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A three-stage competition game in an air transport network under asymmetric valuation of flight frequencies☆

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ABSTRACT

This paper analyzes the effects of changes in aeronautical charges as brought by several airport management regimes on the air transport industry. Airlines compete on both price and non-prices variables, where connecting passengers have asymmetric valuations of flight frequencies in different legs. Changes in landing fees trigger airlines reactions on flight frequencies and airfares, whose sign depends on the weight attached to flight frequencies. Thus, an increase in the spoke landing fee leads to more international flights under low valuations of frequencies at spoke airports. Simulation exercises show that profit-maximizing aeronautical charges only at the spoke airport are preferable to those either only at the hub airport or at both airports. Welfare losses are lower when airports are granted to a unique infrastructure manager rather than to independent ones. When frequencies in the hub are highly valued, profit-maximizing charges only at the spoke airport will likely induce a welfare increase.

1. Introduction

The efficiency and performance of the air transport industry are certainly shaped by the interactions that appear in a vertically structured industry, with airports in the upstream and airlines in the downstream markets. Policy reforms affecting airport management will lead to changes in aeronautical charges which in turn will affect the intensity of airline competition with regard to both price and non-price variables. The characterization of markets as an air transport network introduces new relationships among the agents that makes competition more complex. In particular, when connecting passengers have asymmetric valuations of the frequencies airlines provide at different legs in the network. Taking these elements into account, this paper examines the effects of several airport management regimes on passenger traffic, airline prices and frequencies. Our analysis provides a useful framework for informed policy analysis in today's air transport industry.

The air transport industry has recurrently witnessed policies affecting aeronautical charges, the most common being changes in airport ownership, which definitely involve charges that depart from non-profit objectives. The evolution of airport ownership and governance has been significant over the last decades, ranging from government owned/operated to full or partial private for-profit structures (see Gillen, 2011).[1] Leaving aside the effects on airport operating costs, some policy relevant questions arise. What is the effect of different landing fees on fares and number of flights? How do they affect airport and airline profits, and passenger surplus? Assuming the government opts for implementing changes in airport management, should it embrace all airports in a network or only some of them?

The purpose of this paper is to analyze the effects of several airport management regimes on the market outcomes and on competition among airlines. Changes in airport ownership affect landing fees which, in turn, trigger airline reactions on flight frequencies and airfares. To

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[1] Changes in airport management can be motivated by changes in ownership. Since 1987 and following the privatization of some UK airports, privatization became a popular option in many areas of the world. Airports as diverse as Dusseldorf, Sanford Orlando, Naples, Rome, Birmingham, Bristol, Melbourne, Brisbane and Perth were partially or totally privatized in 1997; further privatizations took place in central and southern American countries in 1999 and 2000. Part of the Spanish infrastructure manager AENA, one of the largest airport managers per passenger volume in the world, is now in private hands (49%) and the government is planning to increase the private stake. See Graham (2014) for a detailed description of the airport privatization process in the world.

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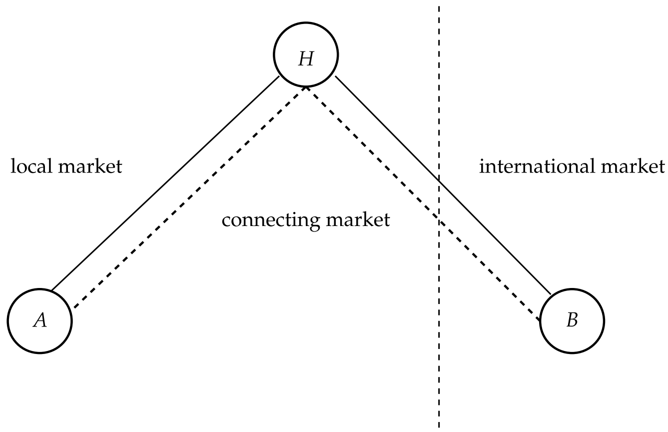

Fig. 1. Airport network and flight type.

undertake the analysis, we consider the simplest airport network with one hub and two spokes. Two airports, a spoke airport (A) and the hub airport (H) are located in a country and the hub connects the network with an airport elsewhere (B). This entails two routes, one domestic and one international operated by different airlines. Domestic or local flights are served by a domestic airline whereas international flights are operated by two different airlines in order to capture that the intensity of competition is different. Airlines are providing services to three types of passengers; two of them just traveling along one of the routes and the third type consisting of passengers that travel from A to B and so using the two routes. For the latter, the so-called connecting passengers, both the departing conditions in the spoke and in the hub airports matter for their purchasing decisions. In the model, the number of flights affects the utility of passengers who are willing to pay more when there are more flights in a route; that is, the number of flights is an indicator of service quality. It is precisely the existence of connecting passengers that makes competition among airlines no longer to be fragmented by routes. As a result, when one airline in one particular route is taking decisions on airfares and flight frequencies, the rival airlines are expected to respond strategically. In fact, all decision variables are linked up so that a policy decision with a local or regional origin that affects an airport with a spoke role in the airport network is finally having implications that affect the whole airport network and the downstream airline industry.

Although the aforementioned questions are recognized to be fundamental in the evaluation of alternative regimes for airport management, to the best of our knowledge, they have not been addressed in a formal model. Because air travel involves different travel segments for connecting passengers, the decisions taken by air carriers become particularly important provided the asymmetric passenger preferences about flight frequencies, which may be biased toward either one or the other airport in the network. Our analysis throws some relevant contributions. First, when the departing conditions of the two airports are similarly valued, an increase in the landing fee per flight of the spoke airport leads to a decrease in the number of local flights and triggers a response by the international airlines in the same manner.[2] Since the number of flights is directly related with the willingness to pay we can find that an increase in the landing fees will reduce airfares. Second, the analysis also unveils some unexpected results, which are driven by the fact that large enough asymmetric valuation of flight frequencies changes the strategic relationship between frequency choices made by airlines. We find that an increase in the spoke landing fee leads to more international flights under very low valuations of flight frequencies at the spoke airport. These relations and responses in turn affect airport and airline profit, as well as passenger surplus. These complex interactions should not be disregarded in taking sound policy measures that affect airport and airline relationships.

These results are confirmed empirically by calibrating the model with actual data from two networks, Malaga-Madrid-Paris and Valencia-Madrid-London for 2007. Then numerical simulations allow us to complete the formal analysis and evaluate five different airport management regimes. These regimes follow from the combination of two alternative airport managing rules, one based on marginal-cost pricing and another one which follows from profit maximization. Comparisons are drawn against the marginal-cost pricing scenario where airports set charges equal to their marginal flight costs, which here ensures cost recovery.[3] The main policy conclusions are the following. In case of allowing profit maximizing landing fees to only one domestic airport, it is preferable that the spoke airport implements this policy. Besides, such policy can generate welfare increases under some particular conditions. When both domestic airports follow a profit maximizing policy, it is better to have one infrastructure manager rather than two independent ones.

1.1. Related literature

Recent survey papers on air transport economics - Basso and Zhang (2007a) Zhang and Czerny (2012) and d'Alfonso and Nastasi (2014) – review airport pricing, capacity investment, airport regulation and privatization, airline alliances, and analyze the vertical relations between airports and carriers.

There is a long list of studies on airport pricing and capacity investment. One strand of the literature, the traditional approach, regards that an airport's demand is directly a function of an airport's own decisions. A comprehensive review of work within this approach is provided by Basso and Zhang (2007a). In particular, the private airport charge is excessive from the social point of view; the regulation of airport charges results in inefficient levels of capacity investments (see e.g. Zhang and Zhang, 2003; Oum et al., 2004). De Borger and Van Dender (2006), in a setting with two congestible facilities, find that under some circumstances a monopoly performs better than a duopoly regarding service quality. Noruzoliaee et al. (2015) examine capacity and pricing decisions in a multi-airport region for several privatization regimes; service prices tend to increase after privatization. A more recent approach, the vertical structure approach, models the airline market as an oligopoly and recognizes that airports provide an input for airlines downstream; the demand for airport services is a derived demand (following from the equilibrium in the airline market). The sophisticated analysis by Daniel (1995) studied airport pricing to alleviate congestion with stochastic queuing and where carriers' behavior is disciplined by the competitive pressure of fringe carriers. Later, in a very influential paper, Brueckner (2002) showed that, with a single airport and Cournot oligopolistic carriers, each airline will internalize the congestion imposed on its flights, which suggests a limited role for congestion pricing by the airport authority. Zhang and Zhang (2006) assume that capacity is a decision variable to show that a private airport overinvests in capacity when carriers have market power. Other contributions have been developed in a multi-airport context. Thus, when airports are run

[2] Czerny and Zhang (2015) also show that an increase in the per-flight charge leads to a decrease in the number of flights and airfares. They do so in a vertical monopoly model with convex demand and schedule delay functions and where the airport also sets per-passenger charges. Our analysis extends this finding to a network setting where strategic interactions play a relevant role and qualifies it for particular relative valuations of local and international flight frequencies.

[3] The five airport managing regimes are, 1) the benchmark where all airports follow the marginal-cost pricing rule, 2) only the spoke airport follows a profit maximizing rule; 3) only the hub airport sets a profit maximizing landing fee; 4) both domestic airports select independently their profit maximizing landing fee; and finally, 5) landing fees are those that maximize joint domestic airport profits.

by separate regulators, the lack of coordination leads to inefficient congestion tolls and welfare losses (Pels and Verhoef, 2004). Capacity and price decisions in a setting with two complementary airports are examined by Basso and Zhang (2007b) and Basso (2008). These papers compare the performances of airports under different objective functions; again profit-maximizing airports would typically lead to allocative inefficiencies and welfare losses although increased coordination would mitigate such inefficiencies. A rich combination of vertical structures is considered by Haskel et al. (2013). They consider profit-maximizing per-passenger landing fees and study various degrees of concentration in the upstream and downstream markets. Fees are higher when airports are jointly owned and airline concentration lowers landing fees. This need not be so when airport complementarities are considered, as done in our paper.

Strategic interaction between hub airports located in different continents is studied by Benoot et al. (2013). Their focus is not the privatization option; instead these authors investigate the welfare losses, relative to the first-best outcome, resulting from the competition of welfare-maximizing airports regulators that choose airport charges and capacities. Equilibrium infrastructure privatization policies have been examined by Mantin (2012) and Czerny et al. (2014). In the former, infrastructure (airport) services are complementary whereas (port) services are substitutes in the latter. Mantin (2012) finds that there is an incentive to privatize, although national welfare is higher when airports are kept public. This is not necessarily so when competition for transport services occurs in a third market, as shown by Czerny et al. (2014). Finally, Lin and Mantin (2015) consider airport privatization in a setup with domestic and international air traffic – each country has a hub and a spoke airport. Privatization is a dominant strategy for each government when the international hub-hub market is sufficiently large; governments are better off keeping their airports under public ownership.

Our analysis emphasizes the relevance of the strategic relationships among variables in establishing the effects of various ownership regimes. Although a simple network is considered, we complement this line of research by considering flight frequency as a strategic choice variable and price competition, which permits the analysis of differentiated substitute bundles that are composed of complementary legs.[4] Compared to earlier contributions, we evaluate the effects of introducing various interactions in a country's airport system on airline competition, where firms compete sequentially in price and non-price variables.[5] The benchmark assumed is a realistic scenario, in which airports follow marginal cost pricing; comparisons will allow us to suggest policy conclusions with regard to the changes induced by different landing fees.

Before the changes witnessed by the air transport industry since the mid 80s, transport economists have inquired into the necessity and role of price regulation following airport privatization processes. Different ownership regimes and regulations have implications on aeronautical charges and subsequently on the efficiency and performance of airports – as pointed out in Oum et al. (2004). At an empirical level, Oum et al. (2006) find that airports with a private majority ownership are more efficient and achieved significantly higher profit margins than airports under other ownership forms; besides they offer lower aeronautical charges as they rely on revenues from non-aviation services.

Some recent contributions have examined the determinants of airport aeronautical charges. Van Dender (2007), for 55 large US airports, and Bel and Fageda (2010) for 100 large EU airports, find that landing fees are lower when airports face airport competition. The latter also report that unregulated private airports charge higher prices than public or regulated airports, yet there is no substantial impact of regulatory regimes. In contrast, Bilotkach et al. (2012) find that single-till regulation indeed generates lower aeronautical charges and so does privatization. We will complement our formal analysis, which consists of solving various multi-stage games with airport-airline interactions, with some numerical simulations. The benchmark case considers that airports follow infrastructure marginal-cost pricing. Then, privatization regimes lead to higher fees thus affecting traffic, prices and the number of flights; allocative inefficiencies can be measured by evaluating welfare variations.

2. The model

2.1. Basic assumptions

Consider the following network of three airports consisting of two airports located in a given country denoted by A and H, where airport H is the hub in the network, and a third airport located elsewhere, denoted by B. Two types of routes are considered, a domestic or local one that connects A and H and an international route connecting H and B. The local route is supplied by one operator (labeled as l), and the international route is supplied by airline 1 and airline 2 -see Fig. 1.[6]

The two routes mentioned above, which describe three markets, are used by three different types of users, with their respective utility functions: i) users flying exclusively in the domestic market, from A to H, ii) users flying in the international route, from H to B, and iii) connecting users flying from A to H and then from H to B.[7] The utility functions are the following (see Dixit, 1979):

$$U_l = \alpha_l q_l - \frac{1}{2}q_l^2, \tag{1}$$

$$U_i = \alpha_{i1} q_{i1} + \alpha_{i2} q_{i2} - \frac{1}{2}\left(q_{i1}^2 + q_{i2}^2 + 2d q_{i1} q_{i2}\right), \tag{2}$$

$$U_c = \alpha_{c1} q_{c1} + \alpha_{c2} q_{c2} - \frac{1}{2}\left(q_{c1}^2 + q_{c2}^2 + 2d q_{c1} q_{c2}\right), \tag{3}$$

where U_l is the utility function of the representative user in the local market, and q_l denotes the number of passengers traveling from airport A to H that are not traveling abroad. The maximum willingness to pay for that service, $\alpha_l = a + vn_l$, is increasing in the number of flights,[8] n_l, offered in this route since the schedule delay is reduced. Finally, a and v are positive parameters, the former is the base willingness to pay in case the number of flights had no effect, while the latter measures the marginal effect of an increase in the number of flights on the corresponding

[4] The literature has regarded airlines' flight frequency as one of the components of full price associated to passenger's schedule delay cost. Some representative papers that have considered frequency in the demand for airlines include Oum et al. (1995), Basso (2008), Aravena et al. (2019), taking a representative consumer approach, and Brueckner (2004), Brueckner and Zhang (2001) and Brueckner and Flores-Fillol (2007), for an address approach with heterogeneous passengers. These alternative modelling strategies, the inverse of frequency and fare in the full price or the addition of frequency to the base willingness to pay, as we assume, both allow for an interpretation of frequency as an attribute of vertical differentiation.

[5] To the best of our knowledge, only Basso (2008) has considered airport strategic behavior together with airline strategic behavior in frequencies affecting demand and airfares as we do.

[6] We do not consider an airline operating both routes to conform with the numerical exercise provided below. To overcome the limitation imposed by this assumption, the possibility of an airline alliance, and hence one ticket price for connecting passengers, is explored there without any significant differences.

[7] This is the simplest network that allows us to study price and non-price airline competition taking into account both complementarity and substitution effects derived from airline pricing and it has been already considered in the literature.

[8] We assume that aircraft size is completely flexible and given by the number of passengers per flight.

willingness to pay. This means that the number of flights is an element of vertical differentiation as it implies higher service quality and, therefore, enhances the willingness to pay.[9] Also, U_i stands for the utility of passengers who board at H to fly to B and not coming from airport A, where q_{i1} and q_{i2} denote the number of passengers that use airline 1 and 2, respectively; $\alpha_{i1} = a + vn_1$ and $\alpha_{i2} = a + vn_2$ are the corresponding maximum willingnesses to pay for such flights, with n_1 and n_2 denoting the number of flights between airports H and B offered by airlines 1 and 2, respectively. While we have assumed away congestion, it is common that hubs have it. Note that parameter v can be reinterpreted as the net effect of two effects of flight frequency on passenger willingness to pay, one positive attached to schedule delay and one negative attached to congestion delay. Parameter d, for $d \in (0, 1)$, measures the degree of substitutability between the services offered by international airlines, so that a higher d implies less differentiated services.[10] Finally, U_c denotes the utility of connecting passengers who travel from A to B via H, and so q_{c1} and q_{c2} denote the number of passengers that use first the domestic airline and then either airline 1 or 2, respectively. Connecting passengers consume a package or a bundle of services and their basic valuation of the service is then assumed, for computational convenience, two times the basic valuation of one service, i.e. $2a$.[11] Since connecting passengers must take off from two different airports, we assume that their willingness to pay is increasing with the number of flights available at each airport. In particular, the corresponding maximum willingness to pay is assumed to be additive and linear as follows,[12,13] $\alpha_{cj} = 2a + v(\lambda n_l + (1-\lambda)n_j)$, for $j = 1, 2$. We use parameter λ, where λ belongs to [0, 1] to weigh the relative importance of the local and international number of flights to these passengers. In fact, the marginal rate of substitution between international and local flights in terms of maximum willingness to pay is easily defined as $MRS_{jl} = \left(\frac{\partial \alpha_{cj}}{\partial n_j} / \frac{\partial \alpha_{cj}}{\partial n_l}\right)$ and coincides with the ratio $\frac{1-\lambda}{\lambda}$ for $j = 1, 2$. Therefore, when $\lambda = 1/2$ the marginal rate of substitution is one, implying a symmetric valuation of flight frequencies in both airports. Similarly, $\lambda < 1/2$ (or $MRS_{jl} > 1$) would indicate that connecting passengers value more a quick connection at airport H rather than at airport A.

The demand functions that correspond to the three markets are the following.

i) Local market demand:

$$q_l = \alpha_l - p_l \tag{4}$$

ii) International market demand system:

$$q_{i1}(p_1, p_2) = \frac{1}{(1-d^2)}(\alpha_{i1} - d\alpha_{i2} - p_1 + dp_2) \tag{5}$$

$$q_{i2}(p_1, p_2) = \frac{1}{(1-d^2)}(\alpha_{i2} - d\alpha_{i1} - p_2 + dp_1) \tag{6}$$

iii) Connecting market demand system:

$$q_{c1}(s_1, s_2) = \frac{1}{(1-d^2)}(\alpha_{c1} - d\alpha_{c2} - s_1 + ds_2) \tag{7}$$

$$q_{c2}(s_1, s_2) = \frac{1}{(1-d^2)}(\alpha_{c2} - d\alpha_{c1} - s_2 + ds_1) \tag{8}$$

where $s_1 = p_l + p_1$ and $s_2 = p_l + p_2$ since the connecting passengers purchase one ticket from the domestic airline and another from one of the international airlines.[14]

There are two types of firms, airlines and airport managers. Airlines profits are as follows:

$$\pi_l = p_l(q_l + q_{c1} + q_{c2}) - cn_l^2 - (f_A + f_H)n_l, \tag{9}$$

$$\pi_1 = p_1(q_{i1} + q_{c1}) - cn_1^2 - (f_B + f_H)n_1, \tag{10}$$

$$\pi_2 = p_2(q_{i2} + q_{c2}) - cn_2^2 - (f_B + f_H)n_2, \tag{11}$$

where f_A, f_B and f_H are the landing fees per flight charged by airports A, B and H, respectively, and, c is a positive parameter that measures how marginal cost per flight increases with the number of flights. We are assuming a decreasing returns cost function in the number of flights to capture the increased complexity in planning operations.[15] Besides, we assume away marginal costs per passenger to simplify the presentation.

Before proceeding, it is pertinent to comment on the complex effects that appear in the airline profit functions derived from connecting passengers demand. The following expressions report the demand for the local airline and that for the international airline j:

[9] Brueckner (2004) suggested that consumer utility is higher for a lower cost of schedule delay, that is, for higher flight frequency. This reasonable assumption is common in the literature and has been made by Heimer and Shy (2006) and Kawasaki (2008), among others. It may be argued that the benefit of flight frequency diminishes with more flights. Our setting delivers similar predictions were benefits modelled as square roots together with linear operating costs per flight.

[10] Note that we exclude $d = 1$ since it would lead to a Bertrand competition model with homogeneous goods, which is not the limit case of the model presented. Besides, the willingness to pay should include the sum of frequencies.

[11] For the given network, consumption of trip A-B implies the successive use of two complementary goods, a bundle, that also have utility when components are consumed separately. In this case, the willingness to pay for the bundle is typically assumed to be larger than or equal to the willingness to pay for the sum of the components of the bundle (see Tauman et al., 1997; Gabszewicz et al., 2001). Were there a direct A-B flight, it would be sensible to assume that the willingness to pay for that service to be larger, since it can be considered as a service of better quality as compared to connecting flight (see e.g. Bilotkach, 2005; Czerny, 2009).

[12] Footnote 4 above, noted the two different modelling strategies regarding the effect of flight frequency in passenger demand. We adopt the additive effect of frequency in the willingness to pay for traveling for reasons of tractability in the role of λ, although both modelling approaches deliver similar results. This is so as long as the fare and the schedule delay function are separable in the number of flights; otherwise, frequency would affect the slope of demands and thus the degree of horizontal differentiation between airline services. Demand asymmetries, as measured by differences in the demand intercepts have a clear interpretation as vertical (quality) differentiation between products, as put forward by Hackner (2000).

[13] Although there are other possible specifications that allow asymmetric valuations of the flight frequencies at different airports, we have opted for this one for its simplicity and flexibility. The average formulation for a one-stop trip, a particular case of ours, has been employed in earlier work by Flores-Fillol (2010) and Silva et al. (2015). Another interesting alternative is to consider the benefit being the lesser of the two frequencies, Brueckner and Flores-Fillol (2018). However, the latter might not be appropriate when the waiting time cost at the hub is considered (see Rietveld and Brons, 2001).

[14] Demand functions with competition between composite products made of complementary components have been used by Economides and Salop (1992) and applied to the airline industry by Flores-Fillol and Moner-Colonques (2007).

[15] Brueckner (2009) employs decreasing returns in the number of flights, Heimer and Shy (2006) also employ quadratic costs. The reason why cost per departure is increasing with frequency is that airport gate slots are scarce.

$$q_l + q_{c1} + q_{c2} = \frac{a(5+d) + v(1-\lambda)(n_1+n_2) + v(1+d+2\lambda)n_l - (p_1+p_2) - (3+d)p_l}{1+d}, \tag{12}$$

$$q_{ij} + q_{cj} = \frac{3a(1-d) + v\lambda(1-d)n_l - v(2-\lambda)dn_k + v(2-\lambda)n_j + 2dp_k - (1-d)p_l - 2p_j}{1-d^2} \tag{13}$$

Consider first the local airline demand in (12). The presence of connecting passengers implies that international airfares, p_1 and p_2, are now complements for local airfares, p_l. This meaning that increases in international airfares are shifting inwards local airline marginal revenues thus inducing a lower local airfare (i.e. strategic substitution). In other words, to keep the same connecting passenger demand, an increase in one component price of the bundle purchased by those passengers is duly compensated by a decrease in the other component price, p_l. Regarding the number of flights, international flights are also considered by connecting passengers as a quality feature for the bundle they are consuming and, therefore, increases in both international and local flights will shift outwards both demand and marginal revenue thus inducing higher local airfares. Our point is that an increase in international flights will have a bigger effect on total demand when λ is low, while that derived from local flights will be stronger as λ increases. Finally, and increase in λ will shift demand outwards in case the number of local flights exceeds the average number of international flights.

Consider now international airline j demand in (13). The effects of connecting passengers using the international flights on an international airline's demand are that local prices enter in each international airline demand as the price of a complementary service. Therefore, an increase in local airfares will shift inwards both demand and marginal revenue functions thus reducing the international airfare that maximizes profits. Notice that the local price is at the same time a component price in the price of the bundle sold by one particular airline, say $s_1 = p_l + p_1$, and a component price of the bundle sold by the competitor, say $s_2 = p_l + p_2$. That is why the effect of p_l on $q_{ij} + q_{cj}$ is smaller than the effect of p_j. Regarding the number of flights, there are three different effects on demand. One is an own effect, which is positive and decreasing in λ, that shifts outwards demand and marginal revenue since more flights are denoting more quality of both its direct $H-B$ services and its bundle service connecting airports $A-B$. There is another positive effect due to local flights that also shifts outwards demand and marginal revenue functions and, finally, a negative effect that shifts inwards demand and marginal revenue functions since more flights scheduled by the rival international airline is reducing the appeal of the international airline under consideration. Finally, the effect of an increase in λ shifts airline j demand inwards if the airline j number of flights is large enough.

Profits for the airport managers are given by

$$\pi_A = (f_A - t)n_l, \tag{14}$$

$$\pi_H = (f_H - t)(n_l + n_1 + n_2), \tag{15}$$

where t are the airport marginal costs per flight, and note that for simplicity we have assumed away any airport costs not related to the number of flights.

Competition in the market is modelled as a three-stage game. In the first stage, airports A and H determine landing fees that are charged per flight. In the second stage, the local airline and airlines 1 and 2 set the number of flights for each route, and finally, in the third stage airlines compete in prices.

2.2. Third stage analysis

The game is solved backwards, where at the third stage the Nash equilibrium in prices is obtained by simultaneously solving the system of first order conditions (FOCs), $\frac{\partial \pi_l}{\partial p_l} = 0$, $\frac{\partial \pi_1}{\partial p_1} = 0$, $\frac{\partial \pi_2}{\partial p_2} = 0$. Denote by p_l^*, p_1^* and p_2^* the solution to the above system. As advanced earlier, p_1 and p_2 behave as strategic complements, while p_l and p_1, and p_l and p_2 behave as strategic substitutes.[16] We are also interested in how equilibrium prices are affected by the number of flights[17]

Result 1. *The number of domestic flights increases domestic price while the number of international flights increases domestic price if and only if* $0<\lambda<\frac{2}{3-d}$. *Besides, the number of international flights of an international airline increases its equilibrium price while rival's number of international flights reduces it if and only if* $0<\lambda<\min\left\{\frac{2(1+11d+4d^2)}{3+10d+3d^2}, 1\right\}$. *Finally, the relationship between the domestic number of flights and the international prices is positive if and only if* $\frac{1+d}{2(2+d)} < \lambda < 1$.

The number of flights is viewed by passengers as a signal of quality, then, more flights will imply a larger willingness to pay for the service. This explains why the number of flights of a given airline has a positive effect on own prices and a negative effect on the prices of the airlines that operate in the international route, that is airlines 1 and 2 in both the international and the connecting markets, which occurs almost always, it is just required that $d > 0.081$. However, the cross effect between the domestic number of flights and the international prices and the sign of the cross effect between the number of flights of international airlines and domestic prices depend on the marginal rate of substitution between flight frequencies. To see the intuition let us consider the effect of one more international flight on the local airfare. One can represent the strategic relation between p_l and $p_1 + p_2$ in reaction-function space where both functions are downward sloping. An increase in n_j will firstly shift the reaction function of $p_1 + p_2$ outwards, which by strategic substitution, exerts a downward pressure on p_l and its magnitude depends in λ. Secondly, it also shifts outwards the reaction function of p_l inducing an upward pressure on p_l; again the magnitude of such a shift depends of the size of λ. The result above identifies the precise condition on λ for the latter effect to offset the former thus resulting in an increase on local airfares. Otherwise, we may obtain an unintuitive effect of n_j on p_l. The effect of one more domestic flight on international fares can be explained in a similar way but now the final effect follows from the interplay of three effects. Notice that when flight valuation is symmetric in both airports, i.e. $\lambda = 1/2$, then $\frac{dp_l^*}{dn_j}$ and $\frac{dp_j^*}{dn_l}$ are positive $\forall d$.

2.3. Second stage analysis

In the second stage, firms maximize profits by choosing the corresponding number of flights. Once equilibrium prices are substituted back into the profit expressions and making use of the FOCs for prices, the second-stage reduced form profits read as follows:

[16] Note that second order conditions (SOCs) are satisfied since $\frac{\partial^2 \pi_l}{\partial p_l^2} = \frac{\partial q_l}{\partial p_l} + \frac{\partial q_{c1}}{\partial p_l} + \frac{\partial q_{c2}}{\partial p_l} < 0$ and $\frac{\partial^2 \pi_j}{\partial p_j^2} = \frac{\partial q_{ij}}{\partial p_j} + \frac{\partial q_{cj}}{\partial p_j} < 0$ for $j = 1, 2$. Besides $\frac{\partial^2 \pi_l}{\partial p_l \partial p_j} = -1 + d < 0$, $\frac{\partial^2 \pi_i}{\partial p_i \partial p_l} = -1 + d < 0$ and $\frac{\partial^2 \pi_i}{\partial p_i \partial p_j} = 2d > 0$ for $i, j = 1, 2$ and $i \neq j$.

[17] See the Appendix for details on the derivation of the results.

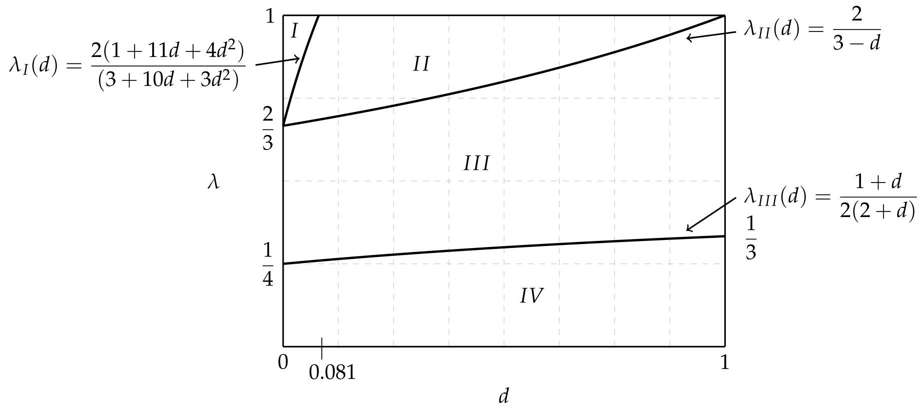

Fig. 2. Areas for the strategic relationships among the number of flights.

$$\pi_l^* = \left(\frac{3+d}{1+d}\right)(p_l^*)^2 - cn_l^2 - (f_A + f_H)n_l$$

$$\pi_1^* = \left(\frac{2}{1-d^2}\right)(p_1^*)^2 - cn_1^2 - (f_B + f_H)n_1$$

$$\pi_2^* = \left(\frac{2}{1-d^2}\right)(p_2^*)^2 - cn_2^2 - (f_B + f_H)n_2$$

The solution to the system of FOCs, $\frac{\partial \pi_l^*}{\partial n_l} = 0$, $\frac{\partial \pi_1^*}{\partial n_1} = 0$ and $\frac{\partial \pi_2^*}{\partial n_2} = 0$ implicitly defines the Nash equilibrium in the number of flights denoted by (n_l^*, n_1^*, n_2^*).[18] In the following result, the strategic relationships among the number of flights set by the different airlines is specified[19]

Result 2. *The strategic relationship among the number of flights depends on the degree of substitutability between international airlines and on the weight passengers give to flights in each airport in a complex way. In particular, if the weight λ belongs to the interval* $\left(\frac{1+d}{2(2+d)}, \frac{2}{3-d}\right)$ *then the number of domestic flights and the number of international flights behave as strategic complements; and also the number of international flights of each international airline behave as strategic substitutes. Outside this interval, the number of domestic flights and the number of international flights might behave as strategic substitutes.*

The strategic relationship among the different number of flights explains the reaction of each airline in response to a change in the number of flights of another. In particular, when the international airline number of flights behave as strategic substitutes, this implies that airline 1's increase in n_1 will shift the marginal profit of airline 2 inwards so the number of flights that would maximize its profits is now lower. It is worth mentioning that the strategic relationship between the number of flights of different airline types can be asymmetric in the sense that an increase in n_l might shift outwards the marginal profit function of an international airline, while at the same time an increase in n_j might produce an inward shift of the local airline's marginal profit function, or the other way round. These asymmetric strategic relationships happen in areas I, II and IV in Fig. 2. Result 2 highlights area III in Fig. 2 where the number of flights of different airline types are strategic complements, while within the same type, international airlines, they are strategic substitutes. Such complementarity or substitutability is explained by the cross effects of second-stage decisions, number of flights, on third stage equilibrium prices. Since local airlines and international airlines are serving each two different passenger types with one type in common, the connecting passenger, the final effect on the equilibrium price of a change in the rival's airline number of flights results from a combination of the corresponding effect on the willingness to pay for each passenger type where the relative effect of each one is related to λ. Then, complementarity happens because λ is large enough (above $\lambda_{III}(d)$ in Fig. 2) for the number of flights in the spoke airport to increase enough the willingness to pay for connecting passengers that justifies an increase in the international airfare, and at the same time small enough (below $\lambda_{II}(d)$ in Fig. 2) for the number of flights in the hub airport to increase enough the willingness to pay for connecting passengers that justifies an increase in the local airfare. In other words, central values of λ correspond with the logical translation of competition between vertically differentiated bundles, where complementarity of different travel segments prevails. Very asymmetric valuations of flight frequencies changes such logic leading to some unexpected results, as shown below.

The various airport managing regimes involve different landing fees, which in turn affect the number of flights. These effects are the object of the next result.

Result 3. *Consider strategic substitution between the number of international flights (areas II, III and IV in Fig. 2), then the following holds:*

i) An increase in the fee set by the spoke airport, f_A, always reduces the equilibrium number of local flights, while it reduces those of the international airlines if and only if the weight λ is large enough. (Areas II and III)
ii) An increase in the fee set by the international airport located abroad, f_B, always reduces the equilibrium number of international flights, while it reduces the local ones if and only if the weight λ is low enough. (Areas III and IV)
iii) For an increase in the fee set by the hub airport, f_H to reduce both the number of local flights and the number international flights it is sufficient that the number of local flights and the number of international flights behave as strategic complements. (Area III)

Therefore, an increase in a landing fee at a domestic spoke or at an airport abroad will always have the effect of reducing the equilibrium number of flights departing from or arriving at them in the proposed network. This is a natural and sensible effect, however, it is also found that changes in landing fees of airports that are not used by local or international airlines affect their equilibrium number of flights. For instance, an increase in the landing fees of airports located abroad will reduce the number of flights of local airlines when the weight passengers attach to flights in the spoke airport is low enough since this is the

[18] For the SOC's to be satisfied it is required that parameter c be large enough, i.e. $\frac{\partial^2 \pi_l}{\partial n_l \partial n_l} = 2\left(\frac{3+d}{1+d}\right)\left(\frac{dp_l^*}{dn_l}\right)^2 - 2c < 0$ and $\frac{\partial^2 \pi_j}{\partial n_j \partial n_j} = 2\left(\frac{4}{1-d^2}\right)\left(\frac{dp_j^*}{dn_j}\right)^2 - 2c < 0$ for $j = 1, 2$. Once the equilibrium number of flights are found, equilibrium prices and number of passengers can be obtained. It is important to note that a sufficiently large basic willingness to pay is required in order to ensure non-negative numbers. See the precise condition in the Appendix.

[19] Result A1 in the Appendix specifies all the possible strategic relationships among the number of flights of the different airlines.

condition for local flights to be strategic complements of international flights. In this case, since an increase in f_B will reduce n_j, and given that n_l is a strategic complement of n_j, then we find that n_l is reduced. A similar reasoning can be applied to the effect of f_A on the number of flights of international airlines. Finally and regarding the effect of variations in the landing fees at the hub airport, the one used by both types of airlines, it is sufficient to have strategic complementarity on both directions, that is a pair (d, λ) belonging to area III in Fig. 2 to have a negative effect on the number of flights.

It is worth emphasizing that by combining results 1 and 3, we find that an increase in landing fees causes airfares to fall rather than rise. Its source is the reduction in flight frequency, which shifts demand inwards at the same time that the fees raise airline costs. Although this effect has been demonstrated in previous papers, in this case it is qualified to the case where the number of flights are strategic complements, which happens for central values of λ.

2.4. First stage analysis

Finally, in the first stage the airport infrastructure managers decide on their corresponding per flight landing fee. We are considering two alternative options, either the fee per flight is chosen to maximize airport profits or it is the one that equals the marginal cost of providing the service. The marginal-cost pricing rule is assumed to be our benchmark. It is justified on the grounds of cost recovery since fixed airport costs are normalized to zero in our model.[20] In case both airports A and H behave as profit maximizers, and they choose independently and simultaneously the corresponding landing fees per flight, the system of FOCs reads[21]

$$\frac{\partial \pi_A}{\partial f_A} = n_l^* + (f_A - t)\frac{dn_l^*}{df_A} = 0 \tag{16}$$

$$\frac{\partial \pi_H}{\partial f_H} = (n_l^* + n_1^* + n_2^*) + (f_H - t)\left(\frac{dn_l^*}{df_H} + \frac{dn_1^*}{df_H} + \frac{dn_2^*}{df_H}\right) = 0 \tag{17}$$

The system of equations by (16) and (17) implicitly defines the equilibrium landing fees, denoted by, (f_A^*, f_H^*) when both airports maximize profits. Formally, $f_A^* \equiv R_A(f_H^*)$ and $f_H^* \equiv R_H(f_A^*)$ where $R_A(f_H)$ and $R_H(f_A)$ represent the corresponding reaction functions. Also, the airport fees behave as strategic substitutes since,

$$\frac{\partial^2 \pi_A}{\partial f_A \partial f_H} = \frac{dn_l^*}{df_H} < 0, \tag{18}$$

$$\frac{\partial^2 \pi_H}{\partial f_H \partial f_A} = \frac{dn_l^*}{df_A} + \frac{dn_1^*}{df_A} + \frac{dn_2^*}{df_A} < 0. \tag{19}$$

Therefore the above mentioned reaction functions are downward sloping. Notice that airport B is not a strategic player in our setting. However, we obtain some interesting conclusions both on i) the reaction of landing fees f_A and f_H in expressions (20) and (21) showing the conditions for strategic substitution, and on ii) the effects to airline profits to changes in f_B in Result 5.

$$\frac{\partial^2 \pi_A}{\partial f_A \partial f_B} = \frac{dn_l^*}{df_B} < 0 \text{ if } \lambda < \frac{2}{3-d} \tag{20}$$

$$\frac{\partial^2 \pi_H}{\partial f_H \partial f_B} = \frac{dn_l^*}{df_B} + \frac{dn_1^*}{df_B} + \frac{dn_2^*}{df_B} < 0 \tag{21}$$

The expressions in (18) and (19) imply that in case both airports are managed to maximize profits an increase in the fee by one of them would reduce the marginal profit of the other. Therefore, if one of the airports sets a marginal cost pricing landing fee, which is certainly lower than the profit maximizing fee, then the profit maximizing airport will react by increasing its landing fee. Formally, $t < f_A^* \equiv R_A(f_H^*) < R_A(t)$ with the similar ranking for the hub airport. Given that, the following result holds.

Result 4. *For a given airport, the largest landing fee set would correspond to the case where it applies a profit maximizing rule and the other airport is applying the marginal cost pricing rule, followed by the case where both airports are profit maximizers.*

We are next interested in analyzing the effect of an increase in per flight landing fees on airline profits. The second stage domestic airline's equilibrium profits are given by,

$$\pi_l^* = \left(\frac{3+d}{1+d}\right)(p_l^*)^2 - cn_l^{*2} - (f_A + f_H)n_l^*. \tag{22}$$

The effect of a variation in f_A on the equilibrium profits can be decomposed into the following effects,

$$\frac{d\pi_l^*}{df_A} = 2\left(\frac{3+d}{1+d}\right)p_l^*\left(\underbrace{\frac{dp_l^*}{dn_1}\frac{dn_1^*}{df_A}}_{se_{l1}^{f_A}} + \underbrace{\frac{dp_l^*}{dn_2}\frac{dn_2^*}{df_A}}_{se_{l2}^{f_A}}\right) - \underbrace{n_l^*}_{\text{direct effect}} \tag{23}$$

First, there is a negative direct effect proportional to the number of flights. Second and given the demand complementarity derived from connecting passengers, a variation in f_A also has two strategic effects, $se_{l1}^{f_A}$ and $se_{l2}^{f_A}$, derived from the effect of f_A on the respective number of international flights, n_1^* and n_2^*, and how it is transmitted to the domestic prices.[22] Note that the sign of the corresponding strategic effects depends on the strategic relationship among the number of flights of the different airlines and the effect of the number of flights on prices as shown in Result 1, 2 and 3. In particular, if the number of domestic and international flights are strategic complements then both strategic effects derived from a variation in f_A are negative and, therefore we conclude that an increase in f_A reduces local airline profits. However, for positive strategic effects, as happens in areas II and IV in Fig. 2, there is room for a positive effect on profits which, if large enough, may override the negative direct effect. This result would not be possible under symmetric valuations of flight frequencies, which, once again, emphasizes the relevance of passenger valuations involving distinct travel segments.

Similarly a variation in f_H and in f_B is affecting the local airline equilibrium profits as follows:

$$\frac{d\pi_l^*}{df_H} = 2\left(\frac{3+d}{1+d}\right)p_l^*\left(\frac{dp_l^*}{dn_1}\frac{dn_1^*}{df_H} + \frac{dp_l^*}{dn_2}\frac{dn_2^*}{df_H}\right) - n_l^* \tag{24}$$

$$\frac{d\pi_l^*}{df_B} = 2\left(\frac{3+d}{1+d}\right)p_l^*\left(\frac{dp_l^*}{dn_1}\frac{dn_1^*}{df_B} + \frac{dp_l^*}{dn_2}\frac{dn_2^*}{df_B}\right) \tag{25}$$

Once again, the total effect is explained by the different signs in the corresponding strategic effects. The following result, presents sufficient conditions for the effects of increases in each landing fee on profits to be negative.

[20] Airport pricing is a complex matter which lies beyond the scope of the current analysis. Note that here the usual welfare maximizing justification does not apply because of the presence of airline market power. We consider landing fees equal to marginal flight cost as a realistic assumption to elaborate sound policy conclusions in the numerical exercises below. Indeed, this practice linking aeronautical fees to given marginal operation cost, has been followed regularly by the Spanish airport authorities.

[21] The SOCs are satisfied since $\frac{\partial n_l^*}{\partial f_A} < 0$, $\frac{\partial n_j^*}{\partial f_H} < 0 \; \forall j$ and $\frac{\partial n_l^*}{\partial f_H} < 0$.

[22] For a given strategic effect se_{st}^g, the superindex g corresponds to the variable that induces the reaction, the first subindex, s, refers to the airline price that is affected while the second, t, to the airline that varies its number of flights.

Table 1
Values used in the calibration.

Local air price elasticity	−0.65
International air price elasticity	−0.65
Cross air price elasticity	0.10
Air frequency elasticity	0.42

Result 5. *It is sufficient that local and international flights be strategic complements in order to find a negative effect on the local airline's profits due to either an increase in f_A or an increase in f_H. This negative effect on the local airline's profits also occurs due to an increase in f_B if the local flights and the international ones are strategic complements, while the strategic relation between the international and the local number of flights can be of either type.*

A similar analysis is undertaken for the international airlines, where equilibrium profits are given by

$$\pi_j^* = \left(\frac{2}{1-d^2}\right)p_j^{*2} - cn_j^{*2} - (f_B + f_H)n_j^* \tag{26}$$

Therefore, a variation in f_A, f_H and f_B affects the equilibrium profits as follows,

$$\frac{d\pi_j^*}{df_A} = 2\left(\frac{2}{1-d^2}\right)p_j^*\left(\frac{dp_j^*}{dn_k}\frac{dn_k^*}{df_A} + \frac{dp_j^*}{dn_l}\frac{dn_l^*}{df_A}\right), \tag{27}$$

$$\frac{d\pi_j^*}{df_H} = 2\left(\frac{2}{1-d^2}\right)p_j^*\left(\frac{dp_j^*}{dn_k}\frac{dn_k^*}{df_H} + \frac{dp_j^*}{dn_l}\frac{dn_l^*}{df_H}\right) - n_j^*, \tag{28}$$

$$\frac{d\pi_j^*}{df_B} = 2\left(\frac{2}{1-d^2}\right)p_j^*\left(\frac{dp_j^*}{dn_k}\frac{dn_k^*}{df_B} + \frac{dp_j^*}{dn_l}\frac{dn_l^*}{df_B}\right) - n_j^*, \tag{29}$$

where the landing fee at the spoke airport affects the international airline profits due to the strategic effects driven by the effect of such fee on the local airline's number of flights and airfares, and also on the competing international airline's strategic decisions. Similarly for the landing fees at the hub and at the airport located abroad with the difference that there are also negative direct effects. For instance, regarding $\frac{d\pi_j^*}{df_A}$ and focusing on area III in Fig. 2, the two strategic effects are of different sign being $se_{jk}^{f_A}$ positive (an increase in f_A reduces n_k which in turn leads to an increase in p_j), while $se_{jl}^{f_A}$ is negative (an increase in f_A lowers n_l which in turn leads to a decrease in p_j). The sign of the total effect is thus explained by the strategic effect of the two that is larger in absolute terms. A similar reasoning can be done with the effects of f_H and f_B where the sign of the total effect includes the direct effect. In particular, regarding $\frac{d\pi_j^*}{df_B}$ and focusing on area III in Fig. 2, we know that $se_{jk}^{f_B}$ is positive while $se_{jl}^{f_B}$ is negative, so that the latter being larger than the former in absolute terms is a sufficient condition to find a total negative effect. However, in area IV the two strategic effects are positive and a total positive effect can be found if the strategic effect is larger than the direct effect in absolute terms. Whether airlines are better off with higher or lower landing fees crucially depends on how their decisions variables are related, which in turn is determined by the relative valuation flight frequencies in both airports as well as the intensity of competition.

To summarize and highlight the effect of asymmetric valuation of flight frequencies on the reactions of frequencies and airfares to an increase in the landing fees, consider the case of an increase in the landing fee of the spoke airport. Two different sequences of reactions are produced. If the valuation of flight frequencies in the spoke and the hub airports are rather close (i.e. $\frac{1+d}{2(2+d)} < \lambda < \frac{2}{3-d}$), we would expect that an increase in f_A reduces the equilibrium frequencies of all airlines. This occurs since all $\frac{dn_l}{df_A}, \frac{dn_j}{df_A}, j = 1, 2$ are negative, which will, in turn, reduce all airfares as all $\frac{dp_l}{dn_l}, \frac{dp_l}{dn_j}, \frac{dp_j}{dn_j}, \frac{dp_j}{dn_l}$ are positive and $\frac{dp_j}{dn_j} > -\frac{dp_j}{dn_k}$. These findings are a natural extension of one of the results in Czerny and Zhang (2015) to a more general air transport network. However, in case the relative valuation of flight frequencies is clearly marked in favor of the hub airport, (i.e. $\lambda < \frac{1+d}{2(2+d)}$), the effect of an increase in f_A will reduce local flights frequencies but *increase* international flights since now $\frac{dn_j}{df_A}, j = 1, 2$ are positive. How do these changes affect airfares? International prices now increase for two reasons that reinforce each other, i) local flights fall and now $\frac{dp_j}{dn_l}$ is *negative*; ii) international flights increase and $\frac{dp_j}{dn_j}$ remains positive. Finally, local airfares decrease because the negative own effect derived from the reduction of local flights offsets the positive cross effect induced by an increase in the international flights. Key to these unexpected results is that a sufficiently large asymmetric valuation of flight frequencies affects the strategic relationship between the local and international flights, becoming now strategic substitutes.

Table 2
Actual data corresponding to 2007.

Number of flights Málaga-Madrid per day and direction	18
Number of flights Madrid-Paris Charles de Gaulle per day and direction per company	9.5
Passengers in Málaga-Madrid per day and direction	1850
Passengers in Madrid-Paris Charles de Gaulle per day and direction	2360
Number of flights Valencia-Madrid per day and direction	16
Number of flights Madrid-London Heathrow per day and direction per company	9
Passengers in Valencia-Madrid per day and direction	1440
Passengers in Madrid-London Heathrow per day and direction	1800
Average local price	100
Average international price	135
Airport fee at the international airports	1800
Marginal cost for Spanish airports	1300

3. A numerical application

3.1. Data and calibration of the model

Next, we are going to simulate the model using a numerical example in order to complete the analysis and provide further policy conclusions. We redefine the utility function parameters to allow for different coefficients in the linear-quadratic terms across markets to provide a setting that fits better with actual data employed in the calibration.[23] In addition, we are going to distinguish two different utility functions for connecting passengers to account for its heterogeneity in more complex networks. In this manner, in the first leg we account for those traveling from A to H and flying elsewhere including B, while in the second leg we account for connecting passengers arriving at H from elsewhere including A and flying to B. The analysis uses sensible values as displayed in Table 1 in order to recover reasonable values for the parameters.

The value of local and international air price elasticity is obtained by an average from different sources (González-Savignat, 2004, IATA report, 2007 and Brons et al., 2002). Although it is usually assumed that international legs are a little more inelastic than local ones, this effect would be offset by stronger competition in the international leg and so we have employed the same value. Regarding the air frequency elasticity, we have employed an average value obtained from the papers by González-Savignat (2004) and Fu et al. (2014).

The calibration analysis considers two air transport networks,

[23] In particular, we allow for different values for the base willingness to pay in every market. Besides, the coefficient for q_l^2 is $\frac{b_l}{2}$ in (1); similarly, b_i and b_c in (2) and (3).

Málaga-Madrid-Paris Charles de Gaulle and Valencia-Madrid-London Heathrow, to provide examples with different traffic intensities and valuations of flights.[24] Table 2 reports actual data of prices, number of flights and traffics per day and direction, airport fees and marginal costs for 2007.[25] The analysis is carried for 2007 because it is a pre-crisis year with no High-Speed-Train services connecting the above two Spanish cities to Madrid, to be consistent with the model. The local routes include both local and connecting passengers. It is assumed that 30% of total traffic in both routes have Madrid as final destination, while the remaining are connecting passengers in transit to other destinations. In the international leg there are two types of passengers boarding in Madrid: those with origin in Madrid and those in transit from different origins. To obtain the number of passengers in transit traveling to either Paris Charles de Gaulle or London-Heathrow, we have consulted averages of connecting passengers at Madrid airport as reported by Hanlom (2007), and have taken a value of 40%, accordingly. For international and local prices we use averages from different international and local routes departing from or arriving at Madrid.[26]

Next, for the network Málaga-Madrid-Paris we define a system of four equations in four unknowns b_l, b_i, d, and v using the values provided in Table 2 to get the following values for the parameters: $b_l = 0.239$, $b_i = 0.266$, $d = 0.041$, $v = 4.046$. Proceeding in the same manner for the network Valencia-Madrid-London, the values obtained are $b_l = 0.352$, $b_i = 0.487$, $d = 0.075$, $v = 4.284$. For simplicity it is assumed that $b_c = (b_l + b_i)/2$.

The benchmark is the case where airports A and H follow the infrastructure marginal cost pricing rule. In particular, $f_A = f_H = t = 1300$ and finally, f_B is chosen to be 1800. The next step is to recover the values for the base willingness to pay for each utility function considered,[27] the marginal cost parameter, c, and the parameter measuring the relative importance of the local and international number of flights for connecting passengers, λ. To do so, we construct a system of six equations taking the equilibrium expressions for traffics and numbers of flights derived from the model in the benchmark case. Making use of the above obtained utility function parameters and the actual data from Table 2 for each network considered, we get the values reported in Table 3 below:

Notice that the value of λ calibrated for the network Málaga-Madrid-Paris would comply with area III in Fig. 2, while that for the network Valencia-Madrid-London complies with area IV. With these values we can numerically run the three-stage game for five different regimes where the behavior of airport manager changes.

- The benchmark scenario has both airports A and H follow infrastructure marginal cost pricing (IMCP).
- Airport A chooses the profit maximizing landing fee whilst airport H follows marginal cost pricing (APMAX).
- Airport H chooses the profit maximizing landing fee whilst airport A follows marginal cost pricing (HPMAX).
- Each airport maximizes its own profits by selecting the corresponding landing fee (AHPMAX).

Table 3
Calibrated values.

	a_l	a_i	a_{cl}	a_{ci}	c	λ
Málaga-Madrid-Paris	228.9	334.3	461.8	412.6	45.2	0.302
Valencia-Madrid-London	295.6	462.7	616.9	543.9	17.6	0.136

- The landing fees are obtained from joint profit maximization (JPMAX).

3.2. Discussion of the results

3.2.1. The case of central values of λ: Málaga-Madrid-Paris

Table 4 reports the results under each one of these regimes considering the network Málaga-Madrid-Paris. We consider the IMCP scenario as the reference case for computing percentage variations. Therefore, for most of the variables, we will include small font italics figures to indicate the relative variation.

Note that any policy that departs from infrastructure marginal cost pricing provokes reductions in domestic and international prices, and even larger reductions in the local and international flights (except for the values of the international leg under APMAX). If only airport A is follows profit maximization, the landing fee increases by 43%. This

Table 4
Calibration results for Malaga-Madrid-Paris.

Málaga – Madrid – Paris (Charles de Gaulle)					
	IMCP	APMAX	HPMAX	AHPMAX	JPMAX
Local price	168.6	159.3	158.9	153.2	156.1
	1	0.94	0.94	0.91	0.93
International price	151.7	151.4	142.6	144	145.1
	1	1.00	0.94	0.95	0.96
# Local flights	18	9	11.8	6.5	8.7
	1	0.50	0.66	0.36	0.48
# Intern. flights per airline	9.5	9.4	3.4	4.4	5.2
	1	0.99	0.35	0.46	0.55
Local passengers A to H	555	446	491	424	450
	1	0.80	0.88	0.76	0.81
Connecting passengers A to H H	1294	1290	1252	1256	1264
	1	1.00	0.97	0.97	0.98
Intern. passengers H to B	1440	1438	1338	1354	1368
	1	1.00	0.93	0.94	0.95
Connecting passengers H to B	960	954	918	922	928
	1	0.99	0.96	0.96	0.97
Landing fee airport A	1300	1854	1300	1698	1607
	1	1.43	1.00	1.31	1.24
Landing fee airport H	1300	1300	1617	1561	1522
	1	1.00	1.24	1.20	1.17
Profits local airline	250502	242886	236471	234844	236909
	1	0.97	0.94	0.94	0.95
Profits intern. airline	148549	148172	148863	148419	148379
	1	1.00	1.00	1.00	1.00
Profits airport A	0	4986	0	2567	2671
Profits airport H	0	0	5872	3970	4240
CS of local pass. A to H	36957	23890	28902	21592	24265
	1	0.65	0.78	0.58	0.66
CS of intern. pass. H to B	159131	159058	137248	140970	143599
	1	1.00	0.86	0.89	0.90
CS of connect. pass. A to H	123230	122392	115398	116186	117264
	1	0.99	0.94	0.94	0.95
CS of connect. pass. H to B	67721	67100	61947	62525	63317
	1	0.99	0.91	0.92	0.93
Total CS	387039	372440	343495	341273	348445
	1	0.96	0.89	0.88	0.90
Total welfare	934639	916656	883564	879492	889023
	1	0.98	0.95	0.94	0.95

[24] Recent research by Landau et al. (2016) measuring passenger air value of time by trip component suggests that the time spent in connection location is perceived as highly costly relative to that spent in a non-stop flight.

[25] The data are obtained from official statistics by AENA (the Spanish airport infrastructure manager) as well as from information provided by the operator and only marginal fees are considered. Regarding airports, AENA does not disaggregate information by airport type, then the marginal cost of providing the airport services is taken the same for both the hub and the spoke airports.

[26] The local routes considered had one airline supplying 85% of total traffic, and two airlines covered around 80% of total traffic in the international routes considered.

[27] That is, a_l, a_i and two base willingness to pay for each of the two types of connecting passengers described above; a_{cl} and a_{ci} for those in the local and international legs, respectively.

produces a 50% decrease in the number of local flights and, subsequently a 6% decrease in local price. Since the valuation of flight frequencies is not too asymmetric, which means that it will qualitatively comply with the comparative statics obtained from area III in the model, the prices and number of flights in the international leg are barely reduced. Then changes basically happen in the local market where traffic decreases by 20% and consumer surplus falls by 35%. As expected, there is a 3% decrease in the profits for the local airline.[28] Although airport profits is now positive, it does not suffice to offset the negative effects on local consumer surplus and local airline profits, ending up in a 2% decrease in total welfare.

Matters change when profit maximization behavior of airport H is considered (HPMAX). The landing fee increases by 24%, which leads to a reduction in the number of international flights. Given that the number of international and local flights are strategic complements, the number of local flights also decreases. Such a decrease in service quality reduces both local and international prices by 6%. Traffic decreases in the three markets, specially in the local market. Profits for the local airlines decrease by 6%, whereas those of the international airlines remain the same, mainly because they adjust down the costs due to fewer flights. Now, in contrast to the above scenario, consumer surplus decreases in all three markets. In sum, HPMAX imposes a 5% fall in welfare.

The fourth column presents the results when airports A and H are independently maximizing their own profits (AHPMAX). It must be noted that the sum of landing fees are the highest for the local airline. This inevitably produces a substantial decrease in the number or local flights (about one third of the flights relative to the benchmark case). Local prices fall by 9% and local traffic notably reduces by 24%. The welfare decrease of 6% is mainly attributed to the reduction in consumer surplus for passengers in the local market. The results when landing fees follow from joint profit maximization are displayed in the fifth column. The internalization of competition among airports makes it such that the landing fee for the hub airport is increased to a larger extent (by 24%) with respect to the fee at the spoke airport (by 17%). The reason why the increase in landing fees is the lowest when the spoke and hub airports maximize profits jointly is the classical Cournot effect. Since both airports are complements the internalization in competition results in a lower sum of fees. The fall in the number of local flights is mitigated since now the sum of the fees is lower than in the AHPMAX scenario. Consequently, local prices only fall by 7% and local traffic by 19%; the welfare decrease is now 5%.

Comparing all the regimes there are some comments to highlight. Firstly, changing the management regime of only the spoke airport is the closest option in terms of social welfare relative to the benchmark case. Secondly, airlines operating at the international market as well as international and connecting passengers are the less affected agents in any scenario (even when only the hub airport sets profit maximizing fees).

3.2.2. The case of low values of λ: Valencia-Madrid-London

In Table 5 the simulation results for a network with less traffic in the international leg, Valencia-Madrid-London, are shown. Recall that the parameter calibration now implies other values for the a's and most importantly for λ. In particular, passenger valuation for connecting time is fairly important. Low values of λ change the strategic nature between the number of flights. Thus an increase in the landing fee f_A under APMAX by 13% entails a decrease in local flights, which is reinforced due to strategic substitutability by the increase in international flights by 29%, ending up with 50% less local flights. Traffic in the international leg and connecting traffic increase resulting in gains in consumer surplus of 4% and 8% respectively. Adding up the increase in the profit of international airlines finally implies a welfare increase by 1%. Looking at columns three, four and five, one can observe that departing from IMCP entails smaller increases in landing fees relative to the values in Table 4. This typically results in smaller reductions in the number of international flights, which is sensible in markets where passengers value connecting time a lot. In fact, consumer surplus for connecting passengers in the JPMAX scenario increases by 2% and 3% in the local and international leg, respectively; while consumer surplus hardly varies for connecting passengers in the AHPMAX scenario. Note that the worst scenario for consumers is the HPMAX regime, given that this is the scenario where international flights fall to a higher extent. Besides, the welfare losses are lower than those obtained in Table 4. The findings in Tables 4 and 5 suggest that governments should not allow profit maximization behavior only at the hub airport.

Finally, one may argue that a code-sharing agreement or interline

Table 5
Calibration results for Valencia-Madrid-London.

Valencia – Madrid – London (Heathrow)					
	IMCP	APMAX	HPMAX	AHPMAX	JPMAX
Local price	210.8	203.7	201.5	197.1	200.5
	1	0.97	0.96	0.94	0.95
International price	197.4	202.7	188.4	192.6	197.4
	1	1.03	0.95	0.98	1.00
# Local flights	16	8	10.6	5.5	6.9
	1	0.50	0.66	0.34	0.43
# Intern. flights per airline	9	11.6	3.2	5.3	8.4
	1	1.29	0.36	0.59	0.93
Local passengers A to H	425	358	396	346	354
	1	0.84	0.93	0.81	0.83
Connecting passengers A to H H	1014	1042	988	1010	1024
	1	1.03	0.97	1.00	1.01
Intern. passengers H to B	1080	1100	1022	1040	1070
	1	1.02	0.95	0.96	0.99
Connecting passengers H to B	720	748	694	714	730
	1	1.04	0.96	0.99	1.01
Landing fee airport A	1300	1474.7	1300	1419.6	1442.6
	1	1.13	1.00	1.09	1.11
Landing fee airport H	1300	1300	1349	1347	1323
	1	1.00	1.04	1.04	1.02
Profits local airline	259651	262005	249118	251638	256662
	1	1.01	0.96	0.97	0.99
Profits intern. airline	148351	149013	151642	151885	150431
	1	1.00	1.02	1.02	1.01
Profits airport A	0	1398	0	653	984
Profits airport H	0	0	841	748	557
CS of local pass. A to H	33350	22601	27663	21081	22052
	1	0.68	0.83	0.63	0.66
CS of intern. pass. H to B	164104	170484	147373	152417	161097
	1	1.04	0.90	0.93	0.98
CS of connect. pass. A to H	127528	134559	121210	126228	130159
	1	1.06	0.95	0.99	1.02
CS of connect. pass. H to B	64171	69186	59712	63250	66041
	1	1.08	0.93	0.99	1.03
Total CS	389153	396830	355958	362976	379349
	1	1.02	0.91	0.93	0.97
Total welfare	945506	958259	909201	919785	938414
	1	1.01	0.96	0.97	0.99

[28] It should be remarked that the reported profits in the Tables are overstated since they do not include actual costs not depending in the number of flights. According to GRA Inc. (2016), direct or variable costs, depending on the number of flights, are about 52 percent of total costs for major passenger air carriers and about 43 percent of total costs for all-cargo air carriers. Variable costs are categorized as fuel and oil, maintenance, and crew. Fixed costs are categorized as depreciation, rentals, insurance, and other. In any case the profits rankings remain unchanged.

ticket booking are a common practice. We have rerun the numerical simulations so that the A-B trip has its own price due to an agreement between the local airline and one of the international airlines, although such an agreement was not in force at the considered route and the year analyzed.[29] The consideration of this possibility delivers qualitatively similar results to those reported at the tables. Thus, the landing fees experience similar increases and the welfare ordering remains.

4. Conclusions

The large increase in passenger traffic in the recent years has prompted both a rapid growth in airport capacities and also some changes in airport management. Airports are providers of services to airlines, and then any changes in aeronautical charges will affect the profitability of the airline industry and, consequently, will induce strategic responses by airlines. Competition in the airline industry includes several variables, e.g. prices and number of flights, which are set considering the demand complementarities between local and international routes and therefore their levels depend on the leg of the air transport network considered. The main goal of our paper is to analyze the effects of changes in airport management that affect landing fees levels on how airlines compete in a given air transport network. This is carried out by paying special attention to the role played by the asymmetric valuation of the number of flights made by connecting passengers. The analysis is undertaken in two parts. Firstly, a theoretical model that incorporates the distinctive features of the airline industry mentioned above is solved. Next, our calibration analysis considers two air transport networks, Málaga-Madrid-Paris Charles de Gaulle and Valencia-Madrid-London Heathrow, to provide examples with different traffic intensities and different relative asymmetric valuations of connecting passengers on the flight frequencies both at the origin and at the hub airports. A general comment is that landing fees increase for any departure from the benchmark scenario and network considered, noting that the largest increase observed in a given airport occurs when only that airport is not following the infrastructure cost marginal pricing rule. Besides, provided both domestic airports choose profit maximizing landing fees, those happen to be higher when granted to two independent managers. We also find that total consumer surplus typically falls, although there are differences across consumer types, with consumers in the local market suffering the most while connecting passengers being the less affected ones.

Some relevant policy implications can be drawn from our analysis. Firstly, should governments decide to allow only a few airports in a network to set profit maximizing landing fees, it is preferable to just allow the spoke airports to do so, while the hub airport should keep following a marginal cost pricing rule. Additionally, when frequencies in the hub are highly valued by connecting passengers, profit-maximizing charges only at the spoke airport will likely induce a welfare increase. Secondly, in case governments opted for allowing all the airports in a network to behave as profit maximizers, welfare losses would be lower when airports set joint profit maximizing landing fees instead of landing fees that maximize the profit of each individual airport. Finally, since airports are forming a network, the position of the airport that is allowed to set profit maximizing landing fees crucially matters. Although our analysis has been conducted for a particular market structure, the methodology and assumptions might be easily accommodated to other more realistic settings. Therefore, a policy decision with a local or regional origin has global implications; these effects should not be disregarded in the design of sound policy reforms.

To be fair, a per-flight charge may not reflect actual practice. A group of infrastructure charges are related to passengers; in fact, airports get an important share of aeronautical revenues from per-passenger based charges. Positive per passenger fees at each airport will affect both the airfares and the number of flights chosen by the three airlines operating in the network. First note that their direct effect is to increase airfares of the airlines affected since marginal costs of providing the service have increased. For the local airline, only the spoke and the hub airport fees directly affect its costs, while for international airlines the hub and the abroad airport fees do. However, per passenger fees also affect the marginal revenues the airlines have for providing one more flight, in fact they shift those marginal revenues inwards since airfare margins are now lower as compared to those with no per passenger fees. The result is that airlines equate the marginal cost of providing flights at a lower number flights. Once again, the weight connecting passengers give to the local flights is relevant, since when this weight is in area III in Fig. 2, then the number of flights behave as strategic complements and therefore, the adjustment triggered by positive per passengers fees is reinforced, thus ending in a situation with higher airfares and lower flights at the new equilibrium. The result of higher airfares is reached because the initial direct effect is larger, in absolute terms, than the indirect one which results from a decrease in flights, which in turn implies a reduction in the willingness to pay. Finally, the introduction of per passenger fees will reduce the per-flight fees when airports maximize profits only under certain conditions. The consideration of per passenger fees, as well the possibility of airport concession services and complementarity with other modes, such as high-speed rail services, are elements that merit attention and would be helpful in further understanding airport-airline interactions.

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Appendix

A. Comparative statics

Third stage comparative statics

After taking the total differentiation of the FOC's for equilibrium prices, solving the dp_l^*, dp_1^* and dp_2^* and noting that i) $\frac{d\alpha_l}{dn_l} = \frac{d\alpha_{ij}}{dn_j} = \nu$, for $j = 1, 2$; ii) $\frac{d\alpha_l}{dn_k} = \frac{d\alpha_{ij}}{dn_k} = \frac{d\alpha_{cj}}{dn_k} = 0$ for $j, k = 1, 2$ and $j \neq k$; iii) $\frac{d\alpha_{cj}}{dn_j} = \nu(1-\lambda)$ or $j = 1, 2$ and iv) $\frac{d\alpha_{cj}}{dn_l} = \nu\lambda$ or $j = 1, 2$, the following derivatives of equilibrium prices with respect to the number of flights are obtained:

[29] The allied carriers can internalize the competition when setting a price for the connecting trip; that price is influenced by the number of flights chosen by the partners. Moreover, the price for the local flights can be chosen to make the alternative combination with the non-allied carrier less attractive, which is again influenced by the corresponding flight frequencies. The overall effect is not straightforward. In the end there is an increased number of flights leading to notable gains in passenger surplus. Besides, given such internalization, the case that changes in spoke airports pricing affect all the agents' subsequent decisions is even stronger.

$$\frac{dp_l^*}{dn_l} = v\left(\frac{\partial p_l^*}{\partial \alpha_l} + \lambda\frac{\partial p_l^*}{\partial \alpha_{c1}} + \lambda\frac{\partial p_l^*}{\partial \alpha_{c2}}\right) > 0$$

$$\frac{dp_l^*}{dn_j} = v\left(\frac{\partial p_l^*}{\partial \alpha_{ij}} + (1-\lambda)\frac{\partial p_l^*}{\partial \alpha_{cj}}\right) > 0,\ \text{if } \lambda < \frac{2}{3-d}\ \text{for } j = 1,2.$$

$$\frac{dp_j^*}{dn_l} = v\left(\frac{\partial p_j^*}{\partial \alpha_l} + \lambda\frac{\partial p_j^*}{\partial \alpha_{c1}} + \lambda\frac{\partial p_j^*}{\partial \alpha_{c2}}\right) > 0,\ \text{if } \lambda > \frac{(1+d)}{2(2+d)}\ \text{for } j = 1,2.$$

$$\frac{dp_j^*}{dn_j} = v\left(\frac{\partial p_j^*}{\partial \alpha_{ij}} + (1-\lambda)\frac{\partial p_j^*}{\partial \alpha_{cj}}\right) > 0,\ \text{for } j = 1,2.$$

$$\frac{dp_j^*}{dn_k} = v\left(\frac{\partial p_j^*}{\partial \alpha_{ik}} + (1-\lambda)\frac{\partial p_j^*}{\partial \alpha_{ck}}\right) < 0,\ \text{if } \lambda < \min\left\{\frac{2\left(1+11d+4d^2\right)}{3+10d+3d^2}, 1\right\}, \text{for } j,k = 1,2\ \text{ and } j \neq k.$$

where it is useful to note that:

i) $\frac{\partial p_l^*}{\partial \alpha_l}, \frac{\partial p_l^*}{\partial \alpha_{cj}}, \frac{\partial p_j^*}{\partial \alpha_{ij}}$ and $\frac{\partial p_j^*}{\partial \alpha_{cj}}$ for $j = 1,2$ are all positive;

ii) $\frac{\partial p_l^*}{\partial \alpha_{ij}}, \frac{\partial p_j^*}{\partial \alpha_l}$ and $\frac{\partial p_j^*}{\partial \alpha_{ck}}$ for $j,k = 1,2$ and $j \neq k$ are all negative, and finally,

iii) $\frac{\partial p_j^*}{\partial \alpha_{ik}}$ for $j,k = 1,2$ and $j \neq k$ are negative if and only if $d > \frac{\sqrt{41}-6}{5} \simeq 0.080$.

iv) $\frac{\partial p_l^*}{\partial \alpha_l} > -\frac{\partial p_l^*}{\partial \alpha_{ij}}; \frac{\partial p_l^*}{\partial \alpha_l} > \frac{\partial p_l^*}{\partial \alpha_{cj}}$ and $\frac{\partial p_l^*}{\partial \alpha_{cj}} > -\frac{\partial p_l^*}{\partial \alpha_{ij}}$ for $j = 1,2$

v) $\frac{\partial p_j^*}{\partial \alpha_{ij}} > \frac{\partial p_j^*}{\partial \alpha_{cj}}, \frac{\partial p_j^*}{\partial \alpha_{ij}} > -\frac{\partial p_j^*}{\partial \alpha_{ik}}; \frac{\partial p_j^*}{\partial \alpha_{ij}} > -\frac{\partial p_j^*}{\partial \alpha_{ck}}$ and $\frac{\partial p_j^*}{\partial \alpha_{ij}} > -\frac{\partial p_j^*}{\partial \alpha_d}$ for $j,k = 1,2$ and $j \neq k$

vi) $-\frac{\partial p_j^*}{\partial \alpha_{ck}} > -\frac{\partial p_j^*}{\partial \alpha_{ik}}$ for $j,k = 1,2$ and $j \neq k$

The use of the above information allows as to state Result 1 in the text.

Second stage comparative statics

Comparative statics of the equilibrium number of flights with respect to the airport fees follows from total differentiation of the first order conditions, which after solving for dn_l^*, dn_1^* and dn_2^* reads, in matrix form, as follows,

$$\begin{pmatrix} dn_l^* \\ dn_1^* \\ dn_2^* \end{pmatrix} = -A^{-1}B\begin{pmatrix} df_A \\ df_H \\ df_B \end{pmatrix}$$

where matrices A and B are respectively,

$$A = \begin{pmatrix} \sigma_{ll} & \sigma_{l1} & \sigma_{l2} \\ \sigma_{1l} & \sigma_{11} & \sigma_{12} \\ \sigma_{2l} & \sigma_{21} & \sigma_{22} \end{pmatrix}; B = \begin{pmatrix} \frac{\partial^2 \pi_l}{\partial n_l \partial f_A} & \frac{\partial^2 \pi_l}{\partial n_l \partial f_H} & \frac{\partial^2 \pi_l}{\partial n_l \partial f_B} \\ \frac{\partial^2 \pi_1}{\partial n_1 \partial f_A} & \frac{\partial^2 \pi_1}{\partial n_1 \partial f_H} & \frac{\partial^2 \pi_1}{\partial n_1 \partial f_B} \\ \frac{\partial^2 \pi_2}{\partial n_2 \partial f_A} & \frac{\partial^2 \pi_2}{\partial n_2 \partial f_H} & \frac{\partial^2 \pi_2}{\partial n_2 \partial f_B} \end{pmatrix}$$

where we use the notation σ_{kl} to denote the second derivative of π_k with respect to n_k and to n_l. Notice that the symmetry in the model implies that a) $\sigma_{11} = \sigma_{22} \equiv \sigma_{jj}$, b) $\sigma_{12} = \sigma_{21} \equiv \sigma_{jk}$, c) $\sigma_{l1} = \sigma_{l2} \equiv \sigma_{lj}$, and d) $\sigma_{1l} = \sigma_{2l} \equiv \sigma_{jl}$.

-Provided SOC's we know that $\sigma_{jj} < 0$ and $\sigma_{ll} < 0$.

-Regarding cross effects.

i) Between the international airlines we have that

$\sigma_{jk} = \left(\frac{4}{1-d^2}\right)\left(\frac{dp_j^*}{dn_j}\right)\left(\frac{dp_j^*}{dn_k^*}\right)$ for all $j,k = 1,2$ and $j \neq k$ which are negative if $\left(\frac{dp_j^*}{dn_k^*}\right)<0$.

Notice that for the negative sign it is sufficient that $d > 0.08$.

ii) Similarly, among the local and the international airlines we have that $\sigma_{jl} = \left(\frac{4}{1-d^2}\right)\left(\frac{dp_j^*}{dn_j}\right)\left(\frac{dp_j^*}{dn_l^*}\right)$ and $\sigma_{lj} = \left(\frac{2(3+d)}{1+d}\right)\left(\frac{dp_l^*}{dn_l}\right)\left(\frac{dp_l^*}{dn_j^*}\right)$ for all $j = 1,2$ which are positive if $\left(\frac{dp_j^*}{dn_l^*}\right)>0$ and if $\left(\frac{dp_l^*}{dn_j^*}\right)>0$, respectively.

Therefore, the number of flights of firms j and l behave as strategic complements if and only if $\lambda \in \left[\frac{1+d}{2(2+d)}, \frac{2}{3-d}\right]$.

-Finally, $\det(A) = (\sigma_{jj} - \sigma_{jk})(\sigma_{ll}(\sigma_{jj} + \sigma_{jk}) - 2\sigma_{lj}\sigma_{jl})$, which is negative meaning that the Nash equilibrium is stable. More precisely, the first term is negative (since $|\sigma_{jj}| > |\sigma_{jk}|$) while the second one, denoted by T, is positive.

The above information is summarized in the following result:

Result 6. *The strategic relationship among the number of flights depends on the degree of substitutability between international airlines and on the weight passengers give to the schedule delay in the spoke airport as follows:*

i) If the weight passengers give to the schedule delay is large enough, that is, if $\min\left\{\frac{2(1+11d+4d^2)}{3+10d+3d^2}, 1\right\} < \lambda < 1$ then

i.a) The number of international flights of each international airline behave as strategic complements;
i.b) The number of local flights and the number of international flights are strategic substitutes; and
i.c) The number of international flights and the number of local flights are strategic complements.

ii) If $\frac{2}{3-d} < \lambda < \min\left\{\frac{2(1+11d+4d^2)}{3+10d+3d^2}, 1\right\}$ then

ii.a) The number of international flights of each international airline behave as strategic substitutes;
ii.b) The number of local flights and the number of international flights are strategic substitutes; and
ii.c) The number of international flights and the number of local flights are strategic complements.

iii) If $\frac{1+d}{2(2+d)} < \lambda < \frac{2}{3-d}$ then

iii.a) The number of international flights of each international airline behave as strategic substitutes;
iii.b) The number of local flights and the number of international flights are strategic complements; and
iii.c) The number of international flights and the number of domestic flights are strategic complements.

iv) If $0 < \lambda < \frac{1+d}{2(2+d)}$.

iv.a) The number of international flights of each international airline behave as strategic substitutes;
iv.b) The number of local flights and the number of international flights are strategic complements; and
iv.c) The number of international flights and the number of local flights are strategic substitutes.

Note that Result 2 in the text structures the information provided in Result A1 to highlight the strategic relationships arising in area III of Fig. 2.

We next report the expressions for the second derivatives in B:

$$\frac{\partial^2 \pi_l}{\partial n_l \partial f_A} = \frac{\partial^2 \pi_l}{\partial n_l \partial f_H} = -1; \frac{\partial^2 \pi_l}{\partial n_l \partial f_B} = 0;$$

$$\frac{\partial^2 \pi_j}{\partial n_j \partial f_B} = \frac{\partial^2 \pi_j}{\partial n_j \partial f_H} = -1; \frac{\partial^2 \pi_j}{\partial n_j \partial f_A} = 0.$$

Finally, the expressions for the comparative statics which result from the $-A^{-1}B$ operation are reported. First, regarding those of the local airline,

$$\frac{dn_l^*}{df_A} = \frac{\sigma_{jj} + \sigma_{jk}}{T} < 0;$$

$$\frac{dn_l^*}{df_H} = \frac{\sigma_{jj} + \sigma_{jk} - 2\sigma_{lj}}{T} < 0 \text{ if } \sigma_{lj} > 0 \text{ that is for } \lambda < \frac{2}{3-d};$$

$$\frac{dn_l^*}{df_B} = \frac{-2\sigma_{lj}}{T} < 0 \text{ iff } \sigma_{lj} > 0 .$$

and, then those for international airlines,

$$\frac{dn_j^*}{df_A} = \frac{-\sigma_{jl}}{T} < 0 \text{ iff } \sigma_{jl} > 0 \text{ that is iff } \lambda > \frac{1+d}{2(2+d)};$$

$$\frac{dn_j^*}{df_H} = \frac{\sigma_{ll} - \sigma_{jl}}{T} < 0 \text{ if } \sigma_{jl} > 0$$

$$\frac{dn_j^*}{df_B} = \frac{\sigma_{ll}}{T} < 0.$$

Notice that the information provided above is used to state Result 3 in the text.

First stage analysis

1) The domestic airline's profits are given by

$$\pi_l^* = \left(\frac{3+d}{1+d}\right)(p_l^*)^2 - cn_l^2 - (f_A + f_H)n_l$$

Then, the effect of a variation in f_A is

$$\frac{d\pi_l^*}{df_A} = 2\left(\frac{3+d}{1+d}\right)p_l^*\left(\frac{dp_l^*}{dn_1}\frac{dn_1^*}{df_A} + \frac{dp_l^*}{dn_2}\frac{dn_2^*}{df_A} + \frac{dp_l^*}{dn_l}\frac{dn_l^*}{df_A}\right) - 2cn_l\frac{dn_l^*}{df_A} - (f_A + f_H)\frac{dn_l^*}{df_A} - n_l^*$$

And by the Envelope Theorem we know that

$$2\left(\frac{3+d}{1+d}\right)p_l^*\frac{dp_l^*}{dn_l} - 2cn_l^* - (f_A + f_H) = 0$$

Therefore,

$$\frac{d\pi_l^*}{df_A} = 2\left(\frac{3+d}{1+d}\right)p_l^*\left(\underbrace{\frac{dp_l^*}{dn_1}\frac{dn_1^*}{df_A}}_{se_1} + \underbrace{\frac{dp_l^*}{dn_2}\frac{dn_2^*}{df_A}}_{se_2}\right) - n_l^*$$

Which is the expression (19) in the text. Similarly a variation in f_H and in f_B affects the domestic airline's profits as appears in expressions f_B(20) and (21).

2) The international airline's profits are given by,

$$\pi_j^* = \left(\frac{2}{1-d^2}\right)\left(p_j^*\right)^2 - cn_j^2 - (f_B + f_H)n_j$$

Applying the same reasoning as in the case of a domestic airline, a variation in f_A, f_H and is obtained and provided in expressions (23), (24) and (25) in the main text.

B. Condition for Non-negative equilibrium number of passengers.

To provide a condition that ensures positive demands for local, international and connecting services at equilibrium, consider first the equilibrium number of flights, n_l^* and $n_1^* = n_2^* = n^*$. Since the equilibrium is symmetric in the per airline international number of flights, then equilibrium prices, $p_1^* = p_2^* = p^*$ and $s_1^* = s_2^* = s^*$; and willingness to pay, $\alpha_{i1} = \alpha_{i2} = a + vn^*$ and $\alpha_{c1} = \alpha_{c2} = 2a + v(\lambda n_l^* + (1-\lambda)n^*)$. We need to ensure that demand functions in (1) to (4) are positive at equilibrium. After substituting the equilibrium expressions in equations (1)–(4), three conditions are required:

i) Equilibrium local demand is positive iff

$$a > p_l^* - vn_l^*$$

ii) Equilibrium international demand is positive iff

$$a > p^* - vn^*$$

iii) Equilibrium connecting demand is positive iff

$$2a > s^* - v\left(\lambda n_l^* + (1-\lambda)n^*\right)$$

Note that by adding up conditions i) and ii), the following is obtained:

$$2a > s^* - v\left(\lambda n_l^* + (1-\lambda)n^*\right) > p_l^* - vn_l^* + p^* - vn^*$$

Therefore, if condition iii) holds then both i) and ii) also hold. Thus, no market is left unserved in the provided network. After some algebra the condition boils down to the next expression,

$$a > \frac{2(1+d)(2+d)v\delta_1(d)^2\left((5+2d+d^2)f_H + 2(2+d)\varphi_1(\lambda)f_B + (3-d)\varphi_3(\lambda)f_A\right) - v^3\delta_1(d)(\varphi_6(\lambda)f_H + 2(1+d)(2+d)(3+d)\varphi_1(\lambda)\varphi_2(\lambda)f_B + \varphi_3(\lambda)\varphi_4(\lambda)f_A)}{4(1+d)(2+d)\left(17+4d-d^2\right)\delta_1(d)^2c^2 - 2v^2\varphi_7(\lambda)\delta_1(d)c + 2v^4(3+d)\varphi_2(\lambda)\varphi_4(\lambda)}$$

where,

$$\delta_1(d) = 11 - d - 2d^2 > 0, \text{ for all } d.$$

$$\varphi_1(\lambda) = 2 - (3-d)\lambda > 0, \text{ for all } \lambda < \frac{2}{3-d}.$$

$$\varphi_2(\lambda) = 2 + d - d^2 + (3-d)\lambda > 0, \text{ for all } \lambda.$$

$$\varphi_3(\lambda) = -(1+d) + 2(2+d)\lambda > 0, \text{ for all } \lambda > \frac{1+d}{2(2+d)}.$$

$$\varphi_4(\lambda) = 42 + 18d - 20d^2 - 8d^3 - \left(19 + 10d - 9d^2 - 4d^3\right)\lambda > 0, \text{ for all } \lambda.$$

$$\varphi_5(\lambda) = 2\left(1 + 11d + 4d^2\right) - \left(3 + 10d + 3d^2\right)\lambda.$$

$$\varphi_6(\lambda) = 2(1+d)\left(3 + 23d + 12d^2 - 4d^3 - 2d^4\right) + \left(187 + 149d - 61d^2 - 45d^3 - 4d^5 - 2d^6\right)\lambda$$
$$-2(2+d)\left(46 + 28d - 21d^2 - 6d^3 + d^4\right)\lambda^2.$$

$$\varphi_7(\lambda) = 2(3+d)\left(41 + 45d - 3d^2 - 17d^3 - 3d^4 + d^5\right) + \left(219 + 197d - 57d^2 - 43d^3 + 8d^4 - 2d^5 - 2d^6\right)\lambda$$
$$-2(2+d)\left(46 + 28d - 21d^2 - 6d^3 + d^4\right)\lambda^2.$$

References

Aravena, O., Basso, L., Figueroa, N., 2019. Effects of asymmetric information on airport congestion management mechanisms. Int. J. Ind. Organ. 62, 4–27.

Basso, L., Zhang, A., 2007a. An interpretative survey of analytical models of airport pricing. In: Lee, D. (Ed.), Advances in Airline Economics, vol 2. Elsevier, pp. 89–124.

Basso, L., Zhang, A., 2007b. Congestible facility rivalry in vertical structures. J. Urban Econ. 61, 218–237.

Basso, L., 2008. Airport deregulation: effects on pricing and capacity. Int. J. Ind. Organ. 26, 1015–1031.

Bel, G., Fageda, X., 2010. Privatization, regulation and airport pricing: an empirical analysis for Europe. J. Regul. Econ. 37, 142–161.

Benoot, W., Brueckner, J., Proost, S., 2013. Intercontinental-airport regulation. Transp. Res. Part B 52, 56–72.

Bilotkach, V., 2005. Price competition between international airline alliances. J. Transp. Econ. Policy 39, 167–189.

Bilotkach, V., Clougherty, J.A., Mueller, J., Zhang, A., 2012. Regulation, privatization and aeronautical charges : panel data evidence from European airports. J. Regul. Econ. 42, 73–94.

Brons, M., Pels, E., Nijkamp, P., Rietveld, P., 2002. Price elasticities of demand for passenger air travel: a meta-analysis. J. Air Transp. Manag. 8 (3), 165–175.

Brueckner, J.K., 2002. Airport congestion when carriers have market power. Am. Econ. Rev. 92 (5), 1357–1375.

Brueckner, J.K., 2004. Network structure and airline scheduling. J. Ind. Econ. 52 (2), 291–312.

Brueckner, J.K., 2009. Price vs. quantity-based approaches to airport congestion management. J. Public Econ. 93 (5–6), 681–690.

Brueckner, J.K., Flores-Fillol, R., 2018. Airline alliances and service quality. Paper presented at the XXXIII Jornadas de Economia Industrial. UB, Barcelona.

Brueckner, J., Zhang, A., 2001. A model of scheduling in airline networks: how a hub-and-spoke system affects flight frequency, fares and welfare. J. Transp. Econ. Policy 35 (2), 195–222.

Czerny, A.I., 2009. Code-sharing, price discrimination and welfare losses. J. Transp. Econ. Policy 43 (2), 193–212.

Czerny, A.I., Höffler, F., Mun, S., 2014. Hub port competition and welfare effects of strategic privatization. Econ. Transp. 3, 211–220.

Czerny, A.I., Zhang, A., 2015. How to mix per-passenger and per-flight based airport charges. Transp. Res. Part A 71, 77–95.

D'Alfonso, T., Nastasi, A., 2014. Airport–Airline interaction: some food for thought. Transp. Rev. 34 (6), 730–748.

Daniel, J.I., 1995. Congestion pricing and capacity of large hub airports: a bottleneck model with stochastic queues. Econometrica 63 (2), 327–370.

De Borger, B., Van Dender, K., 2006. Prices, capacities, and service levels in a congestible Bertrand duopoly. J. Urban Econ. 60, 264–283.

Dixit, A., 1979. A model of duopoly suggesting a theory of entry barriers. Bell J. Econ. 10, 20–32.

Economides, N., Salop, S., 1992. Competition and integration among complements, and network market structure. J. Ind. Econ. 40, 105–123.

Fu, X., Oum, T.H., Yan, J., 2014. An analysis of travel demand in Japan's intercity market: empirical estimation and policy simulation. J. Transp. Econ. Policy 48 (1), 97–113.

Flores-Fillol, R., 2010. Congested hubs. Transportation Research Part B: Methodological 44 (3), 358–370.

Flores-Fillol, R., Moner-Colonques, R., 2007. Strategic formation of airline alliances. J. Transp. Econ. Policy 41 (3), 427–449.

Gabszewicz, J., Sonnac, N., Wauthy, X., 2001. On price competition with complementary goods. Econ. Lett. 70 (3), 431–437.

Gillen, D., 2011. The evolution of airport ownership and governance. J. Air Transp. Manag. 17 (1), 3–13.

González-Savignat, M., 2004. Competition in air transport. J. Transp. Econ. Policy 38 (1), 77–107.

GRA, Incorporated, 2016. Economic Values for FAA Investment and Regulatory Decisions: a Guide, Report Prepared for FAA Office of Aviation Policy and Plans, U.S. Federal Aviation Administration Washington, DC 2059.

Graham, A., 2014. Managing Airports: an International Perspective, fourth ed. Routledge.

Hackner, J., 2000. A note on price and quantity competition in differentiated oligopolies. J. Econ. Theory 93 (2), 233–239.

Hanlom, P., 2007. Global airlines: competition in a transnational industry. Butterworth-Heinemann Elsevier.

Haskel, J., Iozzi, A., Valletti, T., 2013. Market structure, countervailing power and price discrimination: the case of airports. J. Urban Econ. 74, 12–26.

Heimer, O., Shy, O., 2006. Code-sharing agreements, frequency of flights and profits under parallel operation. In: Lee, D. (Ed.), Advances in Airline Economics, vol 1. Elsevier, Amsterdam, pp. 163–181.

IATA report, 2007. Estimating Air Travel Demand Elasticities: Final Report, Prepared by InterVISTAS Consulting Inc.

Kawasaki, A., 2008. Network effects, heterogeneous time value and network formation in the airline market. Reg. Sci. Urban Econ. 38 (4), 388–403.

Landau, S., Gosling, G.D., Small, K., Adler, T., 2016. Measuring air carrier passengers' values of time by trip component. Transp. Res. Rec.: J. Transp. Res. Board 2569, 24–31.

Lin, M.H., Mantin, B., 2015. Airport privatization in international inter-hub and spoke networks. Econ. Transp. 4, 189–199.

Mantin, B., 2012. Airport complementarity: private vs. government ownership and welfare gravitation. Transp. Res. Part B 46 (3), 381–388.

Noruzoliaee, M., Zou, B., Zhang, A., 2015. Airport partial and full privatization in a multi-airport region: focus on pricing and capacity. Transp. Res. Part E 77, 45–60.

Oum, T.H., Zhang, A., Zhang, Y., 1995. Airline network rivalry. Can. J. Econ. 28 (4a), 836–857.

Oum, T.H., Zhang, A., Zhang, Y., 2004. Alternative forms of economic regulation and their efficiency implications for airports. J. Transp. Econ. Policy 28, 217–246.

Oum, T.H., Adler, N., Yu, C., 2006. Privatization, corporatization, ownership forms and their effects on the performance of the world's major airports. J. Air Transp. Manag. 12 (3), 109–121.

Pels, E., Verhoef, E.T., 2004. The economics of airport congestion pricing. J. Urban Econ. 55 (2), 257–277.

Rietveld, P., Brons, M., 2001. Quality of hub-and-spoke networks; the effects of timetable co-ordination on waiting time and rescheduling time. J. Air Transp. Manag. 7 (4), 241–249.

Silva, H.E., Verhoef, E.T., van den Berg, V., 2015. Airline route structure competition and network policy. Transp. Res. Part B Methodol. 67, 320–343.

Tauman, Y., Urbano, A., Watanabe, J., 1997. A model of multiproduct price competition. J. Econ. Theory 77 (2), 377–401.

Van Dender, K., 2007. Determinants of fares and operating revenues at US airports. J. Urban Econ. 62, 317–336.

Zhang, A., Czerny, A.I., 2012. Airports and airlines economics and policy: an interpretive review of recent research. Econ. Transp. 1, 15–34.

Zhang, A., Zhang, Y., 2003. Airport charges and capacity expansion: effects of concession revenues and privatization. J. Urban Econ. 53, 53–75.

Zhang, A., Zhang, Y., 2006. Airport capacity and congestion when carriers have market power. J. Urban Econ. 60, 229–247.