Cleveland and Houston), finding that regional jets are mainly used on new HS routes (longer than routes served with turboprops), and that they appear to increase demand on denser routes where turboprops are replaced. Concerning the provision of air services by means of low-cost carriers, the existing literature finds that the entry of a low-cost carrier on a route exerts a downward pressure on fares.[1] Looking at the type of routes served by low-cost carriers, it should be highlighted the paper by Boguslaski *et al.* (2004), which finds 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 PP thin routes.

The plan of the paper is as follows. Some descriptive data on PP routes operated by the main American and European airlines is 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 empirically the theoretical results. Finally, a brief conclusion closes the paper. All the proofs are provided in Appendix *A*.

2 Some descriptive data on PP routes

We have 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 that are used in the econometric analysis.

Focusing on PP routes, Figs. 1 and 2 below depict the histogram of the variable of distance 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 higher in US. Hence, we must use different categories

[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.

of distance when analyzing which type of airlines are responsible for the high number of PP routes in those distance ranges. Note also that US carriers did not have any LC subsidiary in 2009.

−Insert here Figs. 1 and 2−

Fig. 3 below shows that regional aircraft are the most used type of aircraft by the main American carriers up to a route distance of 900 miles. Indeed, US major airlines are mainly serving PP routes on the distance range 300-900 miles with RJs, and RJs are still highly used on routes on the distance range 900-1200 miles. Turboprops are highly 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 on the distance range of 300-1200 (and particularly on the distance range 300-900 miles), could be related to the advantages that US airlines have gained from using RJs.

−Insert here Fig. 3−

Finally, Fig. 4 shows that RJs are the most used type of aircraft by the main European carriers up to a route distance of 600 miles, especially the distance range 300-600 miles. Turboprops are also highly used on routes shorter than 300 miles. Interestingly, the use of mainline jets with a LC subsidiary is the dominant model on routes longer than 600 miles. Thus, these data provide some evidence showing that the relatively high number of PP routes on the distance range 300-600 miles has 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 here Fig. 4−

The theoretical end empirical analyses that follow try to delve into this observed fact, with the purpose of understanding the impact of both the RJ technology and the LC business model in airline network structure in the US and the EU.

3 The model

We consider a monopoly model builds on the analysis of Brueckner and Pai (2009) to study the impact of regional jet aircraft. The main novelties stemming from our analysis are, on the one hand, the extension of the model to consider new low-cost PP connections and, on the other hand, the introduction of the distance between endpoints as an important element conditioning airlines' choices. As it is explained below, the route distance is introduced in the model by means of a distance-dependent cost function, following Bilotkach *et al.* (2010). 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. In addition, this allows to have 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 here Fig. 5−

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 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 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

[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.

negative shift factor in the utility of connecting passengers since they dislike waiting, and thus $p = z - \mu - \gamma/f$ for connecting passengers.

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 a 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 $\gamma_H > \gamma_L$.

Shifting 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 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

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

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

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

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 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 $l^d \in [0,1]$ is 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

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

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* in 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) that captures the aircraft fixed cost, which includes landing and navigation fees, renting gates, airport maintenance and the cost of fuel. $\omega(d)$ 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) which are unequivocal 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 $f^d = q^d/n^d$,

[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 in our results; the critical distances that will be computed would simply need to be raised to the power $1/r$.

we obtain $C^d = q^d \left(\frac{\omega d}{n^d} + \tau^d\right)$. Proceeding analogously for routes AH and BH, we get $C^c = q^c \left(\frac{\omega}{n^c} + \tau^c\right)$ since distance of routes AH and BH is assumed to be constant and equal to 1. Therefore, *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 type-H and type-L 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 $q^d = 0$), we will consider in the two subsections that follow 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 market AB 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 a RJ technology

The 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

[8] As in Brueckner and Pai (2009), strict convexity requires $\gamma_H > 2\widetilde{\gamma}$ 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 $N > 1$.

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 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 observed

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

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

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

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 is decreasing 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 is increasing 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 is increasing 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 is decreasing with aircraft size and thus increasing 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 is increasing with n^c and thus decreasing with f^c, captures the fact that sending all the H-types direct is more beneficial the worse is the service quality (i.e. flight frequency) of the connecting service.

Finally, Eq. (12) yields this condition

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

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 a 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. Then we 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 a lower aircraft size (and thus a higher flight frequency) and a 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 are decreasing in τ^d and increasing 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 larger distance between cities A and B make more difficult the emergence of a direct connection to serve H-types. On the other hand, type-H passengers' aversion to schedule delay makes easier a new direct connection.

3.2 The emergence of a LC business model

As 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 could also be that the airline itself creates a 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 use similar mainline jets on all routes, the 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 to either decrease θ_L or 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 needed computations, Eq. (10) becomes

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

which shows the gains and losses for the airline from decreasing θ_L (i.e., sending less L-types direct). On the one hand, the airline incurs the connecting discount to compensate for layover time disutility (μ_L) for those passengers that switch from the direct to the connecting service. Additionally, the airline incurs the passenger cost ($2\tau^c$) and the cost of frequency

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

[11] In the case that 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 could be easily relaxed since it is not needed to obtain the results that follow.

($\frac{2\omega}{l^c s^c}$) associated to routes AH and BH, whereas it saves the the passenger cost (τ^d) and the cost of frequency ($\frac{\omega d}{l^d s^d}$) associated to the direct service on route AB. Finally, the last term captures the fact that savings from sending less L-types direct are increasing with load factor of connecting aircraft, capturing the cost advantage in terms of economies of traffic density stemming from a larger aircraft size (and lower frequency), which leads to lower fares.

Equivalently, Eq. (18) reduces to

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

which indicates that the gain from sending all the H-types direct is logically increasing 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 two last terms show the preference of H-types for service quality (i.e., flight frequency). Thus, the higher the load factor on route AB (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 (n^c), the lower the frequency and the higher the savings from switching to a direct connection.

Finally, Eq. (19) yields this condition

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

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

At this point, we can analyze the emergence of a direct connection to serve L-type passengers. We consider a 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

[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 stament that can be made is that $\theta_L^* \in [0, 1)$.

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 Ψ and Υ is unambiguous and $\Psi, \Upsilon > 0$ will occur if Δn^d and $\Delta \tau^d$ are sufficiently important. Finally, the 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

Once studied the setting in which either a RJ or a LC direct connection may arise, 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 low distances, by sending H-types direct and L-types connecting. Thus, a network airline may find it profitable to offer

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

services on PP routes with RJs (for business travelers) for sufficiently low 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 European carriers and some American carriers. As we have observed in Figs. 3 and 4 in Section 2, regional aircraft are the most used type of aircraft by the main American carriers up to a route distance of 900 miles (although RJs are still highly used on routes on the distance range 900-1200 miles), whereas RJs are the most used type of aircraft 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 this case, carriers use RJ aircraft to feed their hubs.

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 amount 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 a lower bound, i.e., $d > d_\Gamma$ and two upper bounds, i.e., $d < d_\Psi$ 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.

[14] Note that the condition $d < d_\Lambda$ (which implies $\frac{\partial \pi(0,0)}{\partial \theta_L} > 0$) is not needed anymore 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 does not consider this aircraft technology to have a more tractable setting and focus on the use of RJs on routes initially served with mailine jets.

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*
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 low-cost 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 have observed in Fig. 4 in Section 2, the viability of the European PP routes on 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 amount 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 where 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,

[16] Note that the condition $d > d_\Upsilon$ (which implies $-\frac{\partial \pi(1,1)}{\partial \theta_L} > 0$) is not needed anymore with $d > d_\Sigma$ (which implies $\pi(1, \theta_L) < \pi(0, \theta_L)$ for $\theta_L \in [0, 1]$).

it unveils some appealing insights that are in line with the observed 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 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 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 here Fig. 6–

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 shows 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 depicted in Fig. 6. The values in Table 1 confirm the results depicted in Fig. 6 above.[17]

−Insert here Table 1−

As we can see, the choice of θ_H and θ_L gives rise to a certain network structure, where lower distances between endpoints A and B support FC structures, whereas higher levels of d favor HS network configurations. Interestingly, for $d \in (d_\Phi, d_\Gamma)$, HS network is the outcome with a RJ technology whereas FC network is the outcome with 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 affect significantly airlines' network structure.

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

4 Empirical model

In this section we develop an empirical analysis to examine the type of aircraft and the business model that is chosen by the main American and European network carriers. First, we explain the criterion for the selection of the sample of routes, and we 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 on aircraft technology and business models.

4.1 Data

As we mentioned above, our data is based on routes from both the US and the EU in 2009. Data on airlines 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 comes from the Official Airlines Guide (OAG) and the webflyer web site.[18]

[17] Note that in the region $d < d_\Omega$ when a RJ model is adopted, $\pi(1, 0) > \pi(1, 1)$ is possible for values of d close to d_Ω (the optimal result is $(\theta_H^*, \theta_L^*) = (1, \theta_L^*)$ with $\theta_L^* \in (0, 1]$); and in the region $d > d_\Psi$ when a LC model is adopted, $d > d_\Psi$ 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, Lufthansa) 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.[20]

We account for routes with different market structures, including monopoly and oligopoly routes. We observe that 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 are not treating airlines' services in different directions on a given route as separate observations because we would miss the fact that airlines supply must be exactly or nearly identical in both directions of the route. In this way, we are just considering 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 distinguish 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 merger Delta-Northwest was not completed until early 2010. Hence, we prefer to treat Delta and Northwest as separate airlines in their choice of aircraft.

[20] Concerning the American carriers, since data for some explanatory variables are not available, the sample used in the regressions reduces to 4895 observations.

[21] We exclude from the analysis 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] This type of decisions are beyond the scope of this paper. Forbes and Lederman (2009) examine in which conditions the major airlines in the US prefer to provide regional air services either using carriers vertically integrated or through contracts with independent regional carriers, finding 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 concerned with 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 do not have any LC subsidiary in 2009. Regarding 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 aircraft choice by US airlines, 6% of the observations refer to turboprops, 52% to RJs and 42% to mainline jets. Looking at the aircraft choice and business model implemented by 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 that refer to airlines operating in their hubs represents 41% for US carriers and 47% for European carriers.[23]

Data on population and Gross Domestic Product per Capita (GDPC) of American end-points 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), and it has been provided by Cambridge Econometrics (European Regional Database publication). We are aware that MSAs in the US and NUTS 3, as it is defined by Eurostat for the EU, are not strictly comparable. Hence, we consider troublesome to make joint estimations using the

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

whole sample of routes that includes airlines from both the US and the EU.

We consider Las Vegas (LAS), Orlando (MCO) and Spokane (GEG) as tourist US destinations. In the EU, we consider the following tourist destinations. On the one hand, all airports located in the following islands: the Balearic and Canary islands (Spain), Sardinia and Sicily (Italy), Corse (France), many Greek islands.[24] On the other hand, we also include the airports of Alicante (ALC), Faro (FAO), Malaga (AGP) and Nice (NCE).

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

4.1.1 US descriptive data

Table 2 below shows some data about the US airlines considered in this analysis. As it can be seen, there is a high diversity in their network of routes. Delta, Northwest and US Airways have an extensive network, so that they offer 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 choose often 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 most used type of aircraft in the case of Continental. Finally, American Airlines mainly operates with mainline jets.

−Insert here Table 2−

Table 3 shows some characteristics of the routes where the major US airlines offer service, related to the type of aircraft used. It can be seen that RJs are used on longer routes than turboprops but shorter than mainline jets. Additionally, regional aircraft are used on thinner routes (lower number of seats) than mainline jets. Overall, RJs are highly used by US airlines.

−Insert here Table 3−

4.1.2 EU descriptive data

Table 4 shows some data about European airlines. As in the case of US airlines, we can also see a high diversity in the network of routes of their European counterparts. British Airways provides services on a relatively low number of European routes, most of them in competition

[24] Details available from the autors on request.

with other airlines. The high majority of its routes are served with mainline jets and it does not have a LC subsidiary. Less than half of the routes have the hub as an endpoint of the route. Air France and Lufthansa have a much more extensive network of routes in Europe and they use quite often either RJs or LC subsidiaries to offer services. However, Air France focuses more its operations on its hubs and also on monopoly routes. Finally, Iberia has similar characteristics to Lufthansa but providing services on a lower number of routes.

–Insert here Table 4–

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

–Insert here Table 5–

4.2 Analysis

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

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

The theoretical analysis shows that air services on spoke-to-spoke routes may emerge with the use of RJs for sufficiently low distances (but longer than with turboprops) to serve business travelers. Additionally, air services on spoke-to-spoke routes may emerge with the use of a LC business model for longer distances to serve leisure travelers.

Hence, we want to address the following questions in the empirical analysis to test the results obtained in the theoretical part. The first one is whether RJs are mainly used to feed hubs or to provide services on PP thin routes. The second one is to check whether RJs are highly used on routes with a high proportion of business travelers, and LC subsidiaries are highly 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, both in the US and the EU.

Although the US network carriers in 2009 do not have any LC subsidiary, these subsidiaries play a remarkable role in Europe. Thus, our analysis of LC subsidiaries is confined to European airlines. This important difference between the US and the EU is explained, at least, by three facts. First, the national interests of the former flag carriers in Europe that make them operate in non-hub national airports to prevent competition in the home market. Second, Europe has a higher number of airports specialized on leisure travelers. Finally, it could also be argued that LC carriers in the US have experienced a certain movement *upmarket* that approaches them to the network carriers. In this context, setting up a new subsidiary LC carrier may be inadvisable for the American network carriers.[25]

4.2.1 The emergence of a RJ technology

To deal with the aircraft choices of airlines, 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 beyond 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 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 they fail to find indisputable evidence of success of this strategy. Concerning the US experience, it seems that the difficulties in effectively separating network operations from those of the LC subsidiary, could 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 those routes where 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 where 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 is increasing 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 less likely used than mainline jets and more likely used 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 is not clear a priori.

Demand should be higher in more populated and richer endpoints. Additionally, monopoly routes should be generally thinner than routes where several airlines are offering air services. As compared to mainline jets, we expect RJs to be more likely used on both monopoly routes and thinner routes, i.e., routes having 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 variable of distance, 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 those routes with a higher proportion of leisure travelers. These routes should be the ones having a tourist destination as endpoint and the ones having airports more distant 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 less likely used on tourist routes with a higher proportion of leisure travelers.

Finally the dummy variable for hub airports allows us to identify whether RJs are more likely 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 where the use of RJs is the reference case. When we consider the move from RJs to other 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 both 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., 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. Results from Table 6 report the statistical significance of the considered relationships, while results from Table 7 report the quantitative impact of each explanatory variable.

−Insert here Tables 6 and 7−

First, we compare the use of RJs as compared to mainline jets. Looking at the effect of distance between endpoints, RJs are more used 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 used than mainline jets on thinner routes. In this regard, our results show that mainline jets are more used 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). On the contrary, mainline jets are less likely used on monopoly routes. The predicted change in probabilities is quite high for all these variables and similar both 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 can make this statement since we observe that RJs are less used than mainline jets on tourist routes and on routes where airports are more distant to the city-center. The predicted change in probabilities is also high for both variables, especially for US airlines.

Finally, RJs are more likely used than mainline jets on spoke-to-spoke routes (i.e., PP routes) rather than on hub-to-spoke routes for European airlines. 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 the direction or the statistical significance of the effect. 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 delves into this effect, showing the results of this variable for each American airline.[27] From Table 8, we conclude that RJs are more likely used by several US airlines on spoke-to-spoke routes than on hub-to-spoke routes as it is the case for European airlines.

−Insert here Table 8−

Shifting attention to the analysis of the use of RJs with respect to turboprops, as it could be expected, we can just derive one strong inference. Turboprops are more likely used than RJs on shorter routes. The predicted decrease in the probability of using 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 airlines. Recall that the main advantage of RJs in relation to turboprops is that they can be used on longer routes. As we have shown above, turboprops are just used on routes shorter than 300 miles, while RJs are dominant 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 dominated by turboprops is between two and three times lower than the mean distance of routes dominated by RJs. From a statistical point of view, there are other variables that are significant, like 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).

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

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 observed empirically. Our empirical results show that RJs are mostly used by business travelers for intermediate-distance routes, and that RJs are mostly used on PP routes (for EU carriers and several US carriers). Consequently, new direct connections could be observed after the irruption of the 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 the attention on routes where mainline jets are used. Our interest here is to examine when it is more likely that the airline chooses to operate the route with a LC subsidiary instead of with the main brand. Recall that this analysis just focuses 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 are offering 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 more likely used 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 highly used on PP thin routes with a high proportion of leisure travelers and relatively long distances. Thus, LC subsidiaries should be more used on spoke-to-spoke routes (than on hub-to-spoke routes), on monopoly routes, on routes having poorer and less populated endpoints, and on routes with a high proportion of leisure travelers, i.e., routes from/to tourist destinations and routes having the airport more distant form 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 used if the sign of this coefficient is positive (negative). Table 9 below shows the results of the estimation of

[28] We exclude the observations of British Airways in the regression because this airline does not have any LC subsidiary in the considered period. Given the reduced number of observations in this regression, we consider that airline fixed effects are not appropriate. The reduced number of observations makes also not advisable to include the square of population as explanatory variable. In any case, this latter variable is highly insignificant when included in the regression.

equation (24).

−Insert here Table 9−

The results above confirm our hypotheses. Indeed, all the coefficients are statistically significant and with the expected sign, except the one corresponding to the variable of the distance of 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 that we find evidence that the LC subsidiary is more likely used 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 more likely used on spoke-to-spoke routes because the coefficient associated to the dummy variable for hub routes is negative and statistically significant. This result could 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 used on monopoly routes and on routes with poorer and less populated endpoints. Therefore, we conclude that LC subsidiaries are more likely used on thinner routes. The predicted change in the probability of using LC subsidiaries is remarkable for all these variables.

Finally, it seems that the LC subsidiary is more likely 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 are in line with 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 LC direct connections could be observed after the surge of these new business models.

5 Concluding remarks

Airlines may take 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 imply some negative consequences. Some of these negative effects are congestion, less competition due to airport dominance (by the *hubbing* airline) and lower service quality of air services for citizens living in cities distant from hub airports.

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

We find that the RJ technology and the LC business model are intensively used on thin PP routes (at least by the major European airlines and several American airlines). 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 PP thin routes with RJ for sufficiently low distances (but longer than with turboprops). This direct connection will be mostly addressed 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 PP thin route by means of a subsidiary LC carrier for sufficiently long distances. This direct connection will be mostly used by leisure travelers that are more fare-sensitive (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 be very different. Thus, policy makers and airport operators should assess which type of airline networks they want to foster in their sphere of influence. In case they want to promote direct connections out of the hub, they could use tools like airport charges (both the level and the relation with the weight of the aircraft), investment in capacities, marketing of the cities where the airports are located, etc.

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Figures and Tables

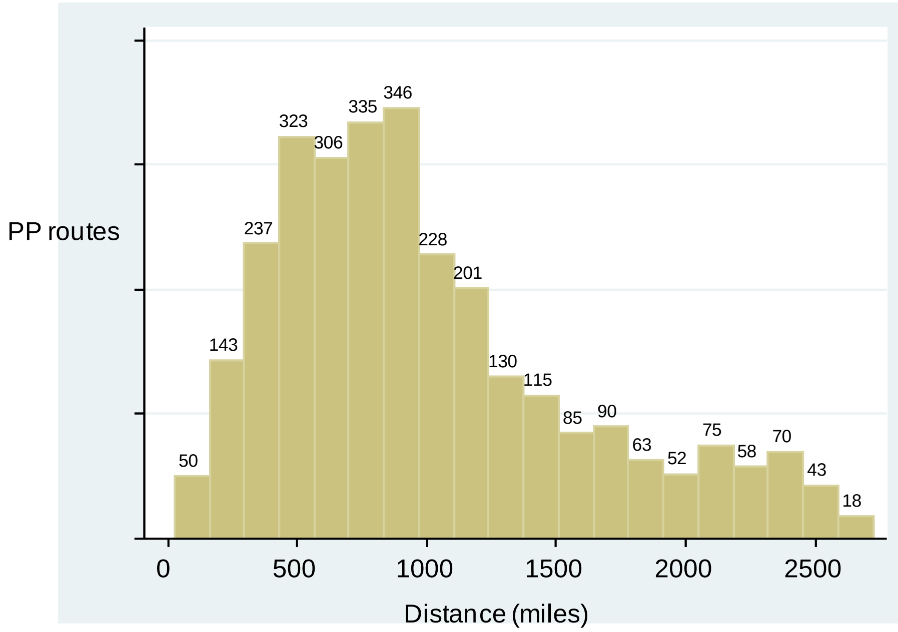

Fig. 1: Histogram of the variable of distance (PP routes – US)

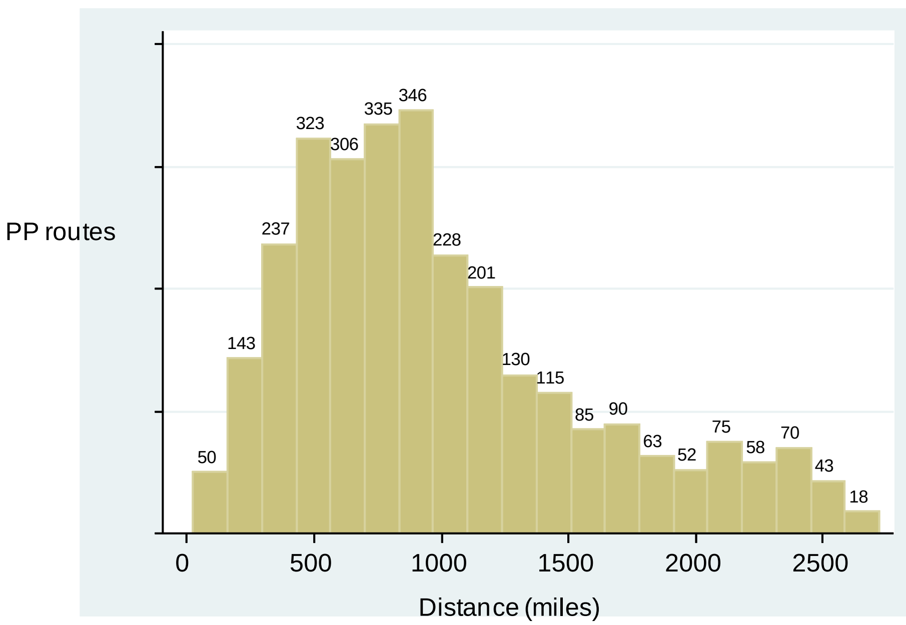

Fig. 2: Histogram of the variable of distance (PP routes – EU)

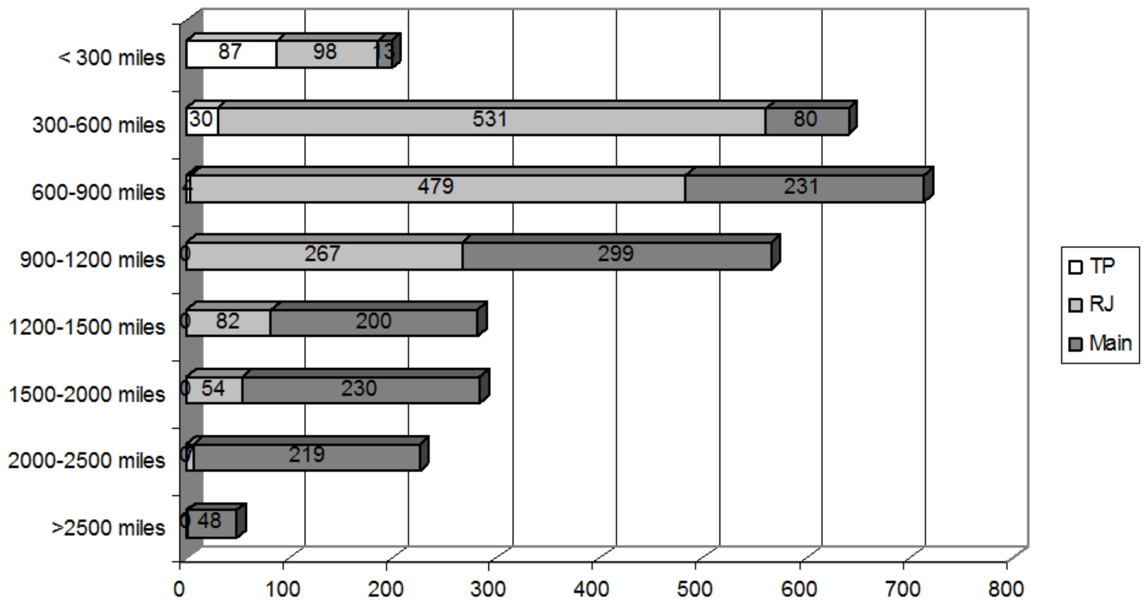

Fig. 3: Aircraft technology by distance (PP routes - US)

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.

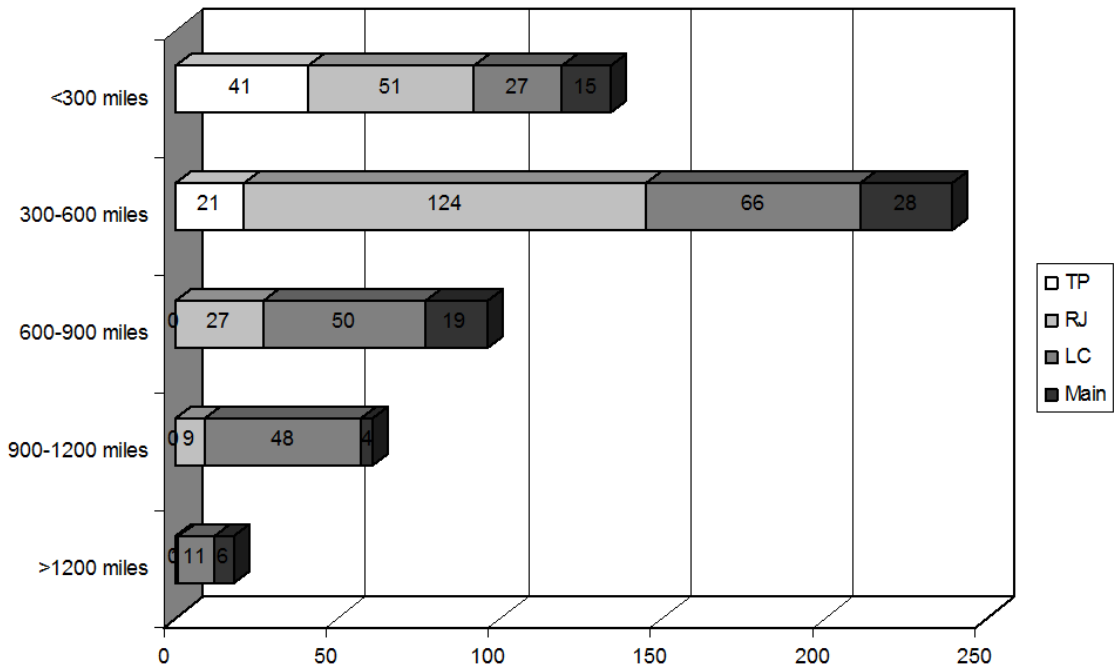

Fig. 4: Aircraft technology and business model by distance (PP routes - EU)

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

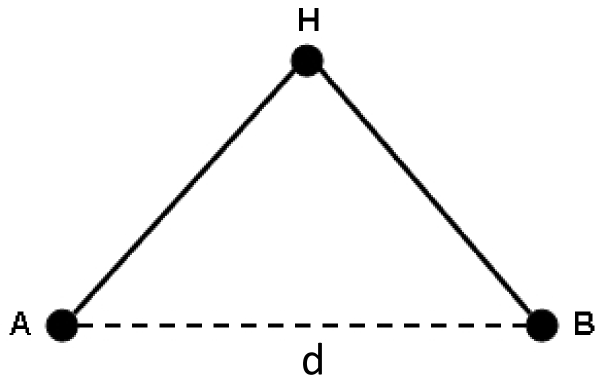

Fig. 5: Network

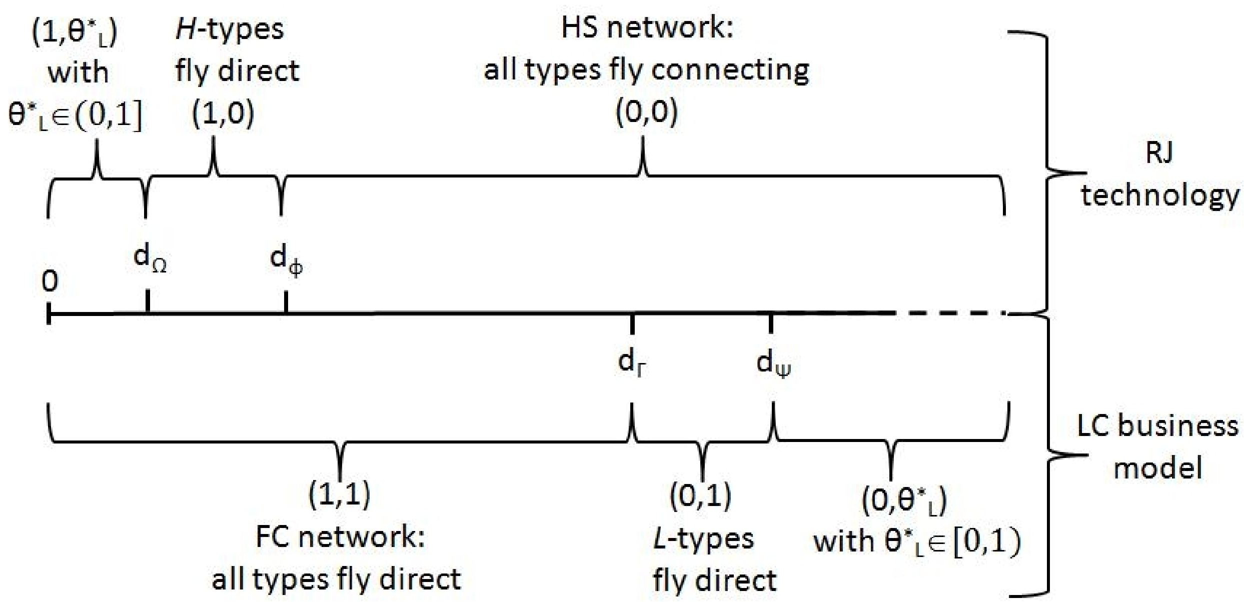

Fig. 6: Optimal network choice

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	$\underline{3.79}$	3.79	$\underline{3.79}$	3.79	$\underline{3.79}$	$\underline{3.79}$
$\pi(1,0)$	6.19	-0.82	$\underline{3.97}$	-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	$\underline{3.84}$	-8.04	3.53
$\pi(1,1)$	$\underline{6.37}$	$\underline{7.54}$	1.93	$\underline{6.61}$	-4.00	$\underline{5.38}$	-12.89	3.54	-15.85	2.92

Note: d_Ω= 1.96, d_Φ= 2.12, d_Γ= 6.01 and d_Ψ= 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)**	-0.04 (0.017)***	-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

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

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

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

where $\Omega, \Lambda < 0$ imply $d > d_\Omega, d_\Lambda$, and $\Phi > 0$ implies $d < d_\Phi$. Therefore, $(\theta_H^*, \theta_L^*) = (1,0)$ 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

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

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

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

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

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

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 $(\theta_H^*, \theta_L^*) = (1, 0)$, 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, $(\theta_H^*, \theta_L^*) = (0, 1)$, 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 $\theta_L^* \in (0, 1]$ 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 $\theta_L^* \in [0, 1)$ 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. ■