Vertical differentiation, schedule delay and entry deterrence: Low cost vs. full service airlines

Jorge Valido[a,#], M. Pilar Socorro[a,b] and Francesca Medda[c]

[a]*Universidad de Las Palmas de Gran Canaria. Departamento de Análisis Económico Aplicado, Campus de Tafira. 35017 Las Palmas de Gran Canaria, Spain.*

[b]*Fundación de Estudios de Economía Aplicada (FEDEA). Jorge Juan 46, 28001 Madrid, Spain.*

[c]*University College London. Chadwick Building, Room 213. Gower Street, London WC1E 6B, United Kingdom.*

Abstract

We consider a market with a full-service (*FS*) carrier (the incumbent) and a low-cost (*LC)* carrier (the potential entrant). If the *LC* carrier enters the market, airlines compete in ticket prices and frequency with vertically differentiated products. The higher the frequency, the lower passenger's generalized price. Thus, more frequency allows airlines to increase ticket prices without losing demand. In this context, we show that the incumbent may increase the frequency offered in order to deter the *LC* carrier entry. We show that if the airport capacity is low enough the *LC* carrier entry can be easily blocked or deterred. However, if the airport capacity is sufficiently high, the *LC* carrier entry must be accommodated.

Keywords: Low-cost (*LC*) carriers, full-service (*FS*) carriers, schedule delay, entry deterrence

JEL Classification: L93, L12, L15

[#] Corresponding author. Telephone: +34928451836; Fax: +34928458183.
E-mail address: jvalido@acciones.ulpgc.es

1. Introduction

Low-cost (*LC*) carriers have acquired a significant market share in the last decades and it seems that it will continue growing in the future (Dobruszkes, 2006). Full-service (*FS*) carriers have been affected for this new model of airline business[1] and the competition between these two types of airlines is commonly observed.[2]

FS carriers and *LC* carriers differ in their quality and their costs, and thus, in the ticket prices charged to passengers.[3] Thus, several authors argue that *LC* and *FS* carriers compete in differentiated products (see, for example, Gillen and Morrison, 2003; Barbot, 2004, 2006, 2008; Fu *et al*., 2011; or Hazledine, 2011).

FS carriers and *LC* carriers not only differ in their quality and fare but they also differ in their frequency. *FS* carriers usually offer more frequent flights than *LC* carriers (Guillen and Morrison, 2003) and for this reason passengers can select a flight departure time that is closer to their preferred one. Passengers will be better off the smaller the difference between the real and the preferred departure time, and this different is the so-called schedule delay.[4] There are some papers in the literature that consider airlines that compete in fare and frequency (see, for example, Yetiskul *et al*., 2005; Brueckner and Flores-Fillol, 2007; or Yetiskul and Kanafani, 2010). However, none of these papers

---

[1] See, for example, Doganis (2001), Franke (2004), or O'Connell and Williams (2005) for historical notes of changes that affected the *FS* carrier model.

[2] See, for example, Pels (2008) for an analysis of the process of airline deregulation and its importance in the "low-cost airline revolution". This author also explains the effects of low-cost revolution in airline network.

[3] Franke (2004) argues that *LC* carriers can deliver 80% of the service quality with approximately 50% of the cost of *FS* carriers.

[4] There are some papers in the literature finding important effects of the scheduling cost (see, for example, Douglas and Miller, 1974; Anderson and Kraus, 1981; Lijesen, 2006; or Hess *et al*., 2007). In a recent paper, Koster *et al.* (2013) point out that travelers do not only consider arrivals delays, but also face scheduling costs because they arrive too early or too late at their destination. Earlier studies that consider travel delay variability for travelers going to the airport are Koster *et al*. (2011) and Tam *et al*. (2008).

consider competition in fares and frequency between airlines that offer flights with different qualities.[5]

In this paper, we consider a vertically differentiated product model as the one used by Shaked-Sutton (1982). However, we depart from Shaked-Sutton's model in the following. On the one hand, contrary to Shaked-Sutton (1982), we assume non-linear cost functions for airlines. Moreover, we assume that *LC* carriers have lower operating costs per flight than *FS* carriers. On the other hand, we assume that passengers' demand depends on airlines' generalized price, which is defined as the sum of the ticket price and the value of the total time spent by the consumer in the travel (which includes not only access, egress and in-vehicle time but also the schedule delay cost). In particular, we consider a market with a *FS* carrier (the incumbent) and a *LC* carrier (the potential entrant) that may enter the market. If the *LC* carrier enters the market, airlines compete in ticket prices and frequency with vertically differentiated products. In this context, we show that the incumbent may increase the frequency offered in order to deter the *LC* carrier entry.

We follow Dixit (1980)'s approach in which an incumbent decides whether to accommodate entry or to deter it through excess capacity. However, there are substantial differences. On the one hand, in our model the higher the frequency (capacity), the lower passenger's generalized price. Thus, more frequency allows airlines to increase ticket prices without losing demand. On the other hand, contrary to Dixit (1980), we do need to assume any fixed cost of entry for the *LC* carrier.

We show that, even if the airport has no capacity constraints, if the airport capacity is low enough the *LC* carrier entry can be blocked. Moreover, we show that the *FS* carrier optimally deters the *LC* carrier entry for intermediate values of the airport capacity. Finally, if the airport capacity is high enough, the *LC* carrier entry cannot be blocked or deterred and, thus, it must be accommodated.

[5] We consider competition between *LC* and *FS* carriers in the same airport. It is also possible the competition between both type of carriers serving different airports (see, for example, Pels *et al*. 2000; 2003; 2009)

Previous research on entry deterrence in the air transport market is mostly devoted to analyze the role of fare as an entry deterrence strategy (see, for example, Windle and Dresner, 1995, 1999; Goolsbee and Syverson, 2008; Huse and Oliveira, 2010; Tan, 2011; or Aydemir, 2012), or the effects on hub and spoke networks (see, for example, Oum *et al.*, 1995) and code share alliances (see, for example, Lin, 2005, 2008). However, few papers analyze the effects of capacity (frequency) on entry deterrence. One exception is Morrison (2004) that highlights that capacity expansion by an incumbent airline may represent a credible threat for potential entrants since some fixed inputs need not be permanently assigned to a particular city pair. Empirical evidence of the use of frequency as an entry deterrence strategy in air transport markets is still scarce. However, we would like to highlight two papers. On the one hand, Goolsbee and Syverson (2008) find weak evidence to support that the incumbents expand capacity as an entry deterrence strategy in air transport markets. On the other hand, Ng *et al.* (1999) interview 36 service firms to explore their practices of capacity usage. Their study shows that 25 per cent of service firms interviewed expand their capacity to deter entrants. Among them, they find an airline that expanded the capacity on certain routes to ensure that others carriers do not enter the market. The results of our paper that relate the use of frequency as an entry deterrence strategy and the level of airport capacity may explain the divergences between the findings of Goolsbee and Syverson (2008) and Ng *et al.* (1999).

The rest of the paper is organized as follows. In section 2 we explain the main assumptions of the model. Section 3 analyzes the competition in prices with vertically differentiated products. In section 4 we describe how the *LC* carrier decides whether to enter or not the market. Section 5 analyzes the *FS* carrier optimal choice of frequency in order to deter or accommodate the *LC* carrier entry. Finally, section 6 concludes.

2. Model setup

Suppose a market which is operated just by one full service (*FS*) carrier, the incumbent. However, there is one low-cost carrier (*LC*) that may enter the market. *FS* and *LC* carriers offer flights with different level of quality. We assume that the *FS* carrier has a first mover advantage and can decide the frequency he will offer before the *LC* carrier decides or not to enter the market. Thus, if the *LC* carrier decides to enter the market, he must decide his frequency and carriers will compete in prices with vertically differentiated products.

Following Brueckner (2004), we can define each flight operating cost by:

$$c_k = \theta_k + \tau_k s_k,$$

where θ_k is a fixed cost for airline k, s_k denotes the number of seats in airline k and τ_k is the marginal cost per seat in airline k, with $k = LC, FS$. Assuming a load factor of the 100%, the connection between frequency (f_k) and traffic (q_k) is given by the equation $q_k = f_k s_k$, that is, the total traffic is equal to the number of flights times the number of seats per flight. We suppose that the *LC* carrier has lower costs than the *FS* carrier, both in the fixed part of the cost of each flight and the marginal cost per seat of each flight, that is, $\theta_{LC} < \theta_{FS}$ and $\tau_{LC} < \tau_{FS}$.[6] We do not assume any fixed cost of entry for the *LC* carrier.[7]

We assume that there is a continuum of consumers who are identical in tastes but they differ in income. The income (m) is assumed to be uniformly distributed between the interval $[a,b]$, with $0 < a \le m \le b$. Consumers have unitary demand, that is, they buy (or not) only one ticket from one of the two carriers at price p_k.

We denote by H the number of available hours and by f_k the number of flights offered by airline k. The value of the total time spent by the consumer in the travel (T_k) is the sum of the value of the time spent in the trip (which includes access, egress and in-

[6] *LC* carriers have lower average cost than *FS* carriers because several reasons: higher seating density, highly daily aircraft utilisation, lower airport charges, minimum cabin crews, lower passenger services (e.g. meals and drinks), e-ticketing, use of secondary airports, minimal station costs (ground staff, check-in, related facilities of the airports,…), etc.

[7] Fixed cost of entry is a common assumption in the entry deterrence literature. In this paper, we show that even if we do not consider such a fixed entry cost, entry can be blocked or deterred.

vehicle time), A_k, and the average schedule delay cost $(\delta H / 4 f_k)$, being δ the cost of each hour of difference between the preferred and the actual departure time. Formally:[8]

$$T_k = A_k + \delta \frac{H}{4 f_k}.$$

Thus, we can define the generalized price for the consumer as the sum of the ticket price and the value of the total time spent by the consumer in the travel, that is:

$$G_k = p_k + A_k + \delta \frac{H}{4 f_k}.$$

The consumers' utility function is given by $U(m,k,G_k)$, which denotes the utility derived from consuming m units of income and one unit of product k, with a generalized cost of G_k. Formally:

$$U\left(m,k,G_k\right) = u_k\left(m - G_k\right) = u_k\left(m - p_k - T_k\right) = u_k\left[m - \left(p_k + A_k + \delta \frac{H}{4 f_k}\right)\right],$$

where u_k denotes the consumer satisfaction when flying with airline k. Since the *LC* carrier has a lower level of quality than the *FS* carrier, we assume that $0 < u_{LC} < u_{FS}$. Thus, a consumer only flies with a *LC* carrier if $G_{LC} < G_{FS}$, that is, if the sum of the price, the value of the time spent in the trip and the schedule delay cost for a *LC* airline is lower than for a *FS* carrier. This is stated in the following lemma.

Lemma 1*: No consumer flies with a LC carrier if* $G_{LC} \geq G_{FS}$.

Lemma 1 states that, even though a *FS* carrier may charge a higher ticket price than the *LC* carrier, if the former manages to offer a frequency high enough to compensate such a higher ticket price, no consumer will fly with a *LC* carrier.

[8] We suppose that consumers´ preferred departure times are spaced around the clock. H/f represents the time interval between flights and if consumers' preferred departure time is uniformly distributed around the clock, $H/4f$ is the average time to the nearest flight (Brueckner, 2004). One prior analysis of scheduling that incorporates these principles is Panzar (1979). See also Koster and Verhoef (2012) for other references in more general scheduling models.

Let $B_{FS} = u_{FS} / (u_{FS} - u_{LC})$ be the marginal utility gain of buying a ticket in a *FS* carrier instead of in a *LC* carrier, that is, it measures how the utility changes when switching from the *LC* to the *FS* carrier. Notice that, since $0 < u_{LC} < u_{FS}$, B_{FS} is strictly higher than zero and higher than one, that is, $B_{FS} > 0$ and $1 - B_{FS} < 0$.

Similarly, we can also define $B_{LC} = u_{LC} / (u_{LC} - u_0)$ as the marginal utility gain of buying a ticket in a *LC* carrier, that is, it measures how the utility changes when switching from an outside option to the *LC* carrier, where u_0 is the satisfaction obtained consuming this outside option. The outside option may represent an alternative mode of transport or even not travel at all. We assume that $u_0 < u_{LC}$ and, for the sake of simplicity, we normalize the parameter $u_0 = 0$. Then, without loss of generality, we assume that $B_{LC} = 1$.

First of all, we have to find the so called "indifferent consumer", that is, we have to find the consumer that is indifferent between flying with a *LC* carrier at a generalized cost G_{LC} or flying with a *FS* carrier at a generalized cost $G_{FS} > G_{LC}$. Formally:

$$U\left(m_{FS}, FS, G_{FS}\right) = U\left(m_{FS}, LC, G_{LC}\right),$$

that is;

$$u_{FS}\left(m_{FS} - G_{FS}\right) = u_{LC}\left(m_{FS} - G_{LC}\right).$$

Thus:

$$m_{FS} = B_{FS} G_{FS} + \left(1 - B_{FS}\right) G_{LC}. \tag{1}$$

Lemma 2: *The consumer that is indifferent between flying with a LC carrier at a generalized cost* G_{LC} *or flying with a FS carrier at a generalized cost* $G_{FS} > G_{LC}$ *has a rent* $m_{FS} = B_{FS} G_{FS} + \left(1 - B_{FS}\right) G_{LC}$.

Similarly, we can find the consumer that is indifferent between travelling with the *LC* carrier and the outside option:

$$U\left(m_{LC}, LC, G_{LC}\right) = U\left(m_{LC}, 0, 0\right),$$

that is:

$$u_{LC}\left(m_{LC} - G_{LC}\right) = 0.$$

Then:

$$m_{LC} = G_{LC}. \tag{2}$$

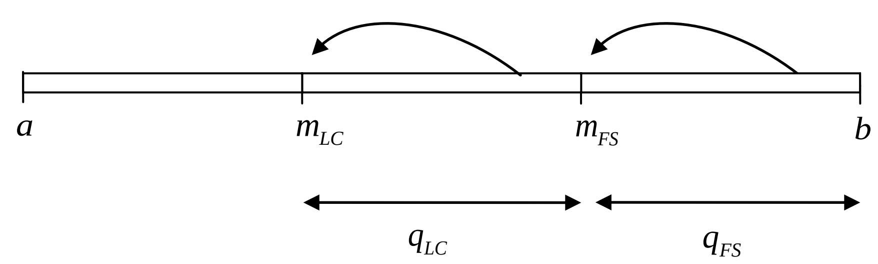
Lemma 3: *The consumer that is indifferent between travelling with a LC carrier at a generalized cost* G_{LC} *or an outside option with* $u_0 = 0$ *has a rent* $m_{LC} = G_{LC}$.

Corollary 1: *In the optimum* m_{LC} *can never be lower than a since it is always profitable for the LC carrier to choose a generalize price* G_{LC} *such that at least the consumer with the lowest rent buys a LC ticket.*

Notice that, given that for a consumer to fly with a LC carrier we need $G_{LC} < G_{FS}$, we have that $m_{FS} - m_{LC} = B_{FS}\left(G_{FS} - G_{LC}\right) > 0.$

We have to take into account that the consumer with income $m > m_{FS}$ strictly prefers the FS flight at the generalized price G_{FS} to the LC flight at the generalized price $G_{LC} < G_{FS}$. Consumers are divided into segments, and these segments correspond with the successive market shares of rival firms, q_{LC} and q_{FS}, as shown in Figure 1.

Figure 1. Indifferent consumer position and market shares



Corollary 2: *There is always space in this market for the two carriers.*

Let us now analyze how the indifferent consumers move in the income space.

Lemma 4: *The indifferent consumer between the LC and FS carrier is moved to the right in the income space if the FS carrier´s generalized price increases and is moved to the left if the LC carrier´s generalized price decreases.*

Proof: It is straight forward to check the sign of the following derivatives: $\frac{\partial m_{FS}}{\partial G_{FS}} > 0$, and $\frac{\partial m_{FS}}{\partial G_{LC}} < 0$. ■

In other words, if any part of the generalized price (ticket price, value of the trip time or schedule delay cost) of the *FS* carrier rises, the indifferent consumer will be a person who has more rent to afford a trip with a *FS* carrier. In contrast, if the *LC* carrier´s generalized price increases, the indifferent consumer will be a person with less income because, given the higher *LC* carrier's generalized price, the previous one would have decided to travel with a *FS* carrier.

Lemma 5: *The indifferent consumer between the LC and the outside option is moved to the right in the income space if the LC carrier´s generalized price increases.*

Proof: It is straight forward to check the sign of the following derivative: $\frac{\partial m_{LC}}{\partial G_{LC}} > 0$. ■

The intuition behind Lemma 5 is similar to the one of Lemma 4.

Carriers' generalized price depends both on the ticket price and the frequency and, thus, both variables are crucial for the computation of carriers' demand.

The timing of the game is as follows: First, the *FS* carrier decides his frequency (with the corresponding first mover advantage). Second, the *LC* carrier decides whether to enter or not in the market. If the *LC* carrier decides to enter, given the frequency of the *FS* carrier, he must decide the frequency to be offered. In the third stage, companies choose the optimal ticket prices. If the *LC* carrier decided not to enter, the *FS* carrier chooses the optimal price as a monopolist. If the *LC* carrier decided to enter, both the *FS* carrier and the *LC* carrier compete in prices with vertically differentiated products. The game is solved by backward induction.

3. Third Stage: Optimal ticket prices

In the last stage of the model carriers must choose the optimal ticket prices. There are only two possibilities: If the *LC* carrier decides to enter the market, we have a duopoly situation. However, if it is not profitable for the *LC* carrier to enter the market (whatever the reason) the market is served only by the *FS* carrier.

3.1 *The duopoly solution*

If the *LC* carrier decides to enter the market, the *FS* and *LC* carrier compete in ticket prices with vertically differentiated products. At this stage *FS* and *LC* frequencies are given.

Recall that $q_k = f_k s_k$, with $k = LC, FS$ and $q_{FS} = b - m_{FS}$. Then, the *FS* carrier solves the following maximization program:

$$\begin{aligned}\underset{p_{FS}}{Max}\ \pi_{FS} &= p_{FS}\left(b-m_{FS}\right)-f_{FS}c_{FS} = p_{FS}\left(b-m_{FS}\right)-f_{FS}\left(\theta_{FS}+\tau_{FS}s_{FS}\right)= \\ &=\left(p_{FS}-\tau_{FS}\right)\left(b-m_{FS}\right)-f_{FS}\theta_{FS}\end{aligned}$$

Similarly, recall that $q_{LC} = m_{FS} - m_{LC}$. Thus, the *LC* carrier solves the following maximization program:

$$\underset{p_{LC}}{Max}\ \pi_{LC} = \left(p_{LC}-\tau_{LC}\right)\left(m_{FS}-m_{LC}\right)-f_{LC}\theta_{LC} \qquad (3)$$

First order conditions for the above maximization programs are given by:

$$
\begin{aligned}
& b - m_{FS} - \left(p_{FS} - \tau_{FS} \right) \frac{\partial m_{FS}}{\partial p_{FS}} = 0 \\
& m_{FS} - m_{LC} + \left(p_{LC} - \tau_{LC} \right) \left(\frac{\partial m_{FS}}{\partial p_{LC}} - \frac{\partial m_{LC}}{\partial p_{LC}} \right) = 0.
\end{aligned} \tag{4}
$$

That is:

$$
\begin{aligned}
& b - m_{FS} - \left(p_{FS} - \tau_{FS} \right) B_{FS} = 0 \\
& m_{FS} - m_{LC} - \left(p_{LC} - \tau_{LC} \right) B_{FS} = 0.
\end{aligned} \tag{5}
$$

The solution to these conditions gives us the optimal ticket prices to be charged by the *LC* and *FS* carrier (given the frequencies that have been chosen in the previous stages of the game) in a duopoly situation:

$$
\begin{aligned}
& p_{FS}^{D} = \frac{2b + 2B_{FS}\tau_{FS} + (B_{FS} - 1)\tau_{LC} - (1 + B_{FS})T_{FS} + (B_{FS} - 1)T_{LC}}{3B_{FS} + 1} \\
& p_{LC}^{D} = \frac{b + B_{FS}\tau_{FS} + 2B_{FS}\tau_{LC} + B_{FS}T_{FS} - (1 + B_{FS})T_{LC}}{3B_{FS} + 1}.
\end{aligned} \tag{6}
$$

The corresponding duopoly benefits are given by:

$$
\begin{aligned}
& \pi_{FS}^{D} = B_{FS} \frac{\left(-2b + (B_{FS} + 1)\tau_{FS} - (B_{FS} - 1)\tau_{LC} + (1 + B_{FS})T_{FS} - (B_{FS} - 1)T_{LC} \right)^2}{3B_{FS} + 1} - \theta_{FS} f_{FS} \\
& \pi_{LC}^{D} = B_{FS} \frac{\left(b + B_{FS}\tau_{FS} - (1 + B_{FS})\tau_{LC} + B_{FS}T_{FS} - (1 + B_{FS})T_{LC} \right)^2}{3B_{FS} + 1} - \theta_{LC} f_{LC}.
\end{aligned} \tag{7}
$$

3.2. *The monopoly solution*

If the *LC* carrier does not enter the market, the *FS* carrier chooses the ticket prices that maximize his profits as a monopolist. Thus, the *FS* carrier solves the following maximization program:

$$
\underset{p_{FS}}{Max} \;\; \pi_{FS} = \left(p_{FS} - \tau_{FS} \right)\left(b - m_{FS} \right) - f_{FS}\theta_{FS}, \tag{8}
$$

with $m_{FS} = G_{FS}$.

The first order condition of the above maximization program is given by:

$$-2p_{FS} + \tau_{FS} + b - T_{FS} = 0. \qquad (9)$$

The optimal ticket price in a monopoly situation is thus given by:

$$p_{FS}^{M} = \frac{1}{2}\left(b + \tau_{FS} - T_{FS}\right). \qquad (10)$$

The monopoly *FS* carrier's profits are given by:

$$\pi_{FS}^{M} = \frac{1}{4}\left((b-\tau_{FS})^2 + T_{FS}(-2b + 2\tau_{FS} + T_{FS})\right) - \theta_{FS} f_{FS}. \qquad (11)$$

Table 1 summarizes the duopoly and monopoly solutions.

Table 1. The duopoly and monopoly solutions

	Duopoly	**Monopoly**
Prices	$p_{FS}^{D} = \frac{2b + 2B_{FS}\tau_{FS} + (B_{FS}-1)\tau_{LC} - (1+B_{FS})T_{FS} + (B_{FS}-1)T_{LC}}{3B_{FS}+1}$ $p_{LC}^{D} = \frac{b + B_{FS}\tau_{FS} + 2B_{FS}\tau_{LC} + B_{FS}T_{FS} - (1+B_{FS})T_{LC}}{3B_{FS}+1}$	$p_{FS}^{M} = \frac{1}{2}\left(b + \tau_{FS} - T_{FS}\right)$
Generalized cost	$G_{FS}^{D} = \frac{2b + 2B_{FS}\tau_{FS} + (B_{FS}-1)\tau_{LC} + 2B_{FS}T_{FS} + (B_{FS}-1)T_{LC}}{3B_{FS}+1}$ $G_{LC}^{D} = \frac{b + B_{FS}\tau_{FS} + 2B_{FS}\tau_{LC} + B_{FS}T_{FS} + 2B_{FS}T_{LC}}{3B_{FS}+1}$	$p_{FS}^{M} = \frac{1}{2}\left(b + \tau_{FS} - T_{FS}\right) + T_{FS}$
Indifferent incomes	$m_{FS}^{D} = \frac{(B_{FS}+1)(b + B_{FS}\tau_{FS}) - (B_{FS}-1)B_{FS}\tau_{LC} + B_{FS}(B_{FS}+1)T_{FS} - (B_{FS}-1)B_{FS}T_{LC}}{3B_{FS}+1}$ $m_{LC}^{D} = \frac{b + B_{FS}\tau_{FS} + 2B_{FS}\tau_{LC} + B_{FS}T_{FS} + 2B_{FS}T_{LC}}{3B_{FS}+1}$	$m_{FS}^{M} = \frac{1}{2}\left(b + \tau_{FS} - T_{FS}\right) + T_{FS}$
Profits	$\pi_{FS}^{D} = B_{FS}\frac{\left(-2b + (B_{FS}+1)\tau_{FS} - (B_{FS}-1)\tau_{LC} + (1+B_{FS})T_{FS} - (B_{FS}-1)T_{LC}\right)^2}{3B_{FS}+1}$ $-\theta_{FS} f_{FS}$ $\pi_{LC}^{D} = B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS} - (1+B_{FS})T_{LC}\right)^2}{3B_{FS}+1} - \theta_{LC} f_{LC}$	$\pi_{FS}^{M} = \frac{1}{4}\left((b-\tau_{FS})^2 + T_{FS}(-2b + 2\tau_{FS} + T_{FS})\right)$ $-\theta_{FS} f_{FS}$

4. Second Stage: The *LC* carrier's decisions

Given the frequency chosen by the *FS* carrier in the first period, the *LC* carrier must decide whether or not enter the market. If the *LC* carrier finally decides to enter the market, he must choose the frequency to be offered taking into account the competition in prices that will take place in the next period.

Let f_{FS} be the frequency offered by the *FS* carrier in the first period, which at this stage is given. Let us denote by K the capacity of the airport. Let f_{LC}^{*} denote the optimal frequency offered by the *LC* carrier if he decides to enter, which is given by:

$$f_{LC}^{*} = Max\left\{0, Min\left\{K - f_{FS}, \overline{f}_{LC}\right\}\right\},$$

where $\overline{f}_{LC}$ is the optimal solution of the following maximization program (the duopoly solution):

$$\underset{f_{LC}}{Max}\ \pi_{LC}^{D}(f_{FS}, f_{LC}) = B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}) - (1+B_{FS})T_{LC}(f_{LC})\right)^{2}}{3B_{FS}+1} - \theta_{LC}f_{LC}. \qquad (12)$$

In other words, the *LC* carrier chooses a frequency that depends on the capacity of the airport. If the capacity is not high enough to allow the *LC* carrier to choose its optimal frequency, it must resign itself with the spare capacity.

Let us denote by $\pi_{LC}^{D}(f_{FS}, f_{LC}^{*})$ the profits obtained by the *LC* carrier if he enters the market. If $0 < K - f_{FS} < \overline{f}_{LC}$, that is, there is no space in the airport in order to allow to *LC* carrier to choose the optimal frequency, then $f_{LC}^{*} = K - f_{FS}$. Thus, in this case, the lower the airport capacity is, the further is f_{LC}^{*} from the optimum $\overline{f}_{LC}$, and the lower $\pi_{LC}^{D}(f_{FS}, f_{LC}^{*})$ is. This is formally stated in the following lemma.

Lemma 6: *If* $0 < K - f_{FS} < \overline{f}_{LC}$, *then* $\partial \pi_{LC}^{D}(f_{FS}, f_{LC}^{*}) / \partial K \geq 0$.

The *LC* carrier decides to enter the market if the profits he obtains when entering are higher than zero, that is, if $\pi_{LC}^{D}(f_{FS}, f_{LC}^{*}) > 0$.

5. First Stage: The *FS* carrier's optimal frequency

Even though Corollary 2 states that there is always space in this market for the two carriers, the *FS* carrier can serve all the market for two reasons. On the one hand, the entry may be blocked (for example, because the airport capacity may be low enough to allow the presence of only one firm). On the other hand, the *FS* carrier may choose a frequency that deters the *LC* carrier entry. We will analyze all the possibilities in this section.

5.1 *Blocked entry*

We say that entry is blocked if, even if the *FS* carrier chooses the frequency that maximizes his profits as a monopolist, the *LC* carrier cannot enter the market.

Let us denote by f_{FS}^{M} the optimal frequency for the *FS* carrier as a monopolist, which is the solution of the following maximization program:

$$\underset{f_{FS}}{Max}\ \pi_{FS}^{M} = \frac{1}{4}\left((b-\tau_{FS})^{2} + T_{FS}(-2b + 2\tau_{FS} + T_{FS})\right) - \theta_{FS} f_{FS}. \quad (13)$$

If given the monopoly frequency for the *FS* carrier f_{FS}^{M}, the *LC* carrier´s benefits are negative, then entry is blocked. Denote by f_{LC}^{M} the frequency offered by the *LC* carrier given the frequency offered by the *FS* carrier as a monopolist, that is:

$$f_{LC}^{M} = Max\left\{0, Min\left\{K - f_{FS}^{M}, \overline{f}_{LC}^{M}\right\}\right\},$$

where $\overline{f}_{LC}^{M}$ is the solution of the following maximization program:

$$\underset{f_{LC}}{Max}\ \pi_{LC}^{D}(f_{FS}^{M}, f_{LC}) = B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{M}) - (1+B_{FS})T_{LC}(f_{LC})\right)^2}{3B_{FS}+1} - \theta_{LC} f_{LC}.$$

Thus, the value of $\bar{f}_{LC}^{M}$ is implicitly defined by the following first order condition:

$$-2(1+B_{FS})B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{M}) - (1+B_{FS})T_{LC}(\bar{f}_{LC}^{M})\right)}{3B_{FS}+1}\frac{\partial T_{LC}}{\partial f_{LC}}(\bar{f}_{LC}^{M}) - \theta_{LC} = 0$$

Proposition 1: *Entry is blocked for the LC carrier if and only if* $\pi_{LC}^{D}(f_{FS}^{M}, f_{LC}^{M}) \leq 0$. *On the contrary, entry cannot be blocked for the LC carrier if* $\pi_{LC}^{D}(f_{FS}^{M}, f_{LC}^{M}) > 0$.

Recall that we are assuming that the *LC* carrier's operating cost per flight is always lower than the *FS* carrier's and there is no fixed cost of entry for the *LC* carrier.[9] Moreover, Corollary 2 states that there is always space in this market for the two carriers. However, we will show that the airport capacity may be too low to allow both carriers to operate the market. Thus, the *LC* carrier entry may be blocked due to capacity restrictions, as it is stated in the following proposition.

Proposition 2: *There always exists a critical value for the airport capacity* $\overline{K}$ *such that if* $K \leq \overline{K}$ *the entry is blocked for the LC carrier. On the contrary, if* $K > \overline{K}$ *entry cannot be blocked and, thus, it must be either deterred or accommodated.*

Proof: If K is too small in the sense that it is impossible for the *LC* carrier to reach the optimal frequency, the *LC* carrier frequency will be either zero or $K - f_{FS}^{M}$. If $f_{LC}^{M} = 0$ the proof is trivial. If $f_{LC}^{M} = K - f_{FS}^{M}$, the *LC* carrier's benefits will be given by:

$$\pi_{LC}^{D}(f_{FS}^{M}, K - f_{FS}^{M}) =$$
$$= B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{M}) - (1+B_{FS})T_{LC}(K - f_{FS}^{M})\right)^2}{3B_{FS}+1} - \theta_{LC}\left(K - f_{FS}^{M}\right).$$

[9] Assuming a fixed cost of entry for the *LC* carrier would reinforce even more our results.

Solving $\pi_{LC}^{D}(f_{FS}^{M}, K - f_{FS}^{M}) = 0$ we can obtain the critical value of the airport capacity $\overline{K}$. This completes the proof.■

5.2. *Entry deterrence versus accommodated entry*

Even if the entry cannot be blocked, the *FS* carrier may be interested in deterring the *LC* carrier entry. This means that the *FS* carrier modifies its frequency in order to make the *LC* carrier´s profits lower or equal than zero.

Let us denote by f_{FS}^{E} the entry deterrence frequency for the *FS* carrier, that is, the frequency that makes the profits for the *LC* carrier in the duopoly equal to zero.

Given f_{FS}^{E}, the *LC* carrier chooses the frequency f_{LC}^{E}, that is:

$$f_{LC}^{E} = Max\left\{0, Min\left\{K - f_{FS}^{E}, \overline{f}_{LC}^{E}\right\}\right\},$$

where the value of $\overline{f}_{LC}^{E}$ comes from the following first order condition:

$$-2(1+B_{FS})B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{E}) - (1+B_{FS})T_{LC}(f_{LC}^{E})\right)}{3B_{FS}+1}\frac{\partial T_{LC}}{\partial f_{LC}}(f_{LC}^{E}) - \theta_{LC} = 0.$$

The *FS* entry deterrence frequency f_{FS}^{E} is then implicitly defined by the following equation:

$$\pi_{LC}^{D}(f_{FS}^{E}, f_{LC}^{E}) = B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{E}) - (1+B_{FS})T_{LC}(f_{LC}^{E})\right)^{2}}{3B_{FS}+1} - \theta_{LC}f_{LC}^{E} = 0.$$

Let us denote by f_{FS}^{D} the frequency offered by the *FS* carrier if he knows that the *LC* carrier will enter the market and he will face a duopoly situation. Thus, f_{FS}^{D} is the solution of the following maximization problem:

$$\underset{f_{FS}}{Max}\ \pi_{FS}^{D} =$$

$$= B_{FS}\frac{\left(-2b + (B_{FS}+1)\tau_{FS} - (B_{FS}-1)\tau_{LC} + (1+B_{FS})T_{FS}(f_{FS}) - (B_{FS}-1)T_{LC}(f_{LC}^{D})\right)^{2}}{3B_{FS}+1} - \theta_{FS}f_{FS}, \quad (14)$$

where $f_{LC}^{D} = \min\left\{K - f_{FS}^{D}, \overline{f}_{LC}^{D}\right\}$, and $\overline{f}_{LC}^{D}$ is implicitly defined by:

$$-2(1+B_{FS})B_{FS}\frac{\left(b+B_{FS}\tau_{FS}-(1+B_{FS})\tau_{LC}+B_{FS}T_{FS}(f_{FS}^{D})-(1+B_{FS})T_{LC}(f_{LC}^{D})\right)}{3B_{FS}+1}\frac{\partial T_{LC}}{\partial f_{LC}}(f_{LC}^{D})-\theta_{LC}=0.$$

(15)

The *FS* carrier will deter the *LC* carrier entry if the profits the former obtains with the frequency f_{FS}^{E} as a monopolist are higher than the *FS* carrier's profits in a duopoly situation with a frequency f_{FS}^{D}. Otherwise, entry is accommodated. This is formally stated in the following proposition.

Proposition 3: *If* $\pi_{FS}^{M}(f_{FS}^{E})>\pi_{FS}^{D}(f_{FS}^{D},f_{LC}^{D})$, *the FS carrier deters the entry for the LC carrier. On the contrary, if* $\pi_{FS}^{M}(f_{FS}^{E})\leq\pi_{FS}^{D}(f_{FS}^{D},f_{LC}^{D})$ *the LC carrier entry is accommodated.*

From Proposition 2 we know that if the airport capacity is higher than the critical value $\overline{K}$, that is $K>\overline{K}$, entry cannot be blocked. However, we can always find a critical value for the airport capacity such that the *LC* carrier entry is deterred. The intuition is that, if the airport capacity is sufficiently close to the critical value $\overline{K}$, we can always find another critical value $\overline{\overline{K}}$ such that if $\overline{K}<K<\overline{\overline{K}}$ it is always profitable for the *FS* carrier to deter the entry. This is formally stated in the following proposition.

Proposition 4: *There always exists a critical value for the airport capacity* $\overline{\overline{K}}$ *such that if* $\overline{K}<K\leq\overline{\overline{K}}$ *the entry is deterred for the LC carrier.*

Proof: Suppose that $\overline{K}<K$. From the proof of Proposition 2 we know that if $\overline{K}<K$ entry cannot be blocked. However, we can always find a frequency for the *FS* carrier, $f_{FS}^{E*}>f_{FS}^{M}$, such that $f_{LC}^{E}=K-f_{FS}^{E*}>0$. Then, the *LC* carrier's benefits will be given by:

$$\pi_{LC}^{D}(f_{FS}^{E*},K-f_{FS}^{E*})=B_{FS}\frac{\left(b+B_{FS}\tau_{FS}-(1+B_{FS})\tau_{LC}+B_{FS}T_{FS}(f_{FS}^{E*})-(1+B_{FS})T_{LC}(K-f_{FS}^{E*})\right)^{2}}{3B_{FS}+1}-\theta_{LC}\left(K-f_{FS}^{E*}\right).$$

Solving for $\pi_{LC}^{D}(f_{FS}^{E*}, K - f_{FS}^{E*}) = 0$ we can obtain the critical value of the airport capacity $\overline{\overline{K}}$. We have just guarantee that the *LC* carrier will not enter if $\overline{K} < K \leq \overline{\overline{K}}$. However, we must also guarantee that there always exist a $\overline{\overline{K}}$ such that if $\overline{K} < K \leq \overline{\overline{K}}$ entry deterrence is profitable for the *FS* carrier, that is, $\pi_{FS}^{M}(f_{FS}^{E*}) > \pi_{FS}^{D}(f_{FS}^{D}, f_{LC}^{D})$. The latter condition will always hold if $\overline{\overline{K}}$ is sufficiently close to $\overline{K}$ and thus f_{FS}^{E*} is close enough to f_{FS}^{M}. This completes the proof.■

Finally, since we have not considered any fixed cost of entry for the *LC* carrier, if the airport capacity is high enough, *FS* carrier will not able to deter or blocked the entry and a duopoly situation will take place. This is formally stated in the following corollary.

Corollary 3*: If the airport capacity is high enough, that is* $K > \overline{\overline{K}}$*, the LC carrier entry cannot be blocked or deterred. Thus, the LC carrier entry must be accommodated.*

6. Conclusions

In this paper we analyze a vertically differentiated product market to explain full-service (*FS*) and low-cost (*LC*) airlines' competition. We consider that passengers have a preferred departure time and dislike the schedule delay, that is, the difference between the real and preferred departure time. As the frequency increases, passengers' schedule delay cost decreases and, hence, airlines can charge a higher ticket price without losing demand. In this context, we analyze under which circumstances the *FS* carrier is interested in increasing his frequency in order to deter the *LC* carrier entry.

We find that the use of the frequency as an entry deterrence strategy is closely related with the level of airport capacity. We show that the higher the airport capacity is, the more difficult is for the incumbent to block or deter the *LC* carrier entry. Although the empirical research to support the use of frequency as an entry deterrence strategy is still scarce in the air transport literature, our results might be used as a justification to explain why *LC* carriers usually operate in airports that are not congested at all.

References

Anderson, JE, M. Kraus (1981): “Quality of Service and the Demand for Air Travel”. Review of Economics and Statistics, 63 (4): 533-540.

Aydemir, R. (2012): “Threat of market entry and low cost carrier competition”. Journal of Air Transport Management, 23: 56-62

Barbot, C. (2004): “Economic effects of re-allocating airports slots: a vertical differentiation approach”. Journal of Air Transport Management, 10(5): 333-343.

Barbot, C. (2006): “Low-cost airlines, secondary airports, and state aid: An economic assessment of the Ryanair–Charleroi Airport agreement”. Journal of Air Transport Management, 12(4): 197-203.

Barbot, C. (2008): “Can low cost carriers deter or accommodate entry?” Transportation Research Part E, 44(5): 883-893.

Brueckner, J. K. (2004): “Structure and Airline Scheduling”. The Journal of Insutrial Economics, 52(2): 291-312.

Brueckner, J., and R. Flores-Fillol (2007): “Airline Schedule Competition”. Review of Industrial Organization, 30(3): 161-177.

Dixit, A. (1980): “The role of Investment in Entry Deterrence”. The Economic Journal, 90: 95-106.

Dobruszkes, F. (2006): “An analysis of European low-cost airlines and their networks”. Journal of Transport Geography, 14(4), 249-264.

Doganis, R. (2001): The Airline Business in the 21st Century. London: Routledge.

Douglas, G.W. and J.C. Miller (1974): “Quality Competition, Industry Equilibrium and Efficiency in the Price-Constrained Airline Market”. American Economic Review, 64 (4): 657-669.

Franke, M. (2004): “Competition between network carriers and low-cost carriers—retreat battle or breakthrough to a new level of efficiency?” Journal of Air Transport Management, 10(1): 15-21.

Fu, X., M. Dresner, and T.H. Oum (2011): “Effects of transport service differentiation in the US domestic airline market”. Transportation Research Part E, 47(3): 297-305.

Gillen, D., and W. Morrison (2003): “Bundling, integration and the delivered price of air travel: are low cost carriers full service competitors?”. Journal of Air Transport Management, 9(1): 15-23.

Goolsbee, A. and C. Syverson (2008): “How do incumbents respond to the threat of entry? Evidence from the major airlines”. The Quarterly Journal of Economics, 123 (4): 1611-1633

Hazledine, T. (2011): “Legacy carriers fight back: Pricing and product differentiation in modern airline marketing”. Jornal of Air Transport Management, 17(2): 130-135.

Hess, S., T. Adler, J. W. Polak (2007): “Modelling airport and airline choice behaviour with the use of stated preference survey data”. Transportation Research Part E: Logistics and Transportation Review, 43 (3): 221-233.

Huse, C. and A. Olivera (2010): “Does product differentiation soften price reactions to entry? Evidence from the airline industry”. Latin American Center for Transportation Economics Working Paper No. 35.

Koster, P.R., E. Kroes and E.T. Verhoef, (2011): “Travel time variability and airport accessibility”. Transportation Research Part B, 45 (10): 1545-1559.

Koster, P.R., E. Pels and E.T. Verhoef (2013): "The User Costs of Air Travel Delay Variability". Tinbergen Institute Discussion Paper 13-056/VIII.

Koster, P. and E. T. Verhoef (2012): "A Rank-dependent Scheduling Model". Journal of Transport Economics and Policy 46 (1): 123-138.

Lijesen, M.G. (2006): "A mixed logit based valuation of frequency in civil aviation from SP-data". Transportation Research Part E: Logistics and Transportation Review 42 (2): 82–94.

Lin, M. H. (2005): "Alliances and entry in a simple airline network", Economics Bulletin 12 (2): 1-11.

Lin, M. H. (2008): "Airline alliances and entry deterrence". Transportation Research Part E: Logistics and Transportation Review, 44 (4): 637-652.

Morrison, W.G. (2004): "Dimensions of Predatory Pricing in Air Travel Markets". Journal of Air Transport Management, 10 (1): 87-95.

Ng, Irene C. L., J. Wirtz, and K. Sheang Lee (1999): "The Strategic Role of Unused Capacity," International Journal of Service Industry Management, 10 (2): 211-38.

O'Connell, J., and G. Williams, G. (2005): "Passengers' perceptions of low cost airlines and full service carriers: A case study involving Ryanair, Aer Lingus, Air Asia and Malaysia Airlines". Journal of Air Transport Management, 11(4): 259-272.

Oum, T. H., A. Zhang and Y. Zhang (1995): "Airline Network Rivalry," Canadian Journal of Economics, 28(4a): 836-857.

Panzar, J.C. (1979): "Equilibrium and welfare in unregulated airline markets". American Economic Review 69 (2): 92-95.

Pels, E. (2008): "Airline network competition: Full-service airlines, low-cost airlines and long-haul markets". Research in Transportation Economics, 24, (1): 68-74.

Pels, E. P. Nijkamp, P. Rietveld (2000): Airport and airline competition for passengers departing from a large metropolitan area”. Journal of Urban Economics, 48 (1): 29–45.

Pels, E., P. Nijkamp, P. Rietveld (2003): “Access to and competition between airports: a case study for the San Francisco Bay area” Transportation Research Part A: Policy and Practice, 37 (1) (2003): 71–83.

Pels E., N. Njegovan and C. Behrens (2009): “Low-cost airlines and airport competition”. Transportation Research Part E: Logistics and Transportation Review, 45 (2): 335-344.

Shaked, A., and J. Sutton (1982): “Relaxing Price Competition Through Product Differenciation”. The Review of Economic Studies, 49(1): 3-13.

Tan, K. M., (2011): “Incumbent Response to Entry by Low-Cost Carriers in the U.S. Airline Industry”. Available at SSRN: http://ssrn.com/abstract=2006471 or http://dx.doi.org/10.2139/ssrn.2006471

Yetiskul, E., and A. Kanafani (2010): “How the presence of low-cost carrier competition scheduling differentiation”. Journal of Air Transport Management, 16(1): 7-11.

Yetiskul, E., K. Matsushima, and K. Kobayashi (2005): “Airline network structure with thick market externality”. Research in Transportation Economics, 13(1): 143-163.

Windle, R. and M. Dresner (1995): “The short and long run effects of entry on US domestic air routes”. Transportation Journal 35(2): 14-25.

Windle, R. and M. Dresner (1999): “Competitive Responses to Low Cost Carrier Entry” Transportation Research Part E 35: 59-75.