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Network competition: the coexistence of hub-and-spoke and point-to-point systems

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Abstract: The paper identifies conditions under which asymmetric equilibria may exist when carriers compete in designing their network configurations in a game-theoretical framework. Two carriers are assumed here, which are allowed to play three different strategies: point-to-point, hub-and-spoke (HS) or multi-hub. We find two main stable outcomes, which depend on the size of the internal market. First, when the internal markets are small, point-to-point network strategies are played by both carriers, while for a specific subset of parameters a collusive equilibrium in a hub-and-spoke configuration can be derived. Second, when the size of the internal markets is large, asymmetric configurations, where one carrier chooses a hub-and-spoke strategy and the other chooses a point-to-point strategy, are the only stable equilibria. The result can be used to describe the co-existence of alternative business models that have recently emerged in the aviation industry: the established full-service model based on the hub-and-spoke system and the recent low-cost model based on the point-to-point system.

Keywords: network competition, low-cost carriers, European airline market.

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1. Introduction

From the mid-1990s to the beginning of the new millennium, the European aviation industry faced one of the biggest booms in its history. However, this tendency was not confirmed in subsequent years. At the beginning of 2000, the economic slowdown brought an end to the growth phase, and the terrorist attacks of 11 September 2001 and the SARS virus in 2003 worsened the situation. In 2004, the airline industry probably faced the most difficult period of its existence.

Nevertheless, during these years, a group of airlines were able to generate profits and positive growth by generating a cost advantage, no frills, and a point-to-point network business model in contrast to the traditional hub-and-spoke national flag carriers. The low-cost business model is currently quite popular and is advocated as an alternative for the traditional airlines business models which, on the contrary, aim to cover all market segments and city-pairs, and therefore these airlines are named 'full-service carriers' (FSCs).

In the past, low-cost carriers (LCCs) were considered a successful separate niche market, characterised by passengers with low willingness-to-pay and connecting secondary city-pairs. Nowadays, the scenario is changed: FSCs and LCCs often compete on the same routes and for coincident segments, while LCCs performance indicators are in general higher than those of FSCs. This change of perspective have pushed the current debate on the future of the aviation sector toward the investigation of the coexistence of these two business models. The ongoing debate focuses on whether the FSC business model, successful during the 1980s and 1990s, is now sustainable in a market crowded by LCCs.

The differences between the two business models are multi-faceted (see e.g. Alderighi et al. 2004). FSCs have an HS network, while LCCs offer PP connections especially from secondary airports. The LCC product is not differentiated as they offer no frills, no lounges at airports, no choice of seats, no newspapers, no catering, no frequent flyer programme, no refund, and no possibility to rebook to other airlines. The distribution is as simple as possible by making use of Internet direct sales and with electronic tickets.

Although previous characteristics still play an important role to provide a cost advantage to LLCs, Franke (2004) found that the most relevant success factors are the network configuration and the streamlined production processes.

In this paper we do not compare the FSC business model and the new LCC business model in each characteristic, but we address the most important one, i.e., the network configuration². The analysis is performed from a theoretical point of view. We examine a game-theoretical context where carriers are allowed to play three different strategies, viz. point-to-point (PP), hub-and-spoke (HS) or multi-hub (MH) and we identify the conditions under which a-symmetric equilibriums may exist. We further discuss how the outcomes of the model can be used to describe the observed coexistence of different business models.

The development of the HS network started quite some time ago in the long history of European aviation. Before liberalization, the HS network in Europe developed out of the former national flag carriers and took advantage of operating in a regulated industry: bilateral agreements, protected markets, and set prices. Indeed, the former bilateral regime of air service agreements had already led to the development of hubs. In this context, the only available international freedom was what is called the 6th freedom, i.e. the right to provide transport services between two countries other than the one where the aircraft is registered across the territory of that country. In other words, this is the possibility to connect two countries via the national hubs. Furthermore, major airlines developed the concept of ‘network planning’, i.e. the process of capacity supply optimization to match the forecasted demand. On the basis of this strategy, carriers bundle more and more traffic flows into their hub by feeding and de-feeding operations. The airline’s unit cost is therefore reduced, as grouping passengers with the same travel origin but different destinations allows the realization of economies of density on both feeder flights and connecting flights to the final destinations.

² In a recent study, Franke (2004) showed that LCCs cost reductions come from the streamlined production process, which is strongly related to the choice of a PP network configuration. Many of the differences between FSC and LCC stem from the choice of the network structure (see below).

The objective of the HS network planning is the maximization of the number of city pairs to cover all traffic segments (business and leisure). A HS network design focuses on the connectivity within hubs which is typically implemented by concentrating the flights' landing and take off time at the hubs (hub waves). The wave design determines the outbound and inbound flights connectivity. The disadvantages of the HS strategy are: the lower quality service to the passenger (who would normally prefer direct flights) and an increase in operational costs for the airline. Indeed, these waves create peak times in the hubs and, consequently, congestion with possible delays, including missing connections.

The point-to-point (PP) network of an LCC is operated by a simple fleet with a limited variety of types of aircraft which are very cost-efficient (Boeing 737 or Airbus 320/319). According to Franke (2004), the considerable cost reduction of LCCs comes from an intensive use of the aircraft: the aircraft of a LCC is in the air, on average, more hours a day compared with the traditional carriers. This generates higher productivity of aircraft and crew. Moreover, lower maintenance costs, due to simpler fleets and lower landing/ground handling fees negotiated with secondary airports without congestion problems, cause also relevant differences in the production process. In the present paper, the economic feasibility of different connectivity structures (HS, PP, MH) will be analysed for both LCCs and FSCs.

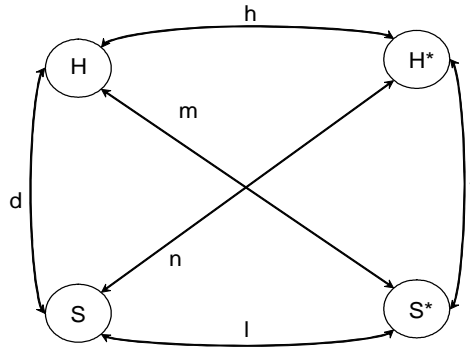
2. The model

We analyse here a simple symmetric network³ which has four nodes (cities). Two nodes are located in a domestic country and two in a foreign one. In the domestic

³ There are a few papers that model airline competition as a network game. Among these, it is worth mentioning that of Oum et al. (1995), who present a network game in which carriers *investing in hubbing* make a firm "tough" in the multi-product market competition. The use of HS networks turns out to be a device for entry deterrence. Another contribution to the analysis of network competition is given by Adler (2001) who studies a two-stage duopoly competition where carriers first choose their hubs, the connections to spokes and the frequencies, while afterwards they compete both on direct and indirect routes. She finds that there are multiple equilibria as well as no equilibria, depending on the parameters. Other papers on the topic include Hansen (1990), who studies hub competition in choosing the level of frequencies, and Hong and Harker (1992), who mainly analyse the competition for slot allocation.

country, there is a big city, H, and a small one, S. The big city is a candidate to be a Hub in a HS network and the small city is a candidate to be a Spoke. Similarly, we call H* and S*, respectively, the big and the small city in the foreign country (see Figure 1). The consumer's demand for flights between the cities depends on the size and distance of the towns and the price charged by the carriers. We assume that the reservation price in each market is normalized to 1, and that the potential size of each market (given by the number of passengers when the price is set equal to zero) is as follows: $h > m = n > l$ and $d = f > m$. These assumptions are consistent with the predictions of gravity models which suggest that traffic flows are proportional to the size of the cities and negatively proportional to the distance. The demand is linear, that is, if the price in the route r is p_r , the inverse demand is $p_r = 1 - \frac{1}{r} q_r$.

Figure 1. Airline markets in a four-node network



On the supply side, we assume that there are 2 carriers: a domestic FSC carrier, and a foreign LCC carrier. Each carrier owns 4 planes of size a , and it can choose among 3 different network structures:

- *P: Point-to-Point*: each carrier allocates one plane on the main routes originating from its country. Carrier 1 covers the routes d , m , n and h , while carrier 2 covers f , n , m , and h .
- *H: Hub-and-Spoke*: each carrier allocates two planes on the domestic route and the other two planes on the routes originating from the Hub H . The domestic carrier covers d (with two planes) and m and h (with one plane each), whilst the foreign carrier covers f (with two planes) and n and h (with one plane each).

Bhaumik (2002) investigated the welfare implications of carriers' competition and the role of a regulator. Finally, Hendricks et al. (1997) analyse asymmetric duopoly competition where departure time is used as a crucial competitive variable.

- *M: Multi Hub-and-Spoke*: each carrier allocates two planes in the domestic market and two planes to connect the main cities. The domestic carrier covers d and h , while the other carrier covers f and h .

We confine our analyses to these three network structures. We have also tested for alternative configurations, but this does not enrich the outcome of the analysis.

To deal with this model we need to make strong assumptions on pricing policies of carriers and preferences of passengers. First, we assume that carriers offer all their capacity to the market (i.e., planes fly full if possible). Hence, the price a carrier receives for its service only depends on market demand, and the carrier does not have a monopoly power. We also assume that carriers charge a price for each route separately, and they cannot give a discount or charge a premium for connected flights. Here, we are not interested in the pricing strategy of the carrier, but only in the network strategy of the carrier. We know that a carrier can increase its profits by using more complex pricing policies, but the result we obtain must be thought of as a benchmark case.

Secondly, it is assumed that the airfare is the only variable on which consumers base their decision. There is neither a frequency premium nor a discount for stops. And finally, we assume that carriers have already chosen their network structures, to allocate their planes on the network. The issue centers around the question how the market determines prices and passenger flows.

3. The pricing rule

The rule for allocating passenger flows on the network, and consequently obtaining prices, rests on the hypothesis of no arbitrage: passengers, who want to fly from one city to another, will choose the least-cost combination of routes. As an example, the price formation is described when the domestic carrier chooses network $P1$ and the other carrier chooses network $P2$. First of all, we identify the number of planes on each route. There is one plane on route d provided by the domestic carrier and two planes on route m , n and h . Note that l is not served directly. We assign the flows to each route and the remained freely on the network. For example, passengers belonging to l can be assumed to choose d plus n and f plus m . Symmetry allows us to assume that half of these passengers will choose the first way of travel and half the second way.

To solve the model exercise, we have to assign numerical values to the parameters. We assume that the capacity of each plane is $a = 3/2$, and that the dimensions of the routes are: $d = h = 4$, $m = 3$ and $l = 2$. The problem can then be specified:

Demand side:

$$p_d = 1 - \frac{1}{4}q_d, p_f = 1 - \frac{1}{4}q_f, p_l = 1 - \frac{1}{2}q_l$$

$$p_m = 1 - \frac{1}{3}q_m, p_n = 1 - \frac{1}{3}q_n, p_h = 1 - \frac{1}{4}q_h$$

Supply side:

$$q_d + \frac{1}{2}q_l = \frac{3}{2}, q_f + \frac{1}{2}q_l = \frac{3}{2}, q_m + \frac{1}{2}q_l = 2 \cdot \frac{3}{2}$$

$$q_n + \frac{1}{2}q_l = 2 \cdot \frac{3}{2}, q_h = 2 \cdot \frac{3}{2}$$

No-arbitrage condition:

$$p_l = p_d + p_m$$

The following prices are obtained $p_d = p_f = \frac{13}{19}$, $p_h = \frac{1}{4}$, $p_l = \frac{29}{38}$, and $p_m = p_n = \frac{3}{38}$.

Now we immediately notice that passengers d and f can choose n plus h and m plus h , respectively, and save money. This implies that there is room for arbitrage. To cross out the opportunity of arbitrage, the flows d and f can be partially re-routed till the prices on the direct and indirect link are the same. Hence, to solve the model we impose the condition that the prices of indirect flights are at least as high as the price of the direct flight. The problem is now as follows:

Supply side:

$$q_d - \delta q_d + \frac{1}{2}q_l = \frac{3}{2}, q_f - \varphi q_f + \frac{1}{2}q_l = \frac{3}{2}, q_m + \frac{1}{2}q_l + \varphi q_f = 2 \cdot \frac{3}{2}$$

$$q_n + \frac{1}{2}q_l + \delta q_d = 2 \cdot \frac{3}{2}, q_h + \delta q_d + \varphi q_f = 2 \cdot \frac{3}{2}$$

No-arbitrage condition:

$$p_l = p_d + p_m, p_d = p_n + p_h, p_f = p_m + p_h$$

The solution to the new problem is: $p_d = p_f = \frac{49}{82}$, $p_h = \frac{34}{82}$, $p_l = \frac{64}{82}$, and $p_m = p_n = \frac{15}{82}$.

In this case, it is not possible to gain more by changing the routes and, hence these are the equilibrium prices. The computation of profit is quite simple, as we assume that all seats are taken. Hence the profit is just the sum of the price on each route times the capacity offer (number of provided seats times capacity of the plane). Hence the profit

of carrier l is $p_d \cdot a + p_h \cdot a + p_m \cdot a + p_n \cdot a = \frac{339}{164} = 2.067$. The same holds for carrier 2. In general, this solution can also be presented as a linear programming problem where total passenger expenditure is minimized subject to demand and supply side constraints and a no-arbitrage condition. This fact is appealing, as the solution is welfare maximizing and the equilibrium is unique. The linear programming problem is:

$$\begin{aligned} \min \quad & \sum_{r \in (d, f, m, n, l, h)} p_r \cdot a \cdot s_r \\ \text{subject to} \quad & r \cdot p_r = r - q_r, \forall r = d, f, m, n, l, h && \text{(demand side)} \\ & q_d - V_d - W_d + V_m + W_n + W_l + W_h = a \cdot s_d \\ & q_f - V_f - W_f + W_m + V_n + V_l + V_h = a \cdot s_f \\ & q_m - V_m - W_m + V_d + W_f + W_l + V_h = a \cdot s_m && \text{(supply side)} \\ & q_n - V_n - W_n + W_d + V_n + V_l + W_h = a \cdot s_n \\ & q_l - V_l - W_l + V_d + V_f + V_m + V_n = a \cdot s_l \\ & q_h - V_h - W_h + W_d + W_f + W_m + W_n = a \cdot s_h \\ & p_d \leq p_m + p_l, p_d \leq p_n + p_h \\ & p_f \leq p_m + p_h, p_f \leq p_n + p_l \\ & p_m \leq p_d + p_l, p_m \leq p_f + p_h && \text{(no arbitrage)} \\ & p_n \leq p_f + p_l, p_n \leq p_d + p_h \\ & p_l \leq p_m + p_d, p_l \leq p_n + p_f \\ & p_h \leq p_m + p_f, p_h \leq p_n + p_d \\ & q_r, p_r, V_r, W_r \geq 0, \forall r = d, f, m, n, l, h. && \text{(positive constraints)} \end{aligned}$$

The problem has been solved using the software OPL studio 5.13. Thanks to the linearity of constraints and of the objective function, solution prices and quantities are unique, and consequently the profit of both firms is unique. Uniqueness is a very appealing result for economists investigating network games, as there are often multiple equilibria.

4. The equilibrium of the game

We assume that each carrier can choose a particular structure independently of the choice of its opponent. In total, this may generate 9 possible configurations. Excluding the symmetric ones, we finally have 6 possible results. Table 1 summarizes the pay-off results of the two carriers when the capacity of each plane is $a=3/2$, and the size of the markets are: $d=h=4$, $m=3$ and $l=2$ (reference case).

Table 1. Pay-off matrix; reference case

	P2		H2		M2	
P1	2.067	2.067	<u>2.477</u>	<u>2.087</u>	2.326	1.124
H1	<u>2.087</u>	<u>2.477</u>	2.085	2.085	2.466	1.380
M1	1.124	2.326	1.380	2.466	1.846	1.846

Note: Underlining indicates Nash equilibrium.

There appear to be two Nash equilibria: P1-H2 and H1-P2. The pay-offs concerning P1-P2 and H1-H2 are both lower than the pay-offs concerning the Nash solutions. Hence, a symmetric PP or a symmetric HS structure cannot be implemented, even under collusion.

To analyse the robustness of the result, the size of the domestic market is changed. If we expand the size of the domestic market of the two carriers, i.e. if we replace $d=f=4$ with $d=f=4.5$ or more, we obtain similar results. When the domestic market is small $d=f=3.5$, then the PP solution can be implemented (see Table 2). Note that the payoffs in the case of P1-P2 are the same for H1-H2, but the HS equilibrium can be implemented under collusion.

Table 2. Pay-off matrix with small domestic market

	P2		H2		M2	
P1	<u>1.964</u>	<u>1.964</u>	2.391	1.884	2.209	1.011
H1	1.884	2.391	1.974	1.974	2.384	1.331
M1	1.011	2.209	1.331	2.384	1.787	1.787

Note: Underlining indicates Nash equilibrium.

Table 3 summarizes the pay-off of the two carriers when the domestic carrier introduces a flight on the route S-S*. The analysis is similar for the foreign carrier. If carriers are free to change the network, the equilibrium is (P1+L, P2). That means that both carriers move to a PP configuration (reference case).

Table 3. Pay-off matrix after introduction of a connecting service

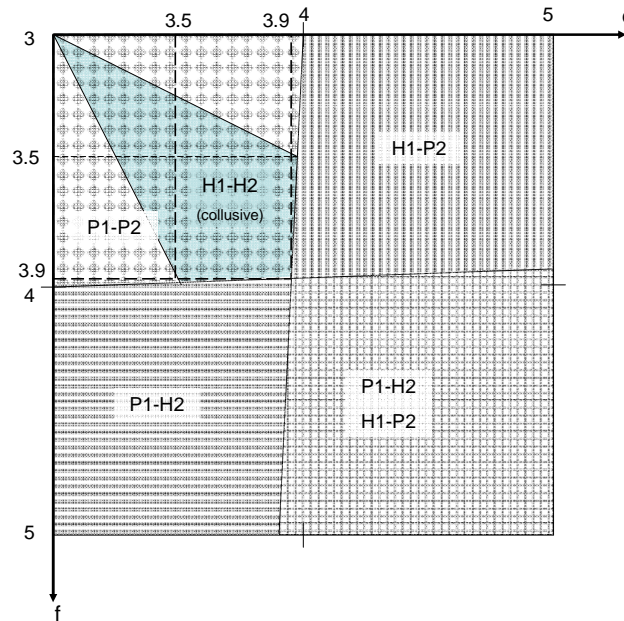
	P2		H2		M2	
P1 - L	<u>2.352</u>	<u>1.773</u>	2.662	1.519	2.637	1.119
H1 - L	1.894	2.287	2.250	1.875	3.100	1.110
M1 - L	1.438	2.317	1.760	2.451	2.221	1.846

Note: Underlining indicates Nash equilibrium.

If the preceding equilibrium is P1-H2, Carrier 1 has no incentive to add a flight, as its payoff reduces from 2.477 to 2.352, while it has a small incentive (2.352-2.087), if it is in the equilibrium situation H1-P2. Hence, if the costs of buying a new carrier are sufficiently high, none of the carriers will decide to invest in a new carrier. Note that if we do not permit a carrier to modify its network, but only to add a flight on the route I, the carrier choosing HS configuration also has a reduction in pay-off compared with the previous equilibrium.

Figure 2 depicts the different equilibrium strategies obtained by varying the size of the domestic and foreign market from 3 to 5. In general, we note that when a carrier's own market is small, the carrier will play a PP strategy and when its own market is large it will play HS strategy. When the domestic market is large for both carriers, an asymmetric equilibrium emerges. The symmetric HS strategy is sustainable only under collusion, and when the size of both the domestic and the foreign market is small and similar.

Figure 2. The solution of the network game depending on the size of d and f.



5. Alternative pricing rule

In the paper we choose to evaluate a firm's profit as a result of welfare maximization which corresponds to the minimal profit it gains, given the network configuration. Real profits are upper-bounded by first-degree price discrimination profits and lower-bounded by consumer surplus maximization profits.

The choice of the latter indicator is based on the following reasons. First, competition may limit the possibility of price discrimination and surplus extraction. Average prices on routes where there is competition are, *ceteris paribus*, lower than on routes where there is no competition.

Second, there are some difficulties in assigning consumers surplus when dealing with connecting passengers. For example, if an indirect flight is provided by different carriers, each carrier would like to extract all the rent (difference between the consumer's willingness to pay and their sum of the competitive prices). Third, even when we assume that carriers split the profit evenly, some problems remain. In fact, in this linear programming setting, we obtain a unique solution for quantities and prices but not for passengers' flows on indirect routes. Differences in passengers' flows on indirect routes have no impact on profit, when calculated assuming lack of monopoly power. However these differences may affect profit returns under first-degree price discrimination.

The model assumes that, in the price setting, carriers have no monopoly power, so that they are implicitly consumer surplus maximizers or welfare maximizers rather than profit maximizers. We provide a brief argument to reconcile the welfare maximization assumption with the profit maximizing behavior.

To keep things simple, the following example can be considered, where there is only one carrier, namely I , and one market, namely d . Assume that the market size is $d=4$, and the capacity supplied is $a \cdot s_d = 1.5 \cdot 2 = 3$. Welfare maximization implies that $p_d = 0.25$, $q_d = 3$, the profit of the firm is 0.75, and the consumer surplus is 1.125. Alternatively, if carrier I has all the monopoly power but it cannot practice price discrimination, it sets $p_d = 0.50$ and $q_d = 2$, and the profit is 1.00, while the consumer surplus is 0.50. In addition to this, consider a case where carrier I can practise a first-degree price discrimination. In this situation, the firm sets personalized prices for each consumer and extracts all the consumer surplus. The first consumer will pay 1.00, the second one will pay a little less than 1.00, and the last consumer will pay 0.25. The

profit of the firm is now given by $0.25 \cdot 3 + 0.5 \cdot 0.75 \cdot 3 = 1.875$, and the consumer surplus is nil. It is a well-established result that, under first-degree price discrimination, the firm gains the maximum profit and concurrently welfare is maximized. Contrary to the first part of this example, the surplus is now given to the firm. Hence, the profit maximizing behavior of a firm is consistent with the welfare maximization choice when it is assumed that firms will extract all the consumer rent.

Indeed, revenue management techniques employed by airline companies usually pursue this goal. Carriers try to segment customers according to their willingness to pay. They charge higher fares to higher willingness-to-pay consumers and lower fares to the others. The market segmentation is quite sophisticated as carriers charge about 10 different fares for each origin-destination. However, this is not a guarantee that they are able to extract the entire consumer surplus.

In Table 4 we provide the pay-off matrix computed under the assumption that carriers practice price discrimination. We assume that carriers continue to price discriminate (even if they are on the same route), that the consumer surplus is split evenly, and that flows on indirect flights are symmetric whenever possible.

Table 4. Pay-off matrix when firms price-discriminate

	P2		H2		M2	
P1	3.759	3.759	<u>4.100</u>	<u>3.768</u>	4.066	3.348
H1	<u>3.768</u>	<u>4.100</u>	3.957	3.957	3.916	3.397
M1	3.348	4.066	3.397	3.916	<u>3.346</u>	<u>3.346</u>

Note: Underlining indicates Nash equilibrium.

Table 4 uses the same values on the market size of Table 1. In this case, as well as in the previous one, we observe two asymmetric equilibria.

6. Conclusions

In the previous section, we have presented a rather simple model with two carriers and four cities (two large and two small ones). Carriers are allowed to play three different strategies: point-to-point (PP), hub-and-spoke (HS) or multi-hub (MH). We find that two main equilibrium outcomes emerge, depending on the size of the internal market. First, when the internal markets are small, the PP network strategy is played by both

carriers, and for a specific subset of parameters, a collusive equilibrium in a HS configuration can be implemented. Second, when the size of the internal markets is large, asymmetric configurations, where one carrier chooses a HS strategy and the other chooses a PP strategy, are the only stable equilibria.

The main result of the paper is that there can be a coexistence between a HS and a PP network and this result seems to be quite robust to variations in parameter and pricing rules. Before relating the outcome of the model to the current situation in the aviation sector, it is worth emphasising that the results are obtained through a rather stylised model under stringent assumptions.

The economic literature identifies two main elements affecting the choice network configuration: first, the spatial distribution of demand for direct flights among different towns, and second, the overall dimension of the market and the opportunity to exploit economies of density. The first factor is related to the choice of the HS network when the spatial distribution is uneven and the location of hubs is in large concentrations. The second factor concerns the choice of a HS network when the market is small, i.e., when the need to exploit the economies of density is stronger.

The driving forces behind our model are the differences in market size for the various city-pair combinations. This is an element that seems to have received less attention in most models presented in the airline literature. Most theoretical models address the problem of a network configuration in terms of economies of scale and density. These factors can stimulate HS networks in small markets and a PP configuration when markets are large enough. However, our model shows that when the traffic flows to an airport are large, i.e. the internal markets are large, the incumbent firm develops its hub in this airport and pushes the LCC to operate in smaller ones. Indeed, we observe, at least in Europe, that most HS carriers such as Lufthansa or Air France, have already developed their hub in large cities (Frankfurt, Munich and Paris). Smaller cities with small traffic flows are left to LCC operations.

There is another important but as yet insufficiently addressed aspect, which suggests the coexistence of HS and PP in European aviation systems. It is noteworthy that FSC carriers are stuck with the HS configuration to sustain the supply of intercontinental

flights. It still seems impossible to fill a Boeing 777 or an Airbus 330 for an intercontinental destination without a HS strategy. A carrier will still need to bundle demand from several origins. The feeder system is critical here, not only for charging intercontinental flights but also for the intra-European traffic flows. Hence, the choice of FSCs to provide intercontinental flights does reinforce and preserve the HS configuration.

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