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Airport Competition in Two-sided Markets*

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Abstract

This paper examines the importance of commercial revenue on optimal airport charges in Hotelling type duopoly airports under a two-sided market framework with two complementary services-concession and aeronautical operations. Each airport sets commercial and landing charges and serves a single airline. The airport-airline bundle competes for leisure and business passengers. The setting of landing charges under different regulatory regimes is investigated. We demonstrate that in the leisure travel market, which ignores schedule delay cost, the optimal landing fee is invariant to the regulatory scheme, and concession revenue is determined by an airport's home market size. In the business travel market, the optimal landing charge is smaller if concession revenue is included in setting the landing fee than if it is not included. In the former case, increasing passenger volume does not guarantee increases in airports' aeronautical revenue, and a negative impact may exist if the weight of concession profit out of total profit is small.

Keywords: Airport competition; airport regulation; two-sided markets; landing fee; commercial charge.

JEL classification: L93, D43, L13, C72.

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1 Introduction

In recent years, the previous view that airports were natural monopolies has been changing. Airports are increasingly perceived as business entities that could stimulate the creation of a competing market structure. In fact, as Airport Council International (ACI) World reported, airports are a very competitive market. Airports differ substantially in terms of competitive position and can compete on different elements or in different markets, such as destination markets, locations for an airline base, and connecting traffic, as well as in the non-aviation market. Many cities have multiple airports, making airport competition very common. For example, in flying from London to Paris, a passenger can choose to depart from London City, Heathrow, Stansted, Gatwick, or Luton; and arrive at Paris-Charles de Gaulle or Orly. One can also refer to airport competition in adjacent cities or towns in a broader region. In Europe, approximately 63% of citizens live within two hours of at least two airports. Large metropolitan areas, for example in the USA, including Boston, Chicago, Los Angeles, New York, San Francisco, and Washington D.C., are typically served by several nearby airports that provide flights to common destinations. These airports differ in terms of accessibility, charges, and quality of service.[1] This underscores the need to provide a theoretical framework to explore how airports compete with rivals for overlapping catchment areas.

The issue of choice among multiple airports in metropolitan areas has been addressed in previous studies (Harvey, 1987; Pels et al., 2003; Başar and Bhat, 2004; Hess and Polak, 2006; Ishii et al., 2009; Lian and Rønnevik, 2011). Among those, Pels et al. (2003) investigate both airport and airline competition in a metropolitan area with multiple departure airports and analyzed the effects of changes in accessibility on the airports' and airlines' competitive positions. Ishii et al. (2009) find that access time, frequency, arrival times, delays and airport–airline combinations strongly affect choice of airport in the San Francisco Bay area. Hess and Polak (2006) find that flight frequency and access time are significant variables for choice of airport in the same area. Lian and Rønnevik (2011) discover that travelers avoid using local airports in their vicinity and use more distant airports instead to benefit from lower airfares and more convenient

[1] When two airports have overlapping catchment areas, they can each serve a home area and compete for the passengers in the overlapping area, or a smaller airport can have a subcatchment area within the main catchment area of a larger airport. This paper is interested in the former.

airline services. De Palma et al. (2018) analyze rivalry between two airports that differ in geographical location and departure time, and examine the influence of differentiation in these two sources on airport fees and airline service prices. These studies highlight that understanding airport competition requires taking into account primary determinants of travelers' choice decisions, such as airport access time, flight frequency, and differences in airfare. Our paper extends existing studies on airport competition in such a way that a fixed profit sharing regime can be studied for the airport industry which displays platform features, with heterogeneous consumer groups that have different valuations for flight frequencies. In the same vein as De Palma et al. (2018), we draw on Hotelling (1929) to develop a model that incorporates a vertical airport-airline-consumers framework in a two-airport system characterized by spatial differentiation. In contrast to De Palma et al. (2018), we drop the schedule decision which is a main component in their work and take into account the total frequency. Moreover, the focus of our paper is on the interaction between aeronautical fee and commericial charge, while commercial revenue is considered as exogenouos in their model.

Another building block of our paper is the literature on two-sided market. A clear definition of a two-sided platform is given by Rochet and Tirole (2006), "A market is two-sided if the platform can affect the volume of transactions by charging more to one side of the market and reducing the price paid by the other side by an equal amount; in other words, the price structure matters, and platforms must design it [the price structure] so as to bring both sides on board."[2] The aviation market displays multiple features of a platform with two end users that show high levels of interdependency: passengers and airlines. Airlines court airports that have high passenger volumes, and passengers attach a higher valuation to an airport where they can fly to more destinations or with shorter waiting time.

The two-sided platform nature of airports is studied (Czerny, 2006; Gillen and Mantin, 2014; Ivaldi et al., 2015; Van Dender, 2007; Zhang and Zhang, 1997, 2003; Flores-Fillol et al., 2018), but none of these works has studied the weight of commercial revenue on the optimal platform charges. In our model, airports are not subject to price regulation

[2]For detailed discussions on the general economics of two-sided markets, provided in various degrees of analytical detail, see Evans (2003); Rysman (2009); Eisenmann et al. (2006); Tirole (1988, 2015); Rochet and Tirole (2003, 2006); Armstrong (2006); **?**

and could set prices for the two markets.[3] What is regulated is the extent to which the airport could integrate commercial revenue into total revenue, based on which the airport optimally chooses per-passenger aeronautical charge (landing fee) and concession fee. Realistically, an airport does not dictate price for retail services, which are actually determined by independent retailers. However, the airport affects retail prices via two channels: the concession fee charged to each retailer, and the number of concessions, which could depress or foster competition among the concessionaires. While the second channel in not explicitly modelled in this paper, the manipulation of competition can be alternatively realized by implementing a concession fee. As such, our study introduces a new dimension of analysis in explaining what has been observed in practice.

In comparison to other platforms, airport industry has its own peculiarity related to the one-way complementarity between the demand for aeronautical services (primary good) and non-aviation services (side good). Airport is increasingly perceived as a business entity that deliver both aeronautical services (transport-related) and non-aeronautical services, or retails, such as facilitating ancillary services occurring within terminals and on airport land, including terminal retail, duty-free shops, food and beverages, car parking and rentals (Starkie, 2001; Zhang and Zhang, 2003; Oum et al., 2004). The non-aviation business has become an important income source to airports within the last two decades, accounting for around half of all revenues Graham (2009). Given the two primary outputs (flights and retail services), the airport faces strategic decisions when pricing aeronautical services (charged to airlines) and concession services (charged to passengers). Since commercial services depend crucially on passenger throughput, the demand for aviation services and for concession services are complementary. Gillen and Mantin (2014) find the airport may lower the aeronautical charges to boost greater flight frequency in order to reduce airfares and attract passengers, which ultimately leads to an increase in concessions revenue. Intuitively, higher charges to airlines may have a positive effect on the aeronautical revenues but a sizeable countervailing negative effect on commercial revenues due to the decrease in the number of flyers, as some flyers respond by not traveling while others switch to nearby rival airports or even other modes

[3] One may also argue that an airport can be subject to price regulation and thus the power to set landing fee is restricted. The price regulation is not within the scope of this paper so we focus on the unregulated case for now.

of travel.[4] As consumers only buy retail products if they fly, to truly reap the benefits, airports must attract consumers first.

The one-way complementarity issue has been tackled by Flores-Fillol et al. (2018), who study how platform's optimal behaviour is affected by consumer foresightedness. Our paper differs from theirs in three ways. Firstly, consumers fully anticipate the surplus they will obtain from the retail service within the airport at the point they buy flight tickets. The complete anticipation is made possible by consumers taking into account whether one needs to park and dine at the airports, as well as, finding parking rates, restaurants brands and the availability of duty-free shops on airport website.[5] Secondly, we differentiate heterogenous consumer groups, with one group of consumers care about product characteristic (flight frequency) from the primary goods. Thirdly, we examine explicitly the spatial competition of two integrated airport-airline pairs, which is not part of Flores-Fillol et al. (2018)'s analysis.

We undertakes a theoretical review of certain aspects of airport competition, with a focus on conceptual issues and interpretation. In this paper, we propose a duopoly competition model to study the optimal pricing strategy of an airport that operates as a platform that generates revenues both from traditional aeronautical activities and from concession activities.

Our main findings are that if consumers care only about direct cost, i.e., airfare and commercial fees, and airports treats the two markets separately, the optimal landing charge and commercial fee are independent of each other. Furthermore, the landing fee is independent of passenger volume, and concession fee is determined by home market size. Under a general setting, especially if airlines' schedule delay is costly for consumers, the results are no longer clear-cut. Increasing in passenger volume does not guarantee an increase in airport's total revenue regardless of the degree of complementarity.

In the remainder of this paper, we first present the model setting and notations in Section 2. Section 3 investigates the leisure travel market, which is indifferent to departure time and does not incur schedule delay costs. Section 4 examines the optimal landing charge in a business travel market for which schedule delay is costly. We conclude in

[4]For multi-airport competition, see Mun and Teraji (2012) and Noruzoliaee et al. (2015).

[5]Most airports display retail shops, restaurants, and parking fees on their websites. For instance, Frankfurt Airport https://www.frankfurt-airport.com/.

Section 5.

2 The model setting and notations

Consider that two non-congested airports provide aviation and commercial services to airlines, and that airports maximise their profits. Following Hotelling (1929), we assume the passengers of the whole region are uniformly distributed, with density normalized to 1, along a line of length l which is also normalized to 1, as shown in Figure 1. Airports i ($i = A, B$) are located on this geographical line, and distance a (respectively b) measures the distance from the remotest passenger to airport A (B). There is only one airline operating at each airport. To ease the notation, we use the same notation i ($i = A, B$) to distinguish the airline that serves airport i. Each consumer purchases exactly one airline ticket, and to travel to the airport to take the flight each incurs a transportation cost equal to k per unit distance. The distance shows how far each individual passenger's most preferred airport is located from thef actual airport. Suppose the whole market along the line is covered. The passenger who is indifferent to travel to either airport is termed indifferent passenger. The distance from the indifferent passenger and airport A is denoted as Y_A and similarly to airport B is denoted as Y_B. We thus have $a \geq 0, b \geq 0$ and $a + b < 1$, where the last inequality guarantees that two airports coexist in the market.

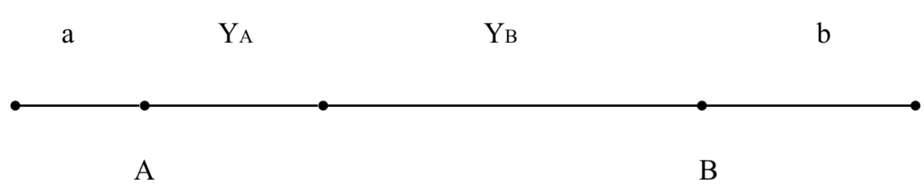

Figure 1: Spatial Competition à la Hotelling

The sequence of the game is as follows. At the first stage, airports set out the landing charge, x_i, and airlines fix the flight frequency, f_i. Price discrimination on aviation services is prohibited by the International Air Transport Association (IATA) rules, hence each airport charges all airlines the same aviation user price x_i. Note that x_i is the charge per flight for aviation services and is unregulated.[6] At the second stage, airports choose the commercial fee,[7] τ_i; at the third stage, passengers choose an airport i to fly from and make their retail purchases. Nonetheless, throughout this paper we assume that passengers have foresight: when they purchase an airline ticket, they already know they will incur commercial expenses at the airport. This assumption fits into reality. For instance, when choosing an airport, passengers know whether they will take a car and then use the parking facility at the airport and that they will buy meals when the departure time is around meal time.

Passenger decisions are made in a two-step process. First, they purchase their airline tickets; second, they make their retail purchases once in the airport. Only passengers who fly may also buy the retail goods, so the retail market is a pure complement to the airline market (but not vice versa).

The game contains full information, and we solve it by backward induction and obtain a subgame perfect equilibrium. The two airlines at corresponding airports charge ticket prices P_A and P_B respectively. As we focus on airport competition, we do not put any restriction on the determination of ticket prices, other than perceiving P_A and P_B as parameters. We use superscripts a and c to distinguish aeronautical and commercial revenue, respectively, and denote the airport profit generated from aeronautical activities as Π_i^a and non-aeronautical (commercial) activities as Π_i^c.

Airport $i,\ i = \{A, B\}$ maximizes its profits $\Pi_i = \Pi_i^a + \Pi_i^c$ by optimally choosing a landing fee, x_i, and imposing a commercial charge, τ_i. Hence both airport possess market power in the two business branches, which is in line with several models of other works Zhang and Zhang (1997); Czerny (2006) The landing fee comes from facility usage, such as runway and terminal usage, which is indifferent to taking-off and landing.[8] A commercial charge can be understood as average revenue generated from each passenger. Airports

[6] In essence, such a set-up resembles a single-till regulation. We choose not to refer to a particular regulation regime since the implication of price regulation is not the focus of this study.

[7] The selection of the commercial fee can be made by selecting either the number of retailers or setting the concession fee. More shops of similar type increases competition and is equivalent in outcome to a lower concession fee.

[8] Despite the longstanding call for more efficient runway pricing, due to the complexity and doubts on the grounds of fairness, in practice, taking-off and landing fees are still based on traditional aircraft maximum take-off weight, which is based per activity.

generate concession revenues from providing services to passengers, for instance, car parking, restaurants and hotels, duty-free shops, and so on. The airport reaps profits from concession services by choosing the number of retailers that lease a concession space to launch business in airport terminals. Suppose airports select concession retailers via competitive auctions. Retailers bid noncooperatively for concession contracts. As a result, an airport fully extracts all profits generated from the commercial side.

2.1 Passenger concerns

Business travelers often cannot predict their travel times and thus purchase refundable tickets that allow them to board the next flight. Hence, they value the convenience of a flight schedule with multiple departure times, which enables them to spend less time waiting to catch the next available flight closest to their desired departure time. By contrast, leisure guests have weaker preferences among flights, and thus, scheduling is less costly to them. To circumvent the complexities of the spatial approach, the present paper eliminates the relevance of particular departure times of individual flights and formalizes the model in a way that consumers care about overall flight frequency.

The discrepancy between the preferred and actual departure time is called schedule delay.[9] The dollar value of this time difference is termed schedule delay cost, reflecting the cost to the consumer of adapting travel plans to the flight's departure time. Theoretical work has tended to specify this cost as inversely proportional to flight frequency. We follow Richard (2003) to express this cost by $\frac{\beta}{\sqrt{f_i}}$, where β is a parameter reflecting a consumer's valuation of the cost and f_i is flight frequency.[10]

Consumers pay an effective price equal to

$$\mathcal{P}_i = P_i + \tau_i + \delta \frac{\beta}{\sqrt{f_i}}, \tag{1}$$

[9]Douglas and Miller III (1974); Douglas and Miller (1974); Richard (2003); Brueckner and Flores-Fillol (2007) have all modeled schedule delay.

[10]This functional form implicitly assumes that flights are evenly placed along the 24h circle and desired departure times are uniformly distributed; thus, the distance to the closest departure time is on average proportional to $1/f_i$. However, Borenstein and Netz (1999) note that an airline usually groups some of its departure flights, so that a specification of $\frac{1}{\sqrt{f_i}}$ is a more appropriate description since the form is less convex in frequency. Moreover, the square root specification fits better empirically than a linear one.

where P_i is airline i's ticket price, and τ_i is the commercial fee charged by airport i. The effective price is modeled in Panzar (1979); Lederer (1993); Morrison and Winston (2010); Brueckner and Zhang (2001), among others. The effective price to a consumer takes an additively separable form that includes an airline's ticket price, commercial price and may include schedule delay cost, depending on the parameter $\delta \in [0, 1]$. δ describes whether and how much a passenger takes into account scheduling. If $\delta = 0$, the passenger is perfectly indifferent to the departure schedule of airlines. If $\delta = 1$, the passenger fully takes scheduling into account and attaches same weight to schedule delay cost as with ticket price and commercial spending, while values between 0 and 1 denote intermediate cases of preference for departure time.

We assume that airlines could pass on, at least partially, landing fee to passengers via ticket price. The impact of landing fee on ticket price is denoted as γ where $\gamma \in [0, 1)$. All other factors that determine ticket price aside from landing fee are denoted altogether as $\Gamma > 0$. This assumption of γ is in line with Sainz-González et al. (2011), who find evidence from Spanish airline market that airlines pass the airport fees onto customers by raising fares. We then use a Cobb-Douglas functional form to describe the composition of ticket price against costs

$$P_i(x_i) = \Gamma x_i^{\gamma}, \tag{2}$$

where $\gamma \in [0, 1)$ shows decreasing returns in landing fee: an increase in one unit of landing fee induces less than one unit of increase in ticket price.

The indifferent passenger departing from airport A or B is determined by

$$\mathcal{P}_A + kY_A = \mathcal{P}_B + kY_B,$$

in which Y_i measures the distance from the indifferent passenger to airport A and B. Thus, we also have

$$a + b + Y_A + Y_B = 1. \tag{3}$$

Since our analysis is limited to both airports coexist and compete in the market, it is legitimate to call a and b the home market (hinterland) of airport A and B, respectively. Thus, the two airports (jointly with airlines using the airports) face Hotelling spatial competition.

In the following, we denote q_i the expected passenger volume using airport i and Q_i the actual passenger volume.

2.2 Airlines' flight frequency

Ivaldi et al. (2012) shows that the optimal level of frequency depends on the number of passengers and landing fee charged by airport. Following Ivaldi et al. (2012), we posit a simple specification for $f(x_i, q_i)$ as

$$f(x_i, q_i) = \left(\frac{\alpha q_i}{x_i}\right)^{\epsilon}, \tag{4}$$

where q_i is the total passenger volume flying with airport i. Parameter $\alpha(> 0)$ reflects an airline's ability to add an additional flight, which is constrained by airport capacity, environmental limits, or regulatory restrictions. A high α implies a higher ability to place more frequent flights. Equation (4) shows that the frequency depends on the passenger volume and the aeronautical fee charged by the airport, as well as on airline's ability to expand frequency. Realistically, frequency is positively correlated with passengers and negatively correlated with aeronautical fee. Airlines' demand for the airport depends both on the aeronautical fee and passenger volume. As a two-sided platform, the airport can affect airline's frequency demand for airport either by adjusting the aeronautical fee or by manipulating the commercial fee. The former has a direct impact, while the latter has an indirect impact on airline demand via first affecting the passenger demand and then the airline demand on the two-sided network platform. Moreover, parameter ϵ represents the elasticity of frequency to the inverse of per-seat fee

$$-\epsilon = \frac{d \ln f(x_i, q_i)}{d \ln \left(\frac{x_i}{\alpha q_i}\right)}, \tag{5}$$

where the ratio $\frac{x_i}{q_i}$ is the average per-seat landing fee. Equation (5) says that when the average per-seat landing fee increases, airline reduces frequency.

By (4), $f(x_i, q_i)$ displays decreasing frequency placement to the average per-seat landing fee. Furthermore, from (4), it is intuitive that the frequency increases in passenger volume, and the effect is greater when the passenger volume is larger: $\frac{\partial f(x_i,q_i)}{\partial q_i} > 0$, $\frac{\partial^2 f(x_i,q_i)}{\partial q_i^2} > 0$. Here, we stress that the airports studied are uncongested, so they have enough capacity to accommodate flight activities. At the airline level, because the two airlines are engaged in competition and flight frequency is perceived as quality indicators by business travelers,[11] it is natural that airlines tend to increase flight frequency to attract passengers. In addition, $\frac{\partial f(x_i, q_i)}{\partial x_i} < 0, \frac{\partial f^2(x_i, q_i)}{\partial x_i^2} > 0$, frequency decreases with the landing fee, and the effect is more prominent when the fee is already high.

3 The Basic Model and Leisure travel Benchmark Case

This section develops the profit-maximization conditions for the simplest (benchmark) case where departure time is perfectly indifferent to passengers. This base case corresponds to leisure traveler market, which typically is not time sensitive and has flexible travel times; thus, frequency of departure is irrelevant, and $\delta = 0$. The effective price (1) thus reduces to

$$\mathcal{P}_i = P_i(x_i) + \tau_i.$$

The framework studied here resembles a two-sided single-homing model as studied in Armstrong (2006), which involves competing platforms, and each agent (Armstrong terms the interacting sides as agents; in our case, airline and passenger embody the two agents) chooses to join a single platform. On each platform, the utilities to one group are positively related to the numbers of participants in the other group.

Airports A and B offer respective charge pairs (x_A, τ_A) and (x_B, τ_B) to the two user groups, which coincide with the conventional way of modeling respective prices charged by the platform to the two groups.

3.1 Leisure passengers' choice

Passengers situated in the home market of each airport fly from corresponding home airport, the market sizes are a and b, respectively. Those who reside between the two airports may choose to fly with one of the two, depending on the factors depicted below. As explained earlier, the distance from the indifferent passenger and the two airports are

[11] See Section 4 for more detailed analysis.

Y_A and Y_B, respectively. In the spirit of Hotelling (1929) and D'Aspremont and Thisse (1979), Y_A and Y_B can be identified in the standard way

$$Y_A = \frac{1}{2}\left(1 - a - b + \frac{P_B + \tau_B - P_A - \tau_A}{k}\right),\ Y_B = \frac{1}{2}\left(1 - a - b - \frac{P_B + \tau_B - P_A - \tau_A}{k}\right).$$

Straightforwardly, total passengers departing from the two airports are

$$Q_A = a + Y_A = \frac{1}{2}\left(1 + a - b + \frac{P_B + \tau_B - P_A - \tau_A}{k}\right), Q_B = b + Y_B = \frac{1}{2}\left(1 - a + b - \frac{P_B + \tau_B - P_A - \tau_A}{k}\right).$$

3.2 Concession revenue in the leisure travel market

We assume concession cost away. Denote airport i's concession revenue as $\Pi_i^c, i = \{A, B\}$. On a single route segment, airport A and B's profit maximization problem can be stated as

$$\max_{\tau_A} \Pi_A^c = \tau_A Q_A = \frac{\tau_A}{2}\left(1 + a - b + \frac{P_B + \tau_B - P_A - \tau_A}{k}\right),$$
$$\max_{\tau_B} \Pi_B^c = \tau_B Q_B = \frac{\tau_B}{2}\left(1 - a + b - \frac{P_B + \tau_B - P_A - \tau_A}{k}\right).$$

There exists a unique interior Nash equilibrium for commercial charge

$$\tau_A^* = k\left(1 + \frac{a-b}{3}\right) + \frac{P_B - P_A}{3},\ \tau_B^* = k\left(1 - \frac{a-b}{3}\right) - \frac{P_B - P_A}{3}, \tag{6}$$

for a and b that fulfill

$$(1 + \frac{a-b}{3})^2 \geq \frac{4}{3}(a + 2b),\ (1 + \frac{b-a}{3})^2 \geq \frac{4}{3}(b + 2a). \tag{7}$$

Airport A's optimal commercial charge is increasing in its home market while decreasing in its rival's. All else equal, possessing location advantage (a larger home market) means enjoying greater market power, which enables a firm to charge a higher commercial fee. Moreover, τ_A^* is decreasing in airline A's ticket price. If airline A charges a lower ticket price, it could benefit from the higher passenger volume attracted to the airport and impose a higher commercial charge.

The difference between optimal commercial charges

$$\tau_A^* - \tau_B^* = \frac{2}{3}[k(a-b) + (P_B - P_A)] \tag{8}$$

is related to both the home market difference, $a - b$, and the ticket price difference, $P_B - P_A$. Ticket price difference outweighs commercial charge difference.

To illustrate the properties of the equilibrium, we undertake a comparative-static approach. Of additional interest, the optimal commercial fees charged by the two airports are characterized in two dimensions: home market size and airline ticket price. In the symmetric case, the two airports have home markets of the same size, i.e., $a = b$, ticket price differential explains the differences in optimal commercial charge: $\tau_A^* - \tau_B^* = \frac{2}{3}(P_B - P_A)$. The optimal commercial charge difference is narrower than the ticket price difference, which can be attributed to the nature of the two-sided market: if the home airline charges a lower ticket price, the airport by nature attracts more passengers and could therefore charge a higher commercial fee, but the difference in commercial fees does not compensate the difference in ticket price, because the commercial fee affects both the passenger number and the airline. This point will be made explicit in the next section.

Finally, according to (8), if ticket prices at each individual airport are set to be equal, $P_B = P_A$, the optimal commercial fee difference will be decided only by the home market size difference, $\tau_A^* - \tau_B^* = \frac{2k(a-b)}{3}$, implying that the airport with a smaller home market should charge a lower fee than its rival.

Proposition 1 *Suppose the conditions of (7) hold, then*

- *airport i's optimal passenger volume is*
$$Q_A^* = \frac{1}{2}\left(1 + \frac{a-b}{3} + \frac{P_B - P_A}{3k}\right),\ Q_B^* = \frac{1}{2}\left(1 - \frac{a-b}{3} - \frac{P_B - P_A}{3k}\right),$$
- *airport i's optimal commercial revenue is*
$$\Pi_A^{c*} = \tau_A^* Q_A^* = \frac{1}{2k}(\tau_A^*)^2,\ \Pi_B^{c*} = \tau_B^* Q_B^* = \frac{1}{2k}(\tau_B^*)^2. \tag{9}$$

The optimal passenger volume of a platform depends on home market size and ticket price. As earlier, we take ticket prices as parameters. Hence, demand by the two platforms is substitutable in the sense that a platform's market share is increasing in another airline's ticket price. Moreover, in putting (6) together with (9) we obtain

$$\frac{\partial \Pi_A^{c\,*}}{\partial(a-b)} = \frac{\tau_A^*}{3} > 0, \frac{\partial \Pi_B^{c\,*}}{\partial(b-a)} = \frac{\tau_B^*}{3} > 0.$$

All other things remaining unchanged, an airport's concession profit is increasing in home market difference.

Combining (9) and (6) we generate the difference of airport optimal commercial revenues as

$$\Pi_A^{c\,*} - \Pi_B^{c\,*} = \tau_A^* - \tau_B^*.$$

The following results are straightforward.

Corollary 1 *Assume the conditions of (7) hold. Then, the difference between optimal total passenger flow is*

$$Q_A^* - Q_B^* = \frac{\tau_A^* - \tau_B^*}{2k},$$

and the difference of optimal concession revenues is

$$\Pi_A^{c\,*} - \Pi_B^{c\,*} = \tau_A^* - \tau_B^*,$$

with $\tau_A^* - \tau_B^*$ given by (8).

The concession profit depends on both commercial charge and total passenger volume. Nevertheless, passenger volume difference is essentially determined by ticket price, which is exogenous. Therefore, concession profit difference relies solely upon that of commercial charge.

3.3 Aeronautical revenue in the leisure travel market

Suppose an airport incurs per-movement marginal operating cost c_i. Aeronautical profit for airport i is generated from aeronautical revenue minus total cost, and is thus expressed as:

$$\Pi_i^a = (x_i - c_i) \cdot f_i(x_i, q_i) = (x_i - c_i)\left(\frac{\alpha q_i}{x_i}\right)^{\epsilon}, \quad i = A, B. \tag{10}$$

The first-order condition with respect to x_i yields:

$$\frac{\partial \Pi_i^a}{\partial x_i} = (\alpha q_i)^{\epsilon} x_i^{-\epsilon-1}\Big((x_i(1-\epsilon) + \epsilon c_i\Big) = 0. \tag{11}$$

Evaluated at the critical point, the second-order condition yields

$$\frac{\partial^2 \Pi_i^a}{\partial x_i^2} = (1-\epsilon)(\alpha q_i)^{\epsilon} x_i^{-\epsilon-1}, \tag{12}$$

which is strictly negative when $\epsilon > 1$. We hereby impose the below assumption for the rest of the paper.

Assumption 1

$$\epsilon > 1.$$

Based on this assumption, airport i's optimal charge is thus[12]

$$x_i^* = \frac{\epsilon c_i}{\epsilon - 1} = c_i + \frac{c_i}{\epsilon - 1} > c_i, \tag{13}$$

where $\frac{c_i}{\epsilon-1}$ is a mark-up.

Proposition 2 *Given airline frequency function (4), and Assumption 1 holds, then*

- *airport i's ($i = A, B$) optimal landing fee is independent of total passengers and linearly increasing in airport operating cost,*
- *airport i's optimal aeronautical profit is*

$$\Pi_i^{a*} = \frac{\epsilon^{-\epsilon}}{(1-\epsilon)^{1-\epsilon}}(\alpha q_i)^{\epsilon} c_i^{1-\epsilon},$$

  which is strictly increasing and convex in total passengers and strictly increasing and concave in operating cost.

The last statement claims that airport profit increases with operating cost. While it might seem counter-intuitive at first glance, the reason can be seen from (13). The airport fully transfers this cost to the airline, and moreover charges a mark-up term that is linearly increasing in operating cost.

[12]Noticing that Ivaldi et al. (2012) assumes $0 < \epsilon < 1$. In their framework the focus is on a monopoly airport that always operates at full capacity, and the aggregate frequency of all airlines is a fixed constant; hence, $0 < \epsilon < 1$. Our setting, however, involves duopoly airport competition, and the airport has not reached full capacity. Hence, we are concerned with a different range of ϵ.

3.4 Airport total profit in the leisure travel market

With the background laid out in previous subsections, this part discusses setting landing fee under different regulatory regimes, i.e., taking into account a certain portion of commercial fee. Note that though this seems to ecco single- and dual-till airport regulatory approach at first glance, our setting does not coincide with single- and dual-till as it does not deal with price-cap, or upper limit, as contrast to single- or dual-till regulatory framework. In our model, landing fee is not subject to price regulation.[13] Rather, this model allows for unregulated prices that are governed by a profit maximizing airport, hence enables us to focus on the impact of cross-subsidisation between commercial and aviation revenues.

Hereby, we analyze an airport's profit maximization under different regulatory regimes, i.e., with various weights of commercial activities being integrated in the derivation of optimal landing charge

$$\max_{x_i}[\Pi_i^a + \omega\Pi_i^c]$$

The parameter $\omega \in [0,1]$ indicates the degree of integration of concession revenue in the airport revenue. When $\omega = 0$, the airport is restrained from subsidizing its aeronautical services with commercial revenue, and the two profit segments are taken separately. When $\omega = 1$, the airport utilizes both business branches to determine landing fee. Any ω value locating in $(0,1)$ indicates a hybrid scheme that lies between the two schemes.

We start with $\omega = 0$. In this case, only aeronautical profit is used to calculate landing charge. Aeronautical and commercial operations are regarded as two independent sources of airport profit, and thus, we maximize each segment separately. Combining Proposition 1 and 2, the profit maximization of airport i from the two segments is thus

$$\max_{\{x_i,\tau_i\}} \Pi_i = \max_{x_i} \Pi_i^a + \max_{\tau_i} \Pi_i^c.$$

Proposition 3 *Given the airline frequency function and that both Assumption 1 and the con-*

[13]The long debate concerning regulation of landing fee centers around whether profits from the provision of concession services should be used to cover the fixed cost of aeronautical activities. The single-till approach takes profits from both segments into account when determining the price-cap, whereas the dual-till approach takes profits from aeronautical activities.

ditions of (7) hold, airport i's optimal profits from the two markets are

$$\Pi_A^* = \Pi_A^{a\,*} + \Pi_A^{c\,*} \text{ and } \Pi_B^* = \Pi_B^{a\,*} + \Pi_B^{c\,*}$$

respectively, where q_i in Proposition 2 is replaced by Q_i^* as given in Proposition 1.

We then look at the case where $\omega \neq 0$. As indicated by (6) and Proposition 1, concession revenue is irrelevant to landing charge for leisure travelers. Therefore, in this market, regulatory regime does not affect an airport's choice of optimal landing charge.

Thus far, our attention has been devoted to a framework with straightforward and tractable functional form. More precisely, the optimal landing fee depends only on the parameter and airport operating cost, while the optimal commercial fee relates to home market size and ticket price, which are both exogenously given. To examine both the complementarity and cross-subsidization between the two sides, we complement the current framework setting by generalizing model specifications and adding more sophisticated features.

4 Business travelers market

Until now, we have confined attention to the leisure traveler market where fliers overlook scheduling. We now look into business traveler market. This demand segment represents fliers who prefer to travel on flights that meet their schedule requirements. To account for the simplicity of the current approach, the precise departure times of individual flights are taken to be irrelevant. A business traveler incorporates valuation of ticket price, commercial fee and flight frequency combined. We use a tilde on top of variables to denote the business travel market, as differentiated from leisure market.

Taking into account the form of $\mathcal{P}_i$ with the presence of schedule delay cost, or equivalently, $\delta = 1$ (from (1)), effective price becomes:

$$\widetilde{\mathcal{P}}_i = P_i(\widetilde{x}_i) + \tilde{\tau}_i + \frac{\beta}{\sqrt{f_i(\widetilde{x}_i, \widetilde{q}_i)}}. \tag{14}$$

Here, $\widetilde{x}_i$ denotes landing fee and $\widetilde{q}_i$ is the total number of passengers using airport i. We impose the natural assumption that both airports at least cover their home markets and no airline could win all the markets, $\widetilde{q_A} \geq a$ and $\widetilde{q_B} \geq b$ with $\widetilde{q_A} + \widetilde{q_B} = 1$. We retain the assumption that airlines stick with frequency function (4) rather than beneficially setting frequency. We solve this three-stage game via backward induction.

4.1 Business passengers' choice

For passengers, flight frequency is already predetermined by (4) a priori. Then, analogous to Subsection 3.2, the indifferent passenger is identified by equating the utility derived from departures at the two airports, which are

$$\widetilde{Y_A} = \frac{1}{2}\left(1 - a - b + \frac{\widetilde{\mathcal{P}_B} - \widetilde{\mathcal{P}_A}}{k}\right), \quad \widetilde{Y_B} = \frac{1}{2}\left(1 - a - b - \frac{\widetilde{\mathcal{P}_B} - \widetilde{\mathcal{P}_A}}{k}\right). \tag{15}$$

Putting (14) together with (15), the total passenger volumes departing from the two airports, respectively, are thus

$$\widetilde{Q_A} = a + \widetilde{Y_A} = \frac{1}{2}\left(1 + a - b + \frac{(P_B + \widetilde{\tau_B} + \frac{\beta}{\sqrt{f_B}}) - (P_A + \widetilde{\tau_A} + \frac{\beta}{\sqrt{f_A}})}{k}\right),$$

$$\widetilde{Q_B} = b + \widetilde{Y_B} = \frac{1}{2}\left(1 - a + b - \frac{(P_B + \widetilde{\tau_B} + \frac{\beta}{\sqrt{f_B}}) - (P_A + \widetilde{\tau_A} + \frac{\beta}{\sqrt{f_A}})}{k}\right). \tag{16}$$

Keeping airline A's commercial charge fixed, the above expression shows that a marginal increase in airline B's commercial charge attracts a further $\frac{1}{2k}$ portion of passengers to A. The ticket price has an impact on the user number of the passenger side. Our interpretation is in line with the two-sided market literature such as Armstrong (2006).

4.2 Revenues in the business travel market

Commercial Revenues Airport i's concession profit maximization problem can be stated as

$$\max_{\widetilde{\tau_i}} \widetilde{\Pi_i^c} = \widetilde{\tau_i}\widetilde{q_i}, \quad i = A, B. \tag{17}$$

The solution[14] to the above optimization problem yields, under conditions (7), the unique interior Nash equilibrium in terms of commercial fee

$$\widetilde{\tau_A}(\widetilde{x_A}, \widetilde{x_B}) = k\left(1 + \frac{a-b}{3}\right) + \frac{P_B(\widetilde{x_B}) + \frac{\beta}{\sqrt{f_B(\widetilde{x_B})}} - P_A(\widetilde{x_A}) - \frac{\beta}{\sqrt{f_A(\widetilde{x_A})}}}{3}$$

$$\widetilde{\tau_B}(\widetilde{x_B}, \widetilde{x_A}) = k\left(1 - \frac{a-b}{3}\right) - \frac{P_B(\widetilde{x_B}) + \frac{\beta}{\sqrt{f_B(\widetilde{x_B})}} - P_A(\widetilde{x_A}) - \frac{\beta}{\sqrt{f_A(\widetilde{x_A})}}}{3}. \tag{18}$$

Business passengers know in advance their preferred departure time, are aware of their scheduled delay cost and would count the monetary value of the waiting time into the effective price. The optimal commercial fee charged by the airport under this circumstance should contain a schedule delay term, which, in turn, depends on flight frequency set by airlines. Implicit in the expressions is the idea that if passengers are aware of time cost, airports' optimal commercial fees are dependent on landing fees.

(16) along with (18) give us concession profits evaluated at critical point

$$\widetilde{\Pi_i}^c = \widetilde{\tau}_i \widetilde{Q_i} = \frac{1}{2k}(\widetilde{\tau}_i)^2, \quad i = A, B. \tag{19}$$

We conclude the above findings in the following proposition.

Proposition 4 *For given ticket prices, assume that effective prices are given by (14). Then*

- *there exists a unique interior Nash equilibrium for commercial charges which is given by (18),*
- *airports' optimal concession profits are given by (19),*
- *if it is further assumed that (4) and (2) hold, then both commercial charge and airport profit increase with the competing airport's landing fee but decrease with own landing fee.*

Aeronautical Revenues Aeronautical profit remains the form as in leisure traveler case (10), with variables now being replaced by corresponding variables with tilde mark to identify business travel market, and can be expressed as

$$\widetilde{\Pi_i^a} = (\widetilde{x}_i - c_i)\left(\frac{\alpha \widetilde{q}_i}{\widetilde{x}_i}\right)^{\epsilon}, \quad i = A, B. \tag{20}$$

[14]As mentioned in the last subsection, commercial charge influences passengers' choice of airport and airline, and consequently the total passenger volume, but flight frequency was determined at a prior step. Thus, at this stage, not only the passengers but also the airports take as given the flight frequency.

4.3 Airport total profit in the business travel market

Combining (19) and (20), airport i's optimization problem can be characterized as

$$\max_{\widetilde{x}_i}[\widetilde{\Pi_i}^a + \omega\widetilde{\Pi_i}^c] = \max_{\widetilde{x}_i}\left[(\widetilde{x}_i - c_i)f(\widetilde{x}_i, \widetilde{q}_i) + \omega\frac{\widetilde{\tau}_i^2(\widetilde{x}_i, \widetilde{x}_j)}{2k}\right],$$

where $i, j = A, B$ and $\widetilde{x}_i \neq \widetilde{x}_j$ with $\widetilde{q_A} \geq a$ and $\widetilde{q_B} \geq b$.

In the rest of the paper, we first study the optimal choice of landing fee under regulation, after which we investigate the impact of the optimal passenger volume on the aeronautical and commercial profits; we close this section by analyzing total profit.

4.3.1 Optimal Landing Fee

The optimal choice of landing fee is derived from the first-order condition with respect to $\widetilde{x}_i$, which yields

$$\begin{aligned}\frac{\partial\widetilde{\Pi}_i}{\partial\widetilde{x}_i} &= \frac{\partial\widetilde{\Pi}_i^a}{\partial\widetilde{x}_i} + \omega\frac{\partial\widetilde{\Pi}_i^c}{\partial\widetilde{x}_i} \\ &= (\alpha\widetilde{q}_i)^\epsilon\widetilde{x}_i^{-\epsilon-1}[c_i\epsilon + (1-\epsilon)\widetilde{x}_i] + \omega\,\frac{\widetilde{\tau}_i}{k}\frac{\partial\widetilde{\tau}_i}{\partial\widetilde{x}_i} = 0. \qquad (21)\end{aligned}$$

In the ensuing analysis, to guarantee the second-order conditions for optimization, whose proof is provided in the Appendix A, we impose the following assumption:

Assumption 2 *Parameter ϵ and ω satisfy*

(1) $1 < \epsilon < 2$,[15]

(2) at the critical point defined by (21), ω fulfills

$$0 \leq \omega < \overline{\omega} \equiv \min\left\{1, \left(\frac{\partial^2\widetilde{\Pi_i}^a}{\partial\widetilde{x}_i^2}\right) / \left(-\frac{\partial^2\widetilde{\Pi_i}^c}{\partial\widetilde{x}_i^2}\right), \quad i = A, B\right\}.$$

Weight parameter ω is bounded by the ratio of the curvatures of two profit functions. Intuitively, it should be smaller than one by definition. Although explicit solution to the

[15]Given our focus is not on the choice of ϵ, condition $\epsilon < 2$ simplifies the calculation and it is not essential for either the existence and uniqueness of optimal choices or the properties we study thereafter.

first-order condition (21) is difficult to obtain, because $\frac{\partial \widetilde{\tau}_i}{\partial \widetilde{x}_i} < 0$, whose proof is relegated to Step 2 of Appendix A, it follows that the first term of (21) must be positive, and therefore

$$c_i \epsilon + (1-\epsilon)\widetilde{x}_i > 0,$$

which is equivalent to

$$\widetilde{x}_i < \frac{\epsilon}{1-\epsilon} c_i = x_i^*.$$

Because the landing charge will be partially or fully added to a ticket price and consequently has impact on the flight frequency, the optimal landing charge is chosen to maximize aeronautical and concession profits combined, although the weight of the latter may vary. The optimal landing fee should be lower than the case where only aeronautical profit is used to derive landing fee.

Proposition 5 *Suppose Assumption 2 holds. There is a unique optimal solution, $\widetilde{x}_i$, given by the first-order condition (21):*

$$\widetilde{x}_i \leq x_i^*.$$

Equality holds if and only if $\omega = 0$.

The intuition behind this result can be explained by the complementary nature of demand for the two sides of services. When facing demand complementarities between aeronautical and commercial activities, in equilibrium an airport sets a lower charge for aeronautical services. In particular, a rise in landing charge leads to a fall in the demand for both aeronautical services and commercial services. Under a hybrid scheme, landing charge magnifies the impact of passenger demand on the airport. Following this reasoning the airport may not seek to increase the landing charge, which supports the viewpoint that airport regulation is not necessary.

4.3.2 Impact of passenger volume on optimal landing charge

In the last section, we considered a setting where optimal landing fee is independent of the passenger volume. We now take into account the impact on the other market and discuss the case where optimal landing fee and passenger volume are intertwined.

Recall the optimal choice of $\widetilde{x}_i$ is given by first-order condition (21). Applying implicit function theorem to (21) yields

$$\frac{d\widetilde{x}_i}{d\widetilde{q}_i} = -\left(\frac{\partial}{\partial \widetilde{q}_i}\left(\frac{\partial \widetilde{\Pi_i}}{\partial \widetilde{x}_i}\right)\right) / \left(\frac{\partial^2 \widetilde{\Pi_i}}{\partial \widetilde{x}_i^{\,2}}\right). \tag{22}$$

Thus, we can conclude the following

$$\frac{d\widetilde{x}_i}{d\widetilde{q}_i}\begin{cases} > 0, & 0 < \omega < \underline{\omega}, \\ < 0, & \underline{\omega} < \omega < \overline{\omega} \end{cases} \tag{23}$$

where $\overline{\omega}$ is given in Assumption 2 and $\underline{\omega}$ is defined as

$$\underline{\omega} = \frac{3\epsilon(c_i\epsilon + (1-\epsilon)\widetilde{x}_i)}{\gamma} \; \frac{f(\widetilde{x}_i, \widetilde{q}_i)}{\widetilde{q}_i P_i(\widetilde{x}_i)}.$$

(23) reflects the fact that the optimal landing fee can either rise or fall with passenger volume. The reason is the following. As concession profit is increasing with passenger volume (for a proof, see equation (B.2) in Appendix B), if ω is large, concession profit puts downward pressure on the aeronautical revenue and eventually the landing fee. Hence, the relationship between passenger volume and landing fee is negative. The reverse holds for a relatively small ω.

Using (23), we proceed to study the impact of passenger volume on both aeronautical and concession profits.

4.3.3 Impact of passenger volume on aeronautical profit

From the expression of aeronautical profit (20), we can derive

$$\frac{d\widetilde{\Pi_i}^a}{d\widetilde{q}_i} = f(x_i, q_i)\frac{d\widetilde{x}_i}{d\widetilde{q}_i} + (\widetilde{x}_i - c_i)\frac{df}{d\widetilde{q}_i}. \tag{24}$$

For given frequency function $f(x_i, q_i) = \left(\frac{\alpha q_i}{x_i}\right)^{\epsilon}$, total differential of f shows

$$\frac{df}{d\widetilde{q}_i} = \frac{\partial f}{\partial \widetilde{x}_i}\frac{d\widetilde{x}_i}{d\widetilde{q}_i} + \frac{\partial f}{\partial \widetilde{q}_i} = \epsilon\frac{f}{\widetilde{q}_i}\left(1 - \frac{d\widetilde{x}_i}{d\widetilde{q}_i} / \frac{\widetilde{x}_i}{\widetilde{q}_i}\right). \tag{25}$$

Substituting the first expression into (24) and rearranging terms, it follows

$$\frac{d\widetilde{\Pi_i}^a}{d\widetilde{q}_i} = f(x_i, q_i)\widetilde{x}_i^{\,-1}[(1-\epsilon)\widetilde{x}_i + c_i\epsilon]\frac{d\widetilde{x}_i}{d\widetilde{q}_i} + (\widetilde{x}_i - c_i)\frac{\partial f}{\partial \widetilde{q}_i}. \tag{26}$$

As we have assumed change of aircraft away, flight frequency does not decrease with passenger volume; thus, $\frac{\partial f}{\partial \widetilde{q}_i} > 0$. The second expression in (25) implies that $\frac{d\widetilde{x}_i}{d\widetilde{q}_i} / \frac{\widetilde{x}_i}{\widetilde{q}_i} < 1$ holds, which says the optimal landing charge must be inelastic with respect to passenger volume. This condition puts no restraint on the sign of $\frac{d\widetilde{x}_i}{d\widetilde{q}_i}$. If $\frac{d\widetilde{x}_i}{d\widetilde{q}_i} > 0$, it follows straightforwardly from equation (26) that $\frac{d\widetilde{\Pi_i}^a}{d\widetilde{q}_i} > 0$. If $\frac{d\widetilde{x}_i}{d\widetilde{q}_i} < 0$ otherwise, the first term in (26) is negative, while the second term is positive. Passenger volume affects aeronautical profit in two opposite directions and the joint effect is not straightforward. This analysis is summarized in the following result.

Proposition 6 *Given frequency function (4) and ticket price expression (2), as well as Assumption 2, the following results hold*

(1) when $0 < \omega < \underline{\omega}$*,*

(1.a) passenger volume positively affects aeronautical profit,

(1.b) optimal landing charge must be inelastic with respect to passenger volume,

(2) when $\underline{\omega} < \omega < \overline{\omega}$*, passenger volume has an ambiguous impact on aeronautical profit.*

The ambiguity comes from the fact that, on the one hand, larger passenger volume leads to more frequent flights, $\frac{df}{d\widetilde{q}_i} > 0$; on the other hand, it directly implies larger non-aeronautical profit, $\frac{\partial \Pi_i^c}{\partial q_i} > 0$; thus, the airport can afford to decrease its landing charge, i.e., $\frac{d\widetilde{x}_i}{d\widetilde{q}_i} < 0$. The outcome can be attributed to the two-sided network: one side of the market (airline) can transfer the lower landing charge via ticket price to the other side of the market (passengers), thus increasing the competitive advantage of the airport-airline bundle together.

4.3.4 Impact of passenger volume on concession profit

The aggregate effect of passenger volume on concession profit depends on both passenger volume and commercial charge

$$\frac{d\widetilde{\Pi_i}^c}{d\widetilde{q}_i} = \widetilde{\tau}_i + \widetilde{q}_i \frac{d\widetilde{\tau}_i}{d\widetilde{q}_i},$$

which can be rewritten, using (18), as

$$\frac{d\widetilde{\Pi}_i^c}{d\widetilde{q}_i} = \underbrace{\left(\widetilde{\tau}_i + \widetilde{q}_i \frac{\partial \widetilde{\tau}_i}{\partial \widetilde{q}_i}\right)}_{>0} + \widetilde{q}_i \underbrace{\frac{\partial \widetilde{\tau}_i}{\partial \widetilde{x}_i}}_{<0} \frac{d\widetilde{x}_i}{d\widetilde{q}_i}, \tag{27}$$

the bracket term is always positive and the second term is ambiguous. Our results are summarized in the following Proposition.

Proposition 7 *Under the same conditions as in Proposition 6. The following are true*

- *when* $0 < \omega < \underline{\omega}$*, passenger volume has an ambiguous impact on concession profits,*
- *when* $\underline{\omega} < \omega < \overline{\omega}$*, concession profits increase with passenger volume.*

Here, ambiguity arises from a different source. It is still true that larger passenger volume leads to larger concession profit; at the same time, however, it also enables the airport to impose higher landing charges, $\frac{d\widetilde{x}_i}{d\widetilde{q}_i} > 0$. Given that the airline can partially pass the charge on to passengers through ticket prices, airlines decreases commercial charges imposed on the passengers to remain attractive.

4.3.5 Impact of passenger volume on airport total profit

To sum up the previous two subsections, we conclude the following

$$\begin{cases} \frac{d\widetilde{\Pi}_i^a}{d\widetilde{q}_i} > 0 \quad \text{and} \quad \frac{d\widetilde{\Pi}_i^c}{d\widetilde{q}_i} \gtrless 0, \quad \text{if} \;\; 0 < \omega < \underline{\omega}, \\ \frac{d\widetilde{\Pi}_i^a}{d\widetilde{q}_i} \gtrless 0 \quad \text{and} \quad \frac{d\widetilde{\Pi}_i^c}{d\widetilde{q}_i} > 0, \quad \text{if} \;\; \underline{\omega} < \omega < \overline{\omega}. \end{cases} \tag{28}$$

Under some conditions, both single-till and dual-till regulations could lead to ambiguous outcomes in terms of an airport's aggregate revenues. Thus, increasing airports' attractiveness to attract more passengers does not automatically increase airports' revenues.

To wrap up this section, taking a two-sided market into consideration, the airports' choices are much more complicated than if two markets are separate. A clear-cut comparison of the airport profitability and the corresponding conditions would call for more empirical studies and careful calibration of airlines' frequency as well as ticket price functions.

5 Conclusion

The aim of this paper is to provide new insights into the theoretical outcome of airport competition. The originality of our approach is to model duopoly airports as a competing platform of two-sided markets: passengers and airlines. The model demonstrates that if passengers only care about direct cost, i.e, airline tickets and commercial fees, and airports can treat the two-sided markets separately, the optimal landing charge and commercial fee are independent of each other. The landing fee is also independent of passenger volume, although commercial fees are determined by home market size. Under a general setting, the above clear-cut results are no longer true. More importantly, increasing passenger volume does not guarantee increases in airports' aggregate revenue regardless of whether the duopoly competing airports are single-till or dual-till regulated.

It is worth noting that our results are based on tractable models and functional forms that ignore many other effects, such as accessing time, airport congestion situation, flight delay and arriving time, of airport related competition. Nevertheless, omitting these features allows us to focus on the main concerns of airport competition. Future work should account for the extensions, which include airline competition and passenger preferences. In particular, how do passenger preferences regarding accessing time, ticket price, frequency, etc., influence the outcome of airport competition and airports charges? Furthermore, with more data available, calibrating airlines' flight frequency and price functions is essential to understanding airports' options.

Appendix A: Proof of second order conditions in Subsection 4.3

Recall

$$\begin{aligned}\max_{\widetilde{x}_i} \widetilde{\Pi}_i &= \max_{\widetilde{x}_i} [\Pi_i^a + \omega \Pi_i^c] \\ &= \max_{\widetilde{x}_i} \big[(\widetilde{x}_i - c_i) f(\widetilde{x}_i, \widetilde{q}_i) + \omega \frac{\widetilde{\tau}_i^{\,2}(\widetilde{x}_i, \widetilde{x}_j)}{2k}\big],\end{aligned}$$

and

$$\widetilde{\tau_A}(\widetilde{x_A}, \widetilde{x_B}) = k\left(1 + \frac{a-b}{3}\right) + \frac{P_B(\widetilde{x_B}) + \frac{\beta}{\sqrt{f_B(\widetilde{x_B})}} - P_A(\widetilde{x_A}) - \frac{\beta}{\sqrt{f_A(\widetilde{x_A})}}}{3},$$

$$\widetilde{\tau_B}(\widetilde{x_B}, \widetilde{x_A}) = k\left(1 - \frac{a-b}{3}\right) - \frac{P_B(\widetilde{x_B}) + \frac{\beta}{\sqrt{f_B(\widetilde{x_B})}} - P_A(\widetilde{x_A}) - \frac{\beta}{\sqrt{f_A(\widetilde{x_A})}}}{3}.$$

Obviously, the first-order condition with respect to $\widetilde{x}_i$ yields:

$$\frac{\partial\widetilde{\Pi}_i}{\partial\widetilde{x}_i} = \frac{\partial\widetilde{\Pi}_i^a}{\partial\widetilde{x}_i} + \omega\frac{\partial\widetilde{\Pi}_i^c}{\partial\widetilde{x}_i} = (\alpha\widetilde{q}_i)^\epsilon \widetilde{x}_i^{\,-\epsilon-1}[c_i\epsilon + (1-\epsilon)\widetilde{x}_i] + \omega\,\frac{\widetilde{\tau}_i}{k}\frac{\partial\widetilde{\tau}_i}{\partial\widetilde{x}_i} = 0,$$

and the second order derivative is

$$\frac{\partial^2\widetilde{\Pi_i}}{\partial x_i^2} = \frac{\partial^2\widetilde{\Pi_i}^a}{\partial x_i^2} + \omega\frac{\partial^2\widetilde{\Pi_i}^c}{\partial x_i^2}.$$

In the following, in order to check and impose conditions for the second order sufficient condition to hold, we study the two terms in the above equation one by one.

Step 1. The sign of $\frac{\partial^2\widetilde{\Pi_i}^a}{\partial x_i^2}$.

From the first order condition, there is internal critical point if and only if at the critical point

$$c_i\epsilon + (1-\epsilon)\widetilde{x}_i > 0.$$

Then it is straightforward that

$$\frac{\partial^2\widetilde{\Pi_i}^a(\widetilde{x}_i)}{\partial x_i^2} = (\alpha q_i)^\epsilon\left[(-\epsilon-1)\widetilde{x}_i^{\,-\epsilon-2}(c_i\epsilon + (1-\epsilon)\widetilde{x}_i) + \widetilde{x}_i^{\,-\epsilon-1}(1-\epsilon)\right] < 0.$$

Step 2. The sign of $\frac{\partial^2\widetilde{\Pi_i}^c}{\partial x_i^2}$.

Direct calculation yields

$$\begin{aligned} \frac{\partial\widetilde{\tau^i}}{\partial x_i} = \quad & -\tfrac{1}{3}\left[\tfrac{\partial P_i}{\partial x_i} - \tfrac{\beta}{2}(f_i(x_i))^{-3/2}\tfrac{\partial f_i}{\partial x_i}\right] \\ & = -\tfrac{1}{3}\left[\Gamma\gamma x_i^{\gamma-1} + \tfrac{\epsilon\beta}{2}(\alpha q_i)^{-\frac{\epsilon}{2}} x_i^{\frac{\epsilon}{2}-1}\right] \quad < 0. \end{aligned} \tag{A.1}$$

It is easy to see

$$\frac{\partial\widetilde{\Pi_i}^c}{\partial x_i} = \frac{\widetilde{\tau}_i}{k}\frac{\partial\widetilde{\tau^i}}{\partial x_i} < 0$$

and

$$\frac{\partial^2 \widetilde{\Pi_i}^c}{\partial x_i^2} = \frac{1}{k}\left(\frac{\partial \widetilde{\tau}^i}{\partial x_i}\right)^2 + \frac{\widetilde{\tau}_i}{k}\frac{\partial^2 \widetilde{\tau}^i}{\partial x_i^2}$$

where

$$\frac{\partial^2 \widetilde{\tau}^i}{\partial x_i^2} = -\frac{1}{3}\left[\Gamma\gamma(\gamma-1)x_i^{\gamma-2} + \frac{\epsilon\beta}{2}\left(\frac{\epsilon}{2}-1\right)(\alpha q_i)^{-\frac{\epsilon}{2}} x_i^{\frac{\epsilon}{2}-2}\right].$$

Depending on parameter setting, $\frac{\partial^2 \widetilde{\tau}^i}{\partial x_i^2}$ could be positive or negative. For simplicity, we assume that

$$1 < \epsilon < 2,$$

then $\frac{\partial^2 \widetilde{\tau}^i}{\partial x_i^2} > 0$ is always true. Therefore at the critical point, $\widetilde{x}_i$:

$$\frac{\partial^2 \widetilde{\Pi_i}^c(\widetilde{x}_i)}{\partial x_i^2} > 0, \quad \forall \epsilon \in (1,2).$$

Step 3. We now turn to prove the second order condition.

The second order sufficient condition for optimization at the critical point (which satisfies the first order condition)

$$\frac{\partial^2 \widetilde{\Pi_i}(\widetilde{x}_i)}{\partial x_i^2} = \frac{\partial^2 \widetilde{\pi}_i{}^a(\widetilde{x}_i)}{\partial x_i^2} + \omega \frac{\partial^2 \widetilde{\pi}_i{}^c(\widetilde{x}_i)}{\partial x_i^2} < 0$$

holds if and only if

$$\frac{\partial^2 \widetilde{\pi}_i{}^a(\widetilde{x}_i)}{\partial x_i^2} < -\omega \frac{\partial^2 \widetilde{\pi}_i{}^c(\widetilde{x}_i)}{\partial x_i^2},$$

which is equivalent to

$$\omega < \left(\frac{\partial^2 \widetilde{\Pi_i}^a(\widetilde{x}_i)}{\partial \widetilde{x}_i{}^2}\right) \Big/ \left(-\frac{\partial^2 \widetilde{\Pi_i}^c(\widetilde{x}_i)}{\partial \widetilde{x}_i{}^2}\right), \quad i = A, B.$$

Furthermore, if parameter setting is established such that

$$\frac{\partial^2 \widetilde{\Pi_i}^c(\widetilde{x}_i)}{\partial x_i^2} < 0, \quad \forall \epsilon,$$

as a weighted variable, we still need to impose that

$$\omega < 1.$$

That completes the proof of the second order condition as we stated in the Assumption 2.

Appendix B: Proof of Subsection 4.3.2

It is then immediate to see that under Assumption 2, the second order condition states that the denominator is always negative. The sign of the numerator, which captures the mixed effects of landing fee and passenger volume on airport's aggregate profit, is ambiguous. Using (21), the numerator of (22) can be wr itten as

$$\frac{\partial}{\partial \widetilde{q}_i}\left(\frac{\partial \widetilde{\Pi}_i}{\partial \widetilde{x}_i}\right) = \frac{\partial^2 \widetilde{\Pi_i}^a}{\partial \widetilde{x}_i \partial \widetilde{q}_i} + \omega \frac{\partial^2 \widetilde{\Pi_i}^c}{\partial \widetilde{x}_i \partial \widetilde{q}_i}, \tag{B.1}$$

where the first term on the right hand side is

$$\frac{\partial^2 \widetilde{\Pi_i}^a}{\partial \widetilde{x}_i \partial \widetilde{q}_i} = \epsilon(\alpha \widetilde{q}_i)^\epsilon \widetilde{q}_i^{-1} \widetilde{x}_i^{-\epsilon-1} \left(c_i \epsilon + (1-\epsilon)\widetilde{x}_i\right) > 0.$$

Marginal aeronautical profit of landing charge always increases with passenger volume. To study the second term, we recall the definition of concession revenue (17), it is thus straightforward that

$$\frac{\partial \widetilde{\Pi_i}^c}{\partial \widetilde{q}_i} = \tau_i + q_i \frac{\partial \widetilde{\tau}_i}{\partial \widetilde{q}_i} > 0. \tag{B.2}$$

Increase in passenger volume has a positive, direct effect on concession revenue. After rearranging terms and simplification, we obtain

$$\frac{\partial^2 \widetilde{\Pi_i}^c}{\partial \widetilde{x}_i \partial \widetilde{q}_i} = \frac{\partial \tau_i}{\partial x_i} + q_i \frac{\partial^2 \tau_i}{\partial \widetilde{x}_i \partial \widetilde{q}_i} = -\frac{\Gamma \gamma}{3} \widetilde{x}_i^{\gamma-1} < 0.$$

(B.1) can now be rewritten as

$$\frac{\partial^2 \widetilde{\Pi}_i}{\partial \widetilde{q}_i \partial \widetilde{x}_i} = \left[\epsilon(c_i \epsilon + (1-\epsilon)\widetilde{x}_i)\frac{f(x_i)}{\widetilde{q}_i} - \omega \frac{\Gamma \gamma}{3} \widetilde{x}_i^{\gamma}\right] \widetilde{x}_i^{-1}.$$

That finishes the proof.

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