Airport capacity and entry deterrence: Low cost versus full service airlines[§]

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Abstract

We study entry deterrence in air transport markets with a full-service (*FS*) carrier (the incumbent) and a low-cost (*LC)* carrier (the potential entrant). We consider a vertically differentiated product model where airlines have different operating cost and different generalized prices so they compete in ticket prices and frequencies. 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. Regulators should take these results into account in order to promote competition among airlines.

Keywords: Low-cost carriers; full-service carriers; entry deterrence; airport capacity.

JEL Classification: L93, L12, L15

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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, changing the whole air transport market (Dobruszkes, 2006; 2013). They carried 3.5 billion passengers on 34 million schedule departures in 2015, and in 2030 these figures probably will be double.[1] Moreover, they accounted for 24% of all aircraft seats in 2011, and they had a 36% market share in Europe, 30% in North America and 19% in Asia/pacific (Graham, 2013). Moreover, full-service (*FS*) carriers have been affected for this new model of airline business[2] and the competition between these two types of airlines is commonly observed.[3]

FS carriers and *LC* carriers differ in their quality and their costs, and thus, in the ticket prices charged to passengers. *LC* carriers can deliver 80% of the service quality with approximately 50% of the cost of *FS* carriers (Franke, 2004). 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 (Gillen 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 difference is the so-called schedule delay.[4] There are some papers in the literature that consider airlines that compete

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[1] Data extracted from ICAO website (https://www.icao.int/sustainability/Pages/Low-Cost-Carriers.aspx).

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

[3] 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 the airline network.

[4] There are some papers in the literature finding important effects of the scheduling delay cost (see, for example, Douglas and Miller, 1974; Anderson and Kraus, 1981; Lijesen, 2006; or Hess *et al*., 2007). Koster

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

The contribution of this paper to the academic literature is twofold: On the one hand, it develops a theoretical model of entry deterrence and vertical differentiated products which is specific to the air transport market. In the air transport market, consumers take their travel decisions taking into account not only the quality and price of the product (as in most traditional industrial organization models) but also the time required to make the trip, which includes not only access, egress and in-vehicle time, but also the schedule delay cost. The higher the frequency, the lower the schedule delay cost. Thus, the frequency can be considered as an additional quality component to be used by airlines and this fact considerably affects the well-known results of traditional industrial organization models of vertical differentiation and entry deterrence. Our theoretical model provides a specific air transport competition model that might be used by regulators to assess the social welfare improvement of any policy aiming at increasing the competition in the air transport market (such as the investment in airports' capacity). On the other hand, this paper allows to theoretically justify some of the empirical results obtained in the academic literature when analysing *LC* and *FS* carriers' competition or the kind of airports from which *LC* carriers usually operate.

In this paper, we consider a vertically differentiated product model as the one used by Shaked and Sutton (1982). However, we depart from Shaked-Sutton's model in the following. On the one hand, contrary to Shaked and Sutton (1982), we assume non-linear cost functions for airlines, capturing the economies from operating larger aircraft

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et al. (2016) point out that travellers 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 travellers going to the airport are Koster *et al*. (2011) and Tam *et al*. (2008).

[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)

(Brueckner, 2004; Brueckner and Flores-Fillol, 2007). 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, which includes access, egress, in-vehicle time, and the schedule delay cost. Given the schedule delay cost, frequency can be considered as an additional quality component and increase airlines' vertical differentiation.

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.[6]

Spence (1977) is one of the early contributions to the literature that links excess capacity with entry deterrence. He argues that "entry is deterred in an industry when existing firms have enough capacity to make a new entrant unprofitable and that this capacity need not be fully utilized in the absence of entry." Dixit (1980) shows that an incumbent decides whether to accommodate entry or to deter it through excess capacity.

In this paper, we also consider a model in which the incumbent (the *FS* carrier) decides whether to accommodate or deter the *LC* carrier's entry. However, there are substantial differences with traditional entry deterrence models. Firstly, in our model the higher the frequency, the lower passengers' generalized price. Thus, more frequency allows airlines to increase ticket prices without losing demand. Therefore, when the incumbent increases the frequency, there are two consequences: on the one hand, it affects *LC* carrier's incentives to enter the market and, on the other hand, it reduces passengers' generalized price which may be compensated with higher ticket prices. Thus, frequency is used not

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[6] There are also scarce literature in product quality competition. See for example Morrison and Winston (1995), Berry an Jia (2010) or Brueckner and Luo (2014). However, our paper is mainly theoretical and focused on the use of frequency as an entry deterrence strategy

only to deter entry but also to increase airlines' vertical differentiation and passengers' willingness to pay. Secondly, contrary to traditional entry deterrence models, we do not need to assume any fixed cost of entry for the *LC* carrier. We have to highlight that 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.

We have to take into account that *LC* carries usually serve regional or secondary airport instead of major airport. However, Dobruszkes *et al.* (2017) pointed out the change of this strategy for some *LC* carriers. This paper tries to find some theoretical justification for the *LC* carriers' selection of airports. We show that if the airport capacity is low enough the *LC* carrier entry can be blocked (the *FS* carrier chooses the frequency that maximizes its profits as a monopolist and the *LC* carrier cannot enter the market). Moreover, we show that the *FS* carrier optimally deters the *LC* carrier entry (the *FS* carrier modifies its frequency in order to make the *LC* carrier´s profits lower than or equal to zero) 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. In order to promote competition between *LC* and *FS* carriers, regulators should take these results into account and force airports with capacity constraints to expand capacity.[7]

Previous research on entry deterrence in the air transport market is mostly devoted to analyse 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; Gayle and Wu, 2013; Tan, 2016; Aydemir, 2012 or Varella *et al.*, 2017), 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 analyse the effects of capacity/ frequency on entry deterrence. One exception is Morrison (2004) that highlights that

[7] For example, Chen (2017) finds a more aggressively response from an established airline to a *FC* than a *FS* carrier entry into its hub airport in Shanghai.

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. Another exception is Sheng *et al*. (2019) that argues that, under a grandfather rights slot policy, airlines may intentionally operate excessive flights

Empirical evidence of the use of frequency as an entry deterrence strategy in air transport markets is still scarce. Goolsbee and Syverson (2008) find weak evidence to support that the incumbents expand capacity as an entry deterrence strategy in air transport markets. 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 other carriers do not enter the market. The results of this 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).

Special attention deserves Ciliberto and Williams (2010), who show that airlines can use "operating practices limiting access to airport facilities" as potential barriers to entry in the United States (US) airline industry, explaining high airline fares. Concretely, airlines need gates to provide service (and also ticket counter, baggage check-in rooms, etc.), that are regulated by long term exclusive contracts between airlines and airports. These practices are barriers to entry because new entrants usually have to pay sublease fees in order to obtain access, and the author find this variable a crucial determinant of price premium.[8]

Recently, Sancho-Esper and Mas-Ruiz (2016) analyse empirically how the incumbent response is (taking a starting point in the classic behavioural strategies in investment decisions) in the Spanish air transport market (route level). Also, they take into account

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[8] Concretely they investigate the size and the determinant of the hub premium, i.e., "the difference between the fares charged for trips into and out of airports where major airlines have their hubs and the fares charged for trips that are similar but do not originate from or end in a hub."

the type of entrant and airport capacity restrictions. They find that, under airport capacity restrictions, established carriers accommodate more the entry of *LC* carriers than the entry of regional or national carriers. In contrast, without restrictions, there is a greater cost retaliation by the incumbent to the entry of *LC* carriers than the others' entry. The product differentiation model predicts these effects. Ciliberto and Zhang (2017) uses a longitudinal dataset from United States airline industry and they found that firms make investments to deter entry. Bettini *et al*. (2018) studies (also empirically), for a major incumbent airline and multiple airports region, the capacity response when that airline faces the entry of a new *LC* carrier. They found that the incumbent pre-emptively increased their flight frequencies on the threatened airport-pairs, i.e., to deter the entry of the *LC* carrier (that "march" from a secondary airport toward an existing primary airport).

In short, entry deterrence is an important issue in industrial organization, and there is empirical evidence in airline industry, so we have developed a theoretical model that can explain the relationship between it and capacity. In this paper, we find through this theoretical model that an incumbent airline may use frequency as an entry deterrence strategy against a *LC* carrier, and it is closely related with the level of airport capacity.

Furthermore, we have to highlight that the European regulation of slots is based on the so-called "Grandfather rights", that is, the rights of the incumbent airlines. Because of it, if an airline uses a slot in the previous season, it will be entitled to continue using it in the next period.[9] After this, the remaining are grouped into a "slot pool", where new entrants have booked up to 50%. The rest are allocated to incumbents for free. This procedure implies the minimization of (flight) changes from season to season (Sheng *et al.* 2019).

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[9] The basic legislation of Grandfather Rights is Council Regulation 95/93 on common rules for the allocation of slots at Community airports. It introduces a new principle: "use it or lose it" (also known as the 80/20 rule). With this principle, an airline could lose its slots if it has not used it the 80% of the time. Moreover, non-used slots and newly created ones must go to a pool, with 50% of them being reserved for new entrants (Betancor and de Rus, 2003). Also there have been several amendments to this regulation (for example, for exceptional circumstances like the last economic crisis).

With this regulation, an airline could use the frequency as an entry deterrence strategy and the potential competitor cannot do anything to avoid it. Similar conclusion could be obtained from US legislation. As pointed by Ciliberto and Williams (2010), airlines require enplaning/deplaning gates to provide service at an airport, and entry deterrence is equivalent to carriers expanding their use of scarce airport gates.[10] In short, this paper focus in cases where an airline is able to limit the access of an airport (through slots rights, gates or even any item regulated by long term exclusive contracts between airlines and airports).

The rest of the paper is organized as follows. In Section 2 we explain the main assumptions of the model. Section 3 analyses 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 analyses 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 levels of quality. We assume that the *FS* carrier has a first mover advantage and can decide the frequency it will offer before the *LC* carrier decides or not to enter the market. For this reason, *FS* carrier may block or deter the entry. We say that entry is blocked if, even if the *FS* carrier chooses the frequency that maximizes its profits as a monopolist, the *LC* carrier cannot enter the market. 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 than or equal to zero. If the entry is not blocked or deterred, *FS* carrier must accommodate

[10] Most of US airports do not use slot control. The runway access is allocated on a "first come, first served" basis, and this procedure induce a full utilization of capacity (Sheng *et al.* 2019).

the entry. Finally, if the *LC* carrier decides to enter the market, it must decide its frequency and carriers will compete in prices with vertically differentiated products.

Following Brueckner (2004) and Brueckner and Flores-Fillol (2007), we can define each flight operating cost by:

$$c_k = \theta_k + \tau_k s_k, \qquad (1)$$

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 a 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.[11] 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 $\tau_{LC} < \tau_{FS}$.[12] We do not assume any fixed cost of entry for the *LC* carrier.[13]

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[11] Note that, with this assumption, airlines could adjust aircraft size in order to satisfy the frequency. For this reason, the incumbent is able to set a low frequency with very high capacity aircraft or, in contrast, the incumbent fills the capacity with a low aircraft size and high frequency. An alternatively formulation could be to allow a load factor lower than 100% in order to adjust the frequency, with a fixed aircraft size.

[12] *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. (Doganis, 2001).

[13] As we have said, 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.

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 $0 < a \leq m \leq b$. Consumers have a 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 (T_k) is the sum of the value of the time spent in the trip (which includes access, egress and in-vehicle time), A_k ,[14] 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:[15]

$$T_k = A_k + \delta \frac{H}{4 f_k}. \tag{2}$$

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, that is:

$$G_k = p_k + A_k + \delta \frac{H}{4 f_k}. \tag{3}$$

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[14] A_k may also include differences in the trip time due to different network configurations (hub and spoke versus point to point).

[15] 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.

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:

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

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.

Let $B_{FS}=u_{FS}/(u_{FS}-u_{LC})$ be the relative 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 relative 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:

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

that is;

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

Thus:

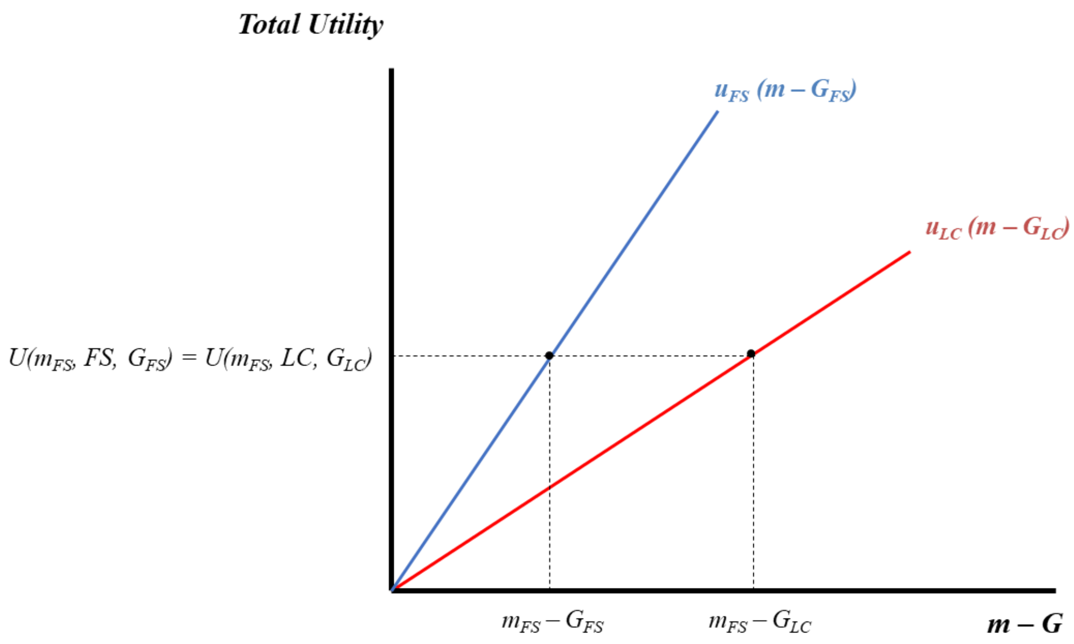
$$m_{FS} = B_{FS} G_{FS} + \left(1 - B_{FS}\right) G_{LC}, \tag{5}$$

where m_{FS} is the income for the indifferent consumer between *FS* and *LC* carriers.

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

As we have already pointed out, the indifferent consumer is the one that enjoys the same utility flying with a *LC* carrier at a generalized cost G_{LC} or flying with a *FS* carrier at a generalized cost $G_{FS} > G_{LC}$. In **Figure 1** we represent the utility function of all consumers (recall passengers are identical in their preferences but differ in their income). Note that utility functions are linear, since u_k is constant. Those passengers with income such that *U(m, FS, G_{FS}) > U(m, LC, G_{LC})* will decide to fly with the *FS* carrier. On the contrary, those passengers with income such that $U(m, FS, G_{FS}) < U(m, LC, G_{LC})$ will decide to fly with the *LC* carrier The indifferent consumer is the one with income m_{FS} , and the same utility when flying with the *LC* or *F*S carrier, that is, $U(m_{FS}, FS, G_{FS}) = U(m_{FS}, LC, G_{LC})$.

Figure 1. Utility function for indifferent consumer between *FS* and *LC* carriers



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

$$U(m, LC, G_{LC}) = U(m, 0, 0),$$

that is:

$$u_{LC}(m - G_{LC}) = 0.$$

Then:

$$m_{LC} = G_{LC}, \tag{6}$$

where m_{LC} is the income for the indifferent consumer between *LC* carrier and the outside option.

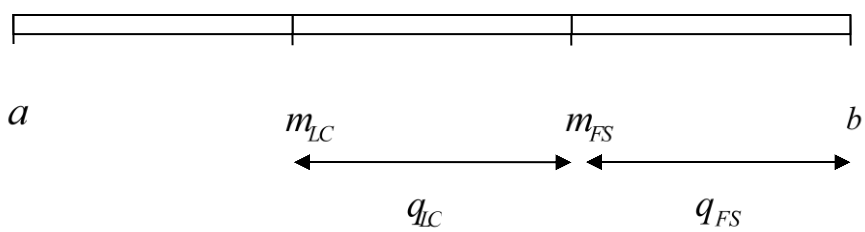
Lemma 3: *The consumer that is indifferent between travelling with a LC carrier at a generalized cost* G_{LC} *or an outside option with* $u_0 = 0$ *has an income* $m_{LC} = G_{LC}$.

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

Corollary 1: *In the optimum* m_{LC} *can never be lower than the lowest income, 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 income buys a LC ticket.*

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 2**.

Figure 2. Indifferent consumer position and market shares



Corollary 2: *If* $G_{LC} < G_{FS}$, *consumers with income between* m_{LC} *and* m_{FS} *are willing to fly with the LC carrier and consumers with income* $m > m_{FS}$ *are willing to fly with the FS carrier. Thus, there is enough demand for both carriers.*

Let us now analyse 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 travel time or schedule delay cost) of the *FS* carrier rises, the indifferent consumer will be a person who has more income 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 will not be indifferent anymore and will 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 its 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, it 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:

$$\begin{aligned}\underset{p_{FS}}{Max}\ \pi_{FS} &= p_{FS}\left(b - m_{FS}\right) - f_{FS}c_{FS} = p_{FS}\left(b - m_{FS}\right) - f_{FS}\left(\theta_{FS} + \tau_{FS}s_{FS}\right) = \\ &= \left(p_{FS} - \tau_{FS}\right)\left(b - m_{FS}\right) - f_{FS}\theta_{FS}.\end{aligned} \tag{7}$$

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

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

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

$$b - m_{FS} - \left(p_{FS} - \tau_{FS}\right)\frac{\partial m_{FS}}{\partial p_{FS}} = 0, \tag{9}$$

$$m_{FS} - m_{LC} + \left(p_{LC} - \tau_{LC} \right) \left(\frac{\partial m_{FS}}{\partial p_{LC}} - \frac{\partial m_{LC}}{\partial p_{LC}} \right) = 0. \tag{10}$$

That is:

$$b - m_{FS} - \left(p_{FS} - \tau_{FS} \right) B_{FS} = 0, \tag{11}$$

$$m_{FS} - m_{LC} - \left(p_{LC} - \tau_{LC} \right) B_{FS} = 0. \tag{12}$$

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:

$$p_{FS}^{D} = \frac{2b + 2B_{FS}\tau_{FS} + (B_{FS} - 1)\tau_{LC} - (1 + B_{FS})T_{FS} + (B_{FS} - 1)T_{LC}}{3B_{FS} + 1}, \tag{13}$$

$$p_{LC}^{D} = \frac{b + B_{FS}\tau_{FS} + 2B_{FS}\tau_{LC} + B_{FS}T_{FS} - (1 + B_{FS})T_{LC}}{3B_{FS} + 1}. \tag{14}$$

The corresponding duopoly benefits are given by:

$$\pi_{FS}^{D} = B_{FS} \frac{\left(-2b + (B_{FS} + 1)\tau_{FS} - (B_{FS} - 1)\tau_{LC} + (1 + B_{FS})T_{FS} - (B_{FS} - 1)T_{LC} \right)^2}{3B_{FS} + 1} - \theta_{FS} f_{FS}, \tag{15}$$

$$\pi_{LC}^{D} = B_{FS} \frac{\left(b + B_{FS}\tau_{FS} - (1 + B_{FS})\tau_{LC} + B_{FS}T_{FS} - (1 + B_{FS})T_{LC} \right)^2}{3B_{FS} + 1} - \theta_{LC} f_{LC}. \tag{16}$$

In order to compute consumer surplus we need to obtain the air transport market demand function, which is given by the horizontal sum of the demand function of the *FS* carrier and *LC* carrier: $Q = q_{FS} + q_{LC} = (b - m_{FS}) + (m_{FS} - m_{LC}) = b - m_{LC} = b - G_{LC}$. Given this market demand function, the consumer surplus in the duopoly equilibrium is given by:

$$CS^D = \frac{1}{2}(b - G_{LC})^2. \quad (17)$$

The social welfare is defined as the sum of consumer surplus and carriers' profits, that is:[16]

$$SW^D = CS^D + \pi_{FS}^D + \pi_{LC}^D. \quad (18)$$

3.2. The monopoly solution

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

$$\underset{p_{FS}}{Max}\ \pi_{FS} = \left(p_{FS} - \tau_{FS}\right)\left(b - m_{FS}\right) - f_{FS}\theta_{FS}, \quad (19)$$

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

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

$$-2p_{FS} + \tau_{FS} + b - T_{FS} = 0. \quad (20)$$

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

[16] Notice that consumer surplus and airlines' profits are assumed to have the same weight in the social welfare function defined in expression (18). However, the regulator may decide to assign different weights to the consumer surplus, *FS* and *LC* carriers' profits in the social welfare function.

$$p_{FS}^{M} = \frac{1}{2}\left(b + \tau_{FS} - T_{FS}\right). \quad (21)$$

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

$$\pi_{FS}^{M} = \frac{1}{4}\left((b - \tau_{FS})^{2} + T_{FS}(-2b + 2\tau_{FS} + T_{FS})\right) - \theta_{FS} f_{FS}. \quad (22)$$

The consumer surplus in the monopoly equilibrium is given by:

$$CS^{M} = \frac{1}{2}(b - G_{FS})^{2}. \quad (23)$$

The social welfare is defined as the sum of the consumer surplus and *FS* carrier's profits, that is:

$$SW^{M} = CS^{M} + \pi_{FS}^{M}. \quad (24)$$

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	$\pi_{FS}^{D}=B_{FS}\frac{\left(-2b+(B_{FS}+1)\tau_{FS}-(B_{FS}-1)\tau_{LC}+(1+B_{FS})T_{FS}-(B_{FS}-1)T_{LC}\right)^{2}}{3B_{FS}+1}$ $-\theta_{FS}f_{FS}$ $\pi_{LC}^{D}=B_{FS}\frac{\left(b+B_{FS}\tau_{FS}-(1+B_{FS})\tau_{LC}+B_{FS}T_{FS}-(1+B_{FS})T_{LC}\right)^{2}}{3B_{FS}+1}-\theta_{LC}f_{LC}$	$\pi_{FS}^{M}=\frac{1}{4}\left((b-\tau_{FS})^{2}+T_{FS}(-2b+2\tau_{FS}+T_{FS})\right)$ $-\theta_{FS}f_{FS}$
Consumer surplus	$CS^{D}=\frac{1}{2}(b-G_{LC})^{2}.$	$CS^{M}=\frac{1}{2}(b-G_{FS})^{2}.$
Social welfare	$SW^{D}=CS^{D}+\pi_{FS}^{D}+\pi_{LC}^{D}.$	$SW^{M}=CS^{M}+\pi_{FS}^{M}.$

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 to enter the market. If the *LC* carrier finally decides to enter the market, it 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 airport capacity. Let f_{LC}^{*} denote the optimal frequency offered by the *LC* carrier if it decides to enter, which is given by:

$$f_{LC}^{*} = Max\left\{0, Min\left\{K - f_{FS}, \overline{f}_{LC}\right\}\right\}, \tag{25}$$

where $\overline{f}_{LC}$ is the optimal solution of the following maximization program (the duopoly solution from table 1):

$$\underset{f_{LC}}{Max}\ \pi_{LC}^{D}(f_{FS}, f_{LC}) = \\ = B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}) - (1+B_{FS})T_{LC}(f_{LC})\right)^{2}}{3B_{FS}+1} - \theta_{LC} f_{LC}. \tag{26}$$

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 conform to the spare capacity.

Let us denote by $\pi_{LC}^{D}(f_{FS}, f_{LC}^{*})$ the profits obtained by the *LC* carrier if it 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* $\partial\pi_{LC}^{D}(f_{FS}, f_{LC}^{*}) / \partial K \geq 0$.

Finally, the *LC* carrier decides to enter the market if the profits it 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 demand in this market for the two carriers, the *FS* carrier can serve the whole market for two reasons. On the one hand, the entry may be blocked because the airport capacity is 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 analyse all the possibilities in this section, using the respective profits solution from table 1.

5.1 Blocked entry

We say that entry is blocked if, even if the *FS* carrier chooses the frequency that maximizes its 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:

$$\underset{f_{FS}}{Max}\ \ \pi_{FS}^{M}(f_{FS}) = \frac{1}{4}\Big((b-\tau_{FS})^2 + T_{FS}(-2b+2\tau_{FS}+T_{FS})\Big) - \theta_{FS}\, f_{FS}. \qquad (27)$$

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:

$$f_{LC}^{M} = Max\Big\{0, Min\Big\{K - f_{FS}^{M}, \bar{f}_{LC}^{M}\Big\}\Big\}, \qquad (28)$$

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

$$\begin{aligned}&\underset{f_{LC}}{Max}\ \ \pi_{LC}^{D}(f_{FS}^{M}, f_{LC}) = \\ &= B_{FS}\frac{\Big(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{M}) - (1+B_{FS})T_{LC}(f_{LC})\Big)^2}{3B_{FS}+1} - \theta_{LC}\, f_{LC}.\end{aligned} \qquad (29)$$

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

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

(30)

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.[17] Moreover, Corollary 2 states that there is always demand 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 1: *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:

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

[17] 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 $\overline{K}$. We have to take into account that *LC* carrier profits are decreasing in *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 than or equal to 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:

$$f_{LC}^{E} = Max\left\{0, Min\left\{K - f_{FS}^{E}, \overline{f}_{LC}^{E}\right\}\right\}, \tag{31}$$

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

$$-2(1+B_{FS})B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{E}) - (1+B_{FS})T_{LC}(\overline{f}_{LC}^{E})\right)}{3B_{FS}+1}\frac{\partial T_{LC}}{\partial f_{LC}}(\overline{f}_{LC}^{E})$$
$$-\theta_{LC} = 0. \tag{32}$$

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

$$\pi_{LC}^{D}(f_{FS}^{E}, f_{LC}^{E}) =$$
$$= B_{FS}\frac{\left(b + B_{FS}\tau_{FS} - (1+B_{FS})\tau_{LC} + B_{FS}T_{FS}(f_{FS}^{E}) - (1+B_{FS})T_{LC}(f_{LC}^{E})\right)^{2}}{3B_{FS}+1} - \theta_{LC}f_{LC}^{E} = 0. \tag{33}$$

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

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

(34)

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

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

(35)

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, that is, if $\pi_{FS}^{M}(f_{FS}^{E}, f_{LC}^{E}) > \pi_{FS}^{D}(f_{FS}^{D}, f_{LC}^{D})$, the *FS* carrier deters the entry for the *LC* carrier. On the contrary, if $\pi_{FS}^{M}(f_{FS}^{E}) \le \pi_{FS}^{D}(f_{FS}^{D}, f_{LC}^{D})$ the *LC* carrier entry is accommodated. From Proposition 1 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 $\overline{K} < K \le \overline{\overline{K}}$ it is always profitable for the *FS* carrier to deter the entry. This is formally stated in the following proposition.

Proposition 2: *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 1 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.*

From Corollary 2 we know that, in absence of airport capacity constraints, consumers with low income are willing to fly with the *LC* carrier and consumers with high income are willing to fly with the *FS* carrier. Thus, there is demand in this market for both types of carriers. However, from Corollary 3 we know that the competition among airlines is only possible if the airport capacity is high enough. Therefore, if regulators want to promote the competition between *LC* and *FS* carriers, they should force airports with capacity constraints to expand capacity. Moreover, they may try to optimal allocate slots among competitive slots, but as we have pointed the European regulation of slots is based on the so-called "Grandfather rights", that is, the rights of the incumbent airlines. Because of it, if an airline uses a slot in the previous season, it will be entitled to continue using it in the next period. With this regulation, an airline could use the frequency as an entry deterrence strategy and the potential competitor cannot do anything to avoid it.

6. Numerical illustration

In order to illustrate the main results of the paper and the welfare loss in the monopoly solution (either because the *LC* carrier's entry is blocked or deterred by the *FS* carrier), let us consider the following numerical example.

Consider a market that is operated by a *FS* carrier with the following operating cost function: $C_{FS} = 5f_{FS} + 5q_{FS}$. A *LC* carrier, with the following operating cost function, may enter the market: $C_{LC} = q_{LC}$.

We consider a continuum of consumers who are identical in their preferences but differ in income. The available income for the transport market is assumed to be uniformly distributed between the interval [1,90]. The relative utility gain for the consumers of buying a ticket in a *FS* carrier instead of in a *LC* carrier is assumed to be $B_{FS} = 1.3$. The generalized price (which includes the ticket price, value of total travel time and schedule delay cost) paid by consumers when flying with a *FS* or *LC* carrier is given by: $G_{FS} = p_{FS} + 10 + \frac{24}{4f_{FS}}$; $G_{LC} = p_{LC} + 1 + \frac{24}{4f_{LC}}$, where f_{FS} and f_{LC} denote the daily frequency offered by the FS and LC carrier and the difference in the trip time is due to different network configurations used by the *FS* and *LC* carrier (hub and spoke versus point to point).

Assuming that slots in the airport are assigned annually, **Table 2** shows the annual frequency offered by the FS carrier and LC carrier in the monopoly and duopoly solution. Notice that when the airport capacity is high enough (it allows for a total frequency higher or equal than 5,545 flights per year), the LC carrier's entry cannot be blocked or deterred.

Thus, the *LC* carrier entry must be accommodated, and the market is operated by both airlines. However, when the airport capacity is lower than the aforementioned threshold, the entry is blocked or deterred, and the market is operated only by the *FS* carrier.

Table 2. Frequency and social welfare (per year) in the monopoly and duopoly solution

	Monopoly		**Duopoly**
	Entry is blocked $K \leq$ **2,429 flights**	**Entry is deterred** **5,545 $\geq$ K > 2,429 flights**	**Entry is accommodated** $K >$ **5,545 flights**
Frequency (annual)	f_{FS}^{M} = 2,385 flights	f_{FS}^{E*} = 5,501 flights	f_{FS}^{D} = 2,413 flights; f_{LC}^{D} = 47 flights
Ticket prices	p_{FS}^{M} = 42.04	p_{FS}^{M} =42.30	p_{FS}^{D} = 37.2140; p_{LC}^{D} = 1.0001
Generalized prices	G_{FS}^{M} = 52.96	G_{FS}^{M} = 52.70	G_{FS}^{D} = 48.1221; G_{LC}^{D} =48.1220
Profits	π_{FS}^{M} = 488,880	π_{FS}^{M} = 480,340	π_{FS}^{D} = 480,340; π_{LC}^{D} = 0.000008
Consumer surplus	CS^{M} = 250,400	CS^{M} = 253,920	CS^{D} = 320,070
Social welfare	SW^{M} = 739,280	SW^{M} = 734,260	SW^{D} = 748,580

As expected, the best situation from the social point of view is the duopoly situation. Notice that when the *FS* carrier deters the *LC* carrier's entry, consumers are better off than under the situation in which the entry is blocked, though the *FS* airline is worse off. Since the final situation strongly depends on the airport capacity, the regulator may use the information provided in **Table 2** to evaluate the possibility of investing in additional airport capacity by comparing the cost of additional capacity and the increase in social welfare due to moving from one situation to the other.[18]

[18] Recall that consumer surplus and airlines' profits are assumed to have the same weight in the social welfare function. However, the regulator may decide to assign different weights to the consumer surplus, *FS* and *LC* carriers' profits in the social welfare function.

7. Conclusions

In this paper we analyse 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 analyse under which circumstances the *FS* carrier is interested in increasing its frequency in order to deter or accommodate 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 deter the *LC* carrier entry and more difficult to have a blocked entry.

This paper provides two policy implications. On the one hand, the European regulation of slots based on the "Grandfather rights" provides *FS* incumbents a first mover advantage, allowing them to use the frequency as an entry deterrence strategy. Moving towards a different system for allocating slots on congested airports (for example, auctions) would favour the competition between both types of airlines. On the other hand, in order to promote the competition between *LC* and *FS* carriers, with the current allocation of slots on congested European airports, airports might be forced to increase their capacity. The welfare analysis performed in this paper might be used by regulators to assess the desirability of airport's capacity investments, by comparing the social welfare increase due to higher competition with the investment cost of expanding airport's capacity.

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 compete with *FS* carriers in airports that are not congested at all.

Finally, we would like to highlight that in this model we assume that an increase in frequency always reduces the schedule delay cost and, thus, passengers' generalized price. However, if the airport capacity is not large enough, more frequency may also imply more congestion and, therefore, more delays. Thus, if the airport capacity is not large enough, an increase in frequency may have no impact (or even a negative impact) in the generalized price since the negative effect on the delay cost may compensate (or even exceed) the positive effect on the schedule delay cost. This fact may limit the possibility of the *FS* carrier to deter the *LC* entry.

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