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INTERCONTINENTAL AIRPORT COMPETITION

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Abstract

This paper analyzes strategic interaction between intercontinental airports, each of which levies airport charges paid by airlines and chooses its own capacity under conditions of congestion. Congestion from intercontinental flights is common across the airports since departure and arrival airports are linked one to one, while purely domestic traffic also uses each airport. The paper focuses on five questions. First, if both continents can strategically set separate airport charges for domestic and intercontinental flights, how will the outcome differ from the first-best solution? Second, how is the impact of strategic airport behavior affected by the extent of market power of the airlines serving the intercontinental market? Third, what happens if one continent has several competing intercontinental airports, each with its own regulator, while the other has a single airport and regulator? Fourth, how effective is a non-discrimination clause for airport charges, which prevents independent strategic use of the intercontinental charge? Fifth, what is the effect of higher airport operating costs on one continent (a result of security or immigration procedures) on the strategic outcome? The questions are addressed with an algebraic model and results are illustrated numerically.

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Keywords: airport regulation, airport congestion, airline market power

JEL: L93,R48,R41

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1. Introduction

For intercontinental flights, most of the attention of policy makers and academia has focused on opening of the skies to competition and more recently on the potential competitive and anti-competitive effects of airline alliances. However, the effects of airport regulations on intercontinental airline markets has received much less attention. In this paper, we argue that strategic interaction between airport regulators could very well be as important in distorting market outcomes as a lack of competition in the intercontinental airline markets themselves.

In the US, the Federal Aviation Authority (FAA) is interested in managing congestion at the most-crowded airports, several of which are international gateways (New York JFK, Newark, Chicago). It uses the airport "slots" as the instrument. For each airport, the total number of slots is fixed so as to limit congestion, with each flight needing a slot to use the airport. Slots were allocated to airlines using the grandfathering principle (reflecting past use) but are currently tradable. In the EU, the different intercontinental gateways (London, Paris, Frankfurt, Amsterdam) also use slots to limit flights to the available capacities. In contrast to the FAA's uniform control, this regulation is done in an uncoordinated way by the national aviation authorities or airports.

Tradable slots are obviously a policy instrument that can be effective in reducing congestion, but they can also be used strategically to extract part of the rents from intercontinental travel. Take as an extreme example the case of no congestion, perfectly competitive airlines and only one airport in each continent, which serves only intercontinental flights. The FAA could extract all the rents from intercontinental travel and give them to the US airlines by selecting a number of airport slots strictly lower than the European number. As every flight needs a slot in the US and in the EU, the value of the European slots will be zero and the value of the slots in the US will equal the monopoly rent on the intercontinental market. Alternatively, the US intercontinental airport (or the FAA) could set an airport charge that extracts the monopoly rents on that market. Thus, airport charges can function as strategic instruments in the same way as the quantity restrictions inherent in airport slot allocations.

In this paper, we focus on the strategic choice of airport charges and capacities by regulators operating airports on different continents, which are connected by intercontinental flights. There is already an extensive literature on congestion regulation, but most papers focus on congestion at a single airport. In this paper, we specifically address the problem of congestion at intercontinental airports, taking into account that congestion levels at departure and arrival airports are linked one to one while recognizing that purely domestic traffic also uses these airports. The analysis also applies to airport competition within the same continent if the airport regulators are sufficiently independent, which is the case in the EU but not in the US.

To study the pricing and capacity interactions between regulators, we use a model with two airports on different continents, each with its own regulator, two intercontinental airlines, and perfectly competitive domestic airlines. Our point of reference is the first-best solution, where a world regulator sets optimal congestion charges and optimal capacities at both intercontinental airports. The first-best outcome can also be seen as a cooperative solution between the two airport regulators.

We focus on five questions. First, when continents strategically set airport congestion charges (which may differ for local and intercontinental traffic) and choose airport capacities, how will the outcome compare to the first-best outcome? In order to exploit international traffic, only half of which is its own, each regulator is expected to set a higher-than-optimal intercontinental airport charge. By cutting traffic, this higher charge makes a lower-than-optimal airport capacity desirable. The results confirm these expectations, showing the emergence of a type of double marginalization in intercontinental travel even if there is perfect competition on the intercontinental airline market.

This finding leads us to the second question: how much more efficiency is lost when one adds market power of intercontinental airlines on top of the strategic behavior of airport regulators? We find that the welfare effect of adding imperfect competition is slight because the airport regulators have already extracted part of the rents. Assuming one airport regulator on each continent is not entirely realistic as, for instance, the EU has many national regulators. We therefore also analyze how the number of regulators affects treatment of intercontinental traffic. Since each continent has an incentive to exploit intercontinental traffic, only half of which consists of its own passengers, an obvious way to limit this exploitation is to require that intercontinental flights and domestic flights be charged the same amount. We show that this is indeed an effective way to limit the distortion from the strategic behavior of airport regulators.

The analysis illustrates that, with market power, an airport regulator can easily add costly requirements to intercontinental passengers and flights as there is no competitive pressure from other airport regulators on the same continent. This notion brings us to the fifth question we address: Who ultimately bears the burden of the measures imposed by one airport regulator? We find that the continent imposing the extra charges itself bears to a large extent the additional burden. This lesson might apply to immigration-control charges in the US, greenhouse gas permits in Europe, etc.

In section 2, we briefly review the literature. In section 3 we define the core concepts of the model. Section 4 is devoted to the analytical study of international airport-charge competition. Section 5 examines capacity and airport-charge competition. As the algebraic model does not generate unequivocal answers for all questions, we turn to numerical illustrations in section 6. Section 7 concludes and discusses possible extensions.

2. A brief review of the literature

The paper is most closely related to a disparate set of studies that explore transportation models characterized by horizontal double marginalization. The closest antecedent is a paper by De Borger, Dunkerley and Proost (DBDP) (2007). This paper focuses on a transport corridor with two serial links, each of which is controlled by a different regional government. "Transit" traffic uses both links, while local traffic uses only one. DBDP (2007) focus both on pricing and investment decisions. Each government fully controls pricing and capacity on its own link and maximizes local welfare, not taking into account the welfare of transit traffic, which pays a separate charge and is a revenue source to be exploited. A transit trip has to use both links and is taxed non-cooperatively by both governments. Every increase in charges by one government reduces the number of transit trips and therefore the revenues of the other government. These spillovers to the other region are not taken into account, thus generating double marginalization, which reflects a variant of the double marginalization problem for successive monopolies in the industrial organization literature (see, e.g., Tirole (1993)).

The DBDP framework bears some resemblance to the model analyzed in this paper. Their congested links are now congested airports, and their transit traffic is analogous to intercontinental flights. But important differences between the models exist. First, the DBDP framework has atomistic consumers using the two links (cars or trucks), while the present model has airlines that may be imperfectly competitive. Second, there may be several airports (each with its own regulator) on a given continent, which would correspond to a serial link structure that has parallel competition on one end. Third, the cost structure of flights is different than that in the DBDP model.

Models of international airline alliances also focus on double marginalization in the pricing of international trips, which is eliminated when an alliance is formed (see, for example, Brueckner (2001) and Brueckner and Proost (BP) (2010)). Without an alliance, an international trip that crosses the networks of two airlines is inefficiently priced, being the sum of two separate "subfares" (payments for use of one network) that are set non-cooperatively by the carriers. A higher subfare for one airline raises the overall fare, reducing traffic and imposing negative, unrecognized spillovers on other airline. Each subfare (and thus the overall fare) is set too high. By maximizing the total profit of the carriers, an airline alliance internalizes these spillovers, leading each airline to reduce its subfare, which lowers the overall fare and raises the level of traffic.

The second related literature, which is surveyed by Basso and Zhang (2007a), analyzes airport pricing and capacity decisions in the presence of congestion. Early contributions to this literature deal solely with airport congestion pricing, abstracting from capacity issues and not considering the airport itself as a separate agent. The main focus of this work is internalization of congestion by the airlines, under which a carrier takes self-imposed congestion into account in choosing its flight volumes (see, for example, Daniel (1995) and Brueckner (2002)). Later work (see Zhang and Zhang (2006), Basso (2008)) treats the airport itself as a separate maximizing agent. The airport, which is free to maximize profit if it is unregulated, sets capacity along with the charge it levies on the airlines, taking into account the impacts on fares, flight volumes and congestion.

This second line of research usually focuses on a single airport interacting with a group of competitive or imperfectly competitive airlines, with interaction *between* airports being absent. There are a few notable exception to this single-airport focus, however. One is the model of Pels and Verhoef (2004), who consider two airports connected by a pair of airlines, with one case of interest involving separate regulators for the two airports. As in the present model, the resulting lack of coordination leads to inefficiencies. We use a framework close to theirs but add capacity choices as well as local users of each airport, who are only indirectly affected by the other airport's decisions. The analysis of Oum, Zhang and Zhang (1996) also uses a model where the airports in a hub-and-spoke network may be controlled by different regulators, and they show that this arrangement is inferior to one where all airports are under the same authority.[2]

The paper is also related to the industrial organization literature on complementary monopolies (Bresnahan and Reiss (1985)). Consider again our extreme example where airports are uncongested and serve only perfectly competitive intercontinental airlines, with airports simply interested in maximizing revenue from airport charges. Feinberg & Kamien (2001) show that, when this general type of problem is studied as a pricing game, an equilibrium only exists in the case where prices are set simultaneously. In such a non-cooperative equilibrium, a double marginalization problem arises, with charges higher than those that would be chosen by a world regulator in a monopoly position. While these findings are a good starting point, the framework can be expanded into a richer, more realistic setting by adding following additional features. First the two monopolists (our airport regulators) are interested in revenues and profits but also in the consumer surplus of passengers and producer surplus of the home airlines. Second, airports are congested, and capacities along with airport charges need to be set. Third, airports supply inputs used by two

[2] Basso and Zhang (2007b) consider a different type of competition between congested facilities (airports). In their model, a consumer uses either one airport or the other depending on proximity to the residence. Airports set charges and capacities to attract passengers. With this either/or choice, however, the model does not involve the kind of airport complementarity that is the main focus of this paper or those just cited.

different products: transcontinental flights and domestic flights. Fourth, flights may be supplied by imperfectly competitive airlines[3].

3. The Model

Model structure and assumptions

Figure 1 sets out the model structure. The structure borrows some elements from the DBDP (2007) model and from BP (2010).

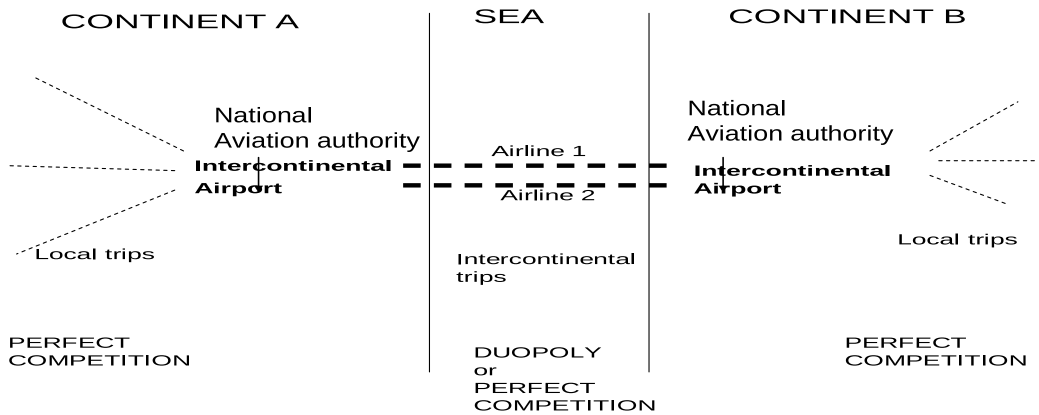

Figure 1: The intercontinental airport model set up

The simple setting we consider consists of two continents A,B that each have one intercontinental airport. Each of the airports serves two types of air traffic: intercontinental “X” and local “Y”. We treat both of them as independent. Adding trips that combine domestic and international segments would be possible but would clutter our main argumentation. Compared to DBDP (2007), we have airlines that are non-atomistic consumers of the congestible facilities. Compared to Pels and Verhoef (2004), we include capacity decisions and also local traffic that uses only one of the two international airports. Compared to Basso and Zhang (2007b), we have airports that are complements (one on each end of the ocean) rather than substitutes.

Prices P_i^j are full prices that include both time costs and fares paid to the airlines, and linear demand functions are used in order to obtain explicit solutions.

[3] After this work was underway, we became aware of paper by Mantin (2012), which analyzes a similar problem. The two papers should be viewed as complementary.

Demand for local transport in regions A and B is represented by the strictly downward sloping linear inverse demand functions $P_A^Y\{Y_A\}$ and $P_B^Y\{Y_B\}$, respectively, where Y_A and Y_B are the local passenger traffic flows on both links (braces { } are used to denote functions, while parentheses denote multiplication). Intercontinental traffic is described by the strictly downward sloping linear inverse demand function $P^X\{X\}$, where X is the total traffic flow between A and B. The price expressions in these curves give the "full" price of travel, which will include the fare as well as the time costs of congestion. The inverse demands are

$$
\begin{aligned}
&P^X\{X\} = a - bX \\
&P_A^Y\{Y_A\} = e_A - d_A Y_A \\
&P_B^Y\{Y_B\} = e_B - d_B Y_B \\
&with\ a, b, e_A, d_A, e_B, d_B > 0
\end{aligned}
\qquad (1)
$$

Demand is met by two types of airlines: international carriers and local carriers. The international carriers operate either in a duopoly (airlines 1 and 2) or under perfect competition. The local carriers provide local trips and act in a perfectly competitive environment. The two international airports A and B are both government regulated and are instructed to maximize a given objective function.

Airport congestion costs, which represent time costs, are allowed to differ between domestic and international passengers. These costs are assumed to depend on the ratio of total airport traffic, $X+Y_A$ or $X+Y_B$, and airport capacity, K_A or K_B. For notational simplicity, we rely on the inverses of the capacities K_A and K_B, denoting them R_A and R_B. Multiplying by a constant that is airport specific, the resulting component of congestion costs for domestic passengers at airport A equals

$$\beta_A \frac{X+Y_A}{K_A} = R_A \beta_A (X+Y_A) = \beta^*_A (X+Y_A)$$

where the expression $\beta^*_A = \beta_A R_A$ is used when capacity is held fixed. Assuming that using the airport in an uncongested state involves a time cost of α_A, and normalizing the remaining trip time costs to zero, the time costs for domestic passengers at the two airports are given by

$$
\begin{aligned}
&C_A\{X+Y_A\}=\alpha_A+\beta*_A(X+Y_A)\\
&C_B\{X+Y_B\}=\alpha_B+\beta*_B(X+Y_B)\\
&where\ \beta_A^*=R_A\beta_A,\beta_B^*=R_B\beta_B\\
&and\ \alpha,\beta>0
\end{aligned}
\tag{2}
$$

In addition to these costs, domestic passengers pay domestic airfares equal to f_A or f_B.

The intercontinental passengers pay an airfare f_{X1} when using international airline 1 or f_{X2} when using airline 2, and since they use both airports, these passengers face time costs of

$$
\begin{aligned}
&C_{X1}\{X,Y_A,Y_B\}=C_A\{X+Y_A\}+C_B\{X+Y_B\}\\
&C_{X2}\{X,Y_A,Y_B\}=C_A\{X+Y_A\}+C_B\{X+Y_B\}
\end{aligned}
\tag{3}
$$

We assume that airline operating costs per passenger (not including congestion effects) are constant and given by γ_A and γ_B for the domestic carriers, while taking the values γ_1 and γ_2 for the international carriers. In addition to incurring these costs, domestic airlines pay airport charges (per passenger) of t_A or t_B, and the intercontinental airlines pay airport charges per passenger of $\tau_A + \tau_B$ (the sum of the charges τ_A and τ_B levied by the two airports). Finally, congestion costs for the carriers, which are expressed on a per passenger basis and represent resource costs not time costs, are given by expressions analogous to those for passenger congestion costs, with parameters η_A and η_B in place of β_A and β_B. Collecting all these costs, cost per passenger for the domestic airlines in A and B and the two intercontinental airlines 1 and 2 are given by

$$
\begin{aligned}
&c_A\{X+Y_A\}=\gamma_A+\eta*_A(X+Y_A)+t_A\\
&c_B\{X+Y_B\}=\gamma_B+\eta*_B(X+Y_B)+t_B\\
&c_{X1}\{X,Y_A,Y_B\}=\gamma_1+\eta*_A(X+Y_A)+\eta*_B(X+Y_B)+\tau_A+\tau_B\\
&c_{X2}\{X,Y_A,Y_B\}=\gamma_2+\eta*_A(X+Y_A)+\eta*_B(X+Y_B)+\tau_A+\tau_B\\
&where\ \eta_A^*=R_A\eta_A,\eta_B^*=R_B\eta_B,\\
&and\ \gamma,\eta>0
\end{aligned}
\tag{4}
$$

The airports incur two types of costs: fixed operating costs per passenger and the rental costs (κ) per unit of capacity. The airports' costs per passenger are then

$$
\begin{aligned}
&c_A=\mu_A+\frac{\kappa_A K_A}{Y_A+X}\\
&c_B=\mu_B+\frac{\kappa_B K_B}{Y_B+X}
\end{aligned}
\tag{5}
$$

Assumptions must be made on the market behavior of both types of airlines, and on the behavior of airports with respect to airlines. We assume perfectly competitive behavior for the domestic airlines, which sell at their marginal costs. In addition, the perfect competition assumption means that these airlines do not internalize any of the congestion they create (Brueckner 2002). The international airlines are either perfectly competitive or behave as a Cournot duopoly (see Brander and Zhang (1990) for empirical evidence on the realism of the latter assumption). The airports are Stackelberg leaders with respect to the airlines. They first choose capacity in a Cournot game and then play a Nash game in airport charges.

We look for equilibrium of this game by solving four stages. In stage 1, capacity is chosen by the airports; in stage 2, airport charges are chosen by airports; in stage 3, airfares are chosen by the airlines; in stage 4, consumers select the number of trips and airline. We work backwards, starting with stage 4 and next solving stage 3. The results of stages 3 and 4 will be summarized by "reduced-form" demand functions that will be used in stages 1 and 2. We analyze the reduced-form demands in the next section.

Equilibrium in the domestic markets

The consumers of domestic trips have only to decide on the number of trips, not on the airline as all airlines offer the same services. It is useful to first solve for the demand for domestic trips as a function of the fare and of the volume of intercontinental flights X, which co-determine the level of congestion. Using (1) and (2) we find

$$\begin{aligned} Y_A &= z_A\left\{f_A, X\right\} = \frac{e_A - \alpha_A}{\beta_A * + d_A} - \frac{\beta_A *}{\beta_A * + d_A} X - \frac{1}{\beta_A * + d_A} f_A \\ Y_B &= z_B\left\{f_B, X\right\} = \frac{e_B - \alpha_B}{\beta_B * + d_B} - \frac{\beta_B *}{\beta_B * + d_B} X - \frac{1}{\beta_B * + d_B} f_B \end{aligned} \quad (6)$$

Higher international traffic (X) increases congestion and decreases the volume of domestic travel, as does a higher domestic fare.

With perfect competition, the domestic fare equals cost per passenger, as given by (4). Thus,

$$\begin{aligned} f_A &= \gamma_A + \eta *_A (X + Y_A) + t_A \\ f_B &= \gamma_B + \eta *_B (X + Y_B) + t_B \end{aligned} \quad (7)$$

Substituting in (6) and solving for Y_A and Y_B then gives the equilibrium volume of domestic trips. For airport A,

$$Y_A = \frac{e_A - \alpha_A}{\beta_A{*} + d_A} - \frac{\beta_A{*}}{\beta_A{*} + d_A} X - \frac{1}{\beta_A{*} + d_A}(\gamma_A + \eta{*}_A (X + Y_A) + t_A)$$

$$Y_A = \frac{e_A - \alpha_A - \gamma_A}{\nu{*}_A} - \frac{\beta_A{*} + \eta{*}_A}{\nu{*}_A} X - \frac{1}{\nu{*}_A} t_A \quad (8)$$

$$\text{where } \nu{*}_A = (1 + \frac{\eta{*}_A}{\beta_A{*} + d_A})(\beta_A{*} + d_A)$$

As expected, the equilibrium volume of domestic trips is decreasing in airline operating costs (γ), in uncongested travel time (α), in the airport charge (t), and in intercontinental traffic, a result of higher congestion.

Equilibrium in the intercontinental market

The consumers of international trips select an airline and then decide on the number of trips on that airline, X1 or X2. We distinguish two regimes: perfect competition and duopoly. For the case of perfect competition, the international market is served by a large number of airlines that take prices as parametric. The demand for international trips is then given by the following equation (where we do not specify the identity of the airline and where bars denote variables viewed as parametric):

$$f_X = a - \alpha_A - \alpha_B - (b + \beta_A^* + \beta_B^*)X - \beta_A^* \overline{Y_A} - \beta_B^* \overline{Y_B} \quad (9)$$

Since the demand for international trips depends on the level of congestion at the two airports, it depends on the domestic traffic volumes.

In the case of a duopoly we assume that the flights offered by the airlines 1 and 2 are perfect substitutes and that we have Cournot competition. The demand for international trips by airline 1 will then be a function of the quantity supplied by the other international airline as well as of the volume of domestic trips, which the airlines take as given. We can derive the following equation for the airfare of the international airline 1 by using the inverse demand function (1) and the passenger costs in (3):

$$f_{X1} + C_A\left\{X1 + \overline{X2} + \overline{Y_A}\right\} + C_B\left\{X1 + \overline{X2} + \overline{Y_B}\right\} = a - bX1 - b\overline{X2}$$

$$f_{X1} = a - \alpha_A - \alpha_B - (b + \beta_A^* + \beta_B^*)X1 - (b + \beta_A^* + \beta_B^*)\overline{X2} - \beta_A^* \overline{Y_A} - \beta_B^* \overline{Y_B} \quad (10)$$

The maximum fare an international airline can charge is thus decreasing in the quantity supplied by its rival airline (X2), as in all duopolies. The fare is also decreasing in domestic traffic volumes as a result of higher congestion.

To find the equilibrium under perfect competition (index "p"), we must assume identical variable costs for the two carriers, so that $\gamma_1 = \gamma_2 = \gamma$. We then equate the fare in (9) to the (common) international-carrier cost expression in (4) and solve for X, which yields

$$
\begin{aligned}
& X^p = z_X^* - \frac{(\beta_A^* + \eta_A^*)}{v_X^*} Y_A - \frac{(\beta_B^* + \eta_B^*)}{v_X^*} Y_B - \frac{\tau_A}{v_X^*} - \frac{\tau_B}{v_X^*} \\
& \text{where} \\
& z_X^* = \frac{1}{v_X^*}\{a - \alpha_A - \alpha_B - \gamma\} \\
& v_X^* = b + \beta_A^* + \eta_A^* + \beta_B^* + \eta_B^*
\end{aligned}
\tag{11}
$$

The equilibrium volume of intercontinental trips decreases with the volume of domestic trips, a result of congestion, and is also decreasing in the airport charges of the two airports.

Alternatively, to find the Cournot duopoly equilibrium (index "d") we first derive the reaction function of airline 1 by maximizing its profits taking the output of the other intercontinental airline as given. Using the inverse demand function (1), profit equals

$$
\begin{aligned}
& f_1\left\{X_1^d + \overline{X_2^d}, Y_A, Y_B\right\} X_1^d - (\gamma_1 + \tau_A + \tau_B) X_1^d \\
& -\eta^*_A (X_1^d + \overline{X_2^d} + \overline{Y_A}) X_1^d - \eta^*_B (X_1^d + \overline{X_2^d} + \overline{Y_B}) X_1^d
\end{aligned}
\tag{12}
$$

The first-order condition for maximization of (12) with respect to X_1^d can be written in terms of the resulting international fare, which is given by

$$
\begin{aligned}
f_1 = & (\gamma_1 + \tau_A + \tau_B) + bX_1^d + (\beta_A^* + \beta_B^*) X_1^d + (\eta_A^* + \eta_B^*) X_1^d \\
& + (\eta_A^* + \eta_B^*)(X_1^d + \overline{X_2^d}) + \eta_A^* \overline{Y_A} + \eta_B^* \overline{Y_B}
\end{aligned}
\tag{13}
$$

We see that this fare is a sum of four terms:

- the constant variable cost and airport charges per passenger ($\gamma_1 + \tau_A + \tau_B$)
- the monopoly mark-up (bX_1^d)
- the marginal external congestion cost for airlines 1's passengers and for its own operations, which is internalized $(\beta_A^* + \beta_B^*) X_1^d + (\eta_A^* + \eta_B^*) X_1^d$ (Brueckner (2002))
- the average operation cost $(\eta_A^* + \eta_B^*)(X_1^d + \overline{X_2^d}) + \eta_A^* \overline{Y_A} + \eta_B^* \overline{Y_B}$

Substituting for the fare on the LHS of (13) using (10), and writing an analogous equation for carrier 2, we can derive the reaction functions and the Cournot equilibrium:

$$X_1^d = \frac{v_1^*}{2v*} - \frac{1}{2} X_2^d$$
$$X_2^d = \frac{v_2^*}{2v*} - \frac{1}{2} X_1^d$$

solving:

$$X_1^d = \frac{1}{3v*}(2v_1^* - v_2^*)$$
$$X_2^d = \frac{1}{3v*}(2v_2^* - v_1^*) \tag{14}$$

where

$$v* = b + \beta_A^* + \beta_B^* + \eta_A^* + \eta_B^*$$
$$v_1^* = a - (\gamma_1 + \alpha_A + \alpha_B + \tau_A + \tau_B) - (\beta_A^* + \eta_A^*)\overline{Y_A} - (\beta_B^* + \eta_B^*)\overline{Y_B}$$
$$v_2^* = a - (\gamma_2 + \alpha_A + \alpha_B + \tau_A + \tau_B) - (\beta_A^* + \eta_A^*)\overline{Y_A} - (\beta_B^* + \eta_B^*)\overline{Y_B}$$

From the reaction functions, when the competitor increases output by 2 units, the airline will reduce output by 1 unit. The airline with lowest operation cost (v_1 decreases in γ_1) will have the highest output in equilibrium. Higher local airline activity (*Y*) and higher airport charges (τ) will, in equilibrium, reduce the number of international flights.

From (14), the total volume of international airline trips under the Cournot equilibrium equals

$$\begin{aligned} X^d &= X_1^d + X_2^d \\ &= \frac{2}{3}\left\{ \frac{a - \alpha_A - \alpha_B - 0.5(\gamma_1 + \gamma_2)}{v_X^*} - \frac{(\beta_A^* + \eta_A^*)}{v_X^*} Y_A - \frac{(\beta_B^* + \eta_B^*)}{v_X^*} Y_B - \frac{\tau_A}{v_X^*} - \frac{\tau_B}{v_X^*} \right\} \\ &= \frac{2}{3} X^p \end{aligned} \tag{15}$$

Thus, the Cournot-equilibrium output corresponds to 66% of what would be produced under perfect competition. More generally, the total volume under the Cournot-equilibrium as

$$X^d = \frac{N}{N+1} X^P \tag{16}$$

Where N equals the number of intercontinental airlines.

The First Best Solutions

Before considering the choices of the airports game, it is instructive to discuss the first best solution, which will be used as a benchmark. Consider first the easier case where there are no international trips. Since there is perfect domestic competition and no interactions between airports, implementation of first-best congestion charges and airport capacities ensures attainment of the optimum .

Each government instructs its airport to maximize welfare, equal to the sum of consumer surplus of local users (three first terms in (17) below) plus the producer surplus of the local airline (next term) plus tax revenue minus capacity costs (the last terms):

$$SW_A = \int_0^{Y_A} P(y)dy - Y_A C_A(Y_A) - f_A Y_A + [f_A - \gamma_A - \eta^*_A\, Y_A - t_A]Y_A + (t_A - \mu_A)Y_A - \frac{\kappa_A}{R_A} \quad (17)$$

Noting that the terms involving f_A and t_A cancel, (17) is differentiated to find the welfare maximizing level of Y_A, which satisfies the first equation in (18). The t_A required to sustain this level of Y_A is then found by substituting $C_A(Y_A) + f_A$ in place of the full price $P(Y_A)$ and using (7) to substitute for f_A. Rearranging yields the t_A solution given by the second equation of (18):

$$\begin{aligned} P(Y_A) &= \alpha_A + \gamma_A + \mu_A + 2(\beta^*_A + \eta^*_A)Y_A \\ t_A &= \mu_A + (\beta^*_A + \eta^*_A)Y_A \end{aligned} \quad (18)$$

Thus, the welfare-maximizing airport charge t_A equals the constant variable operating cost plus the marginal external congestion cost borne by passengers and by the local airlines. As the local airlines are atomistic, they do not internalize these congestion costs and must be charged for them.

Given first-best congestion charges, the optimal airport capacity can then be chosen so as to minimize passenger and airline costs. Recalling that β_A* and η_A* depend on R_A from (2) and (4), maximizing (17) with respect to this inverse-capacity measure yields the following optimal airport capacity condition:

$$(\beta_A + \eta_A)Y_A^2 = \frac{\kappa_A}{R_A^2} \quad (19)$$

The right-hand side represents the savings in airport capacity cost when capacity is decreased (R_A is increased) and the left-hand side represents the extra passenger and airline operating costs associated with a lower capacity.

We can now add the international trips and derive the world first-best pricing and capacity at the two airports. When all national and international airlines are perfectly competitive, it is sufficient for a world planner to control all airport fees and airport capacities to reach the social optimum. When the international airlines behave as a duopoly, fares will be set too high, which means that the planner must control the two airports as well as the international fares to achieve the optimum.

The planner maximizes welfare, which implies maximizing the consumer surplus of local users plus the consumer surplus of international travellers plus the producer surplus of the local airline plus producer surplus of international airlines plus revenue minus capacity costs of the two airports:

$$\begin{aligned}SW_{A+B} &= \sum_{j=A,B}\left[\int_0^{Y_j} P_j(y)dy - Y_j C_j(Y_j+X) - f_j Y\right] + \int_0^X P(x)dx - \sum_{i=1,2}(X_i\left[\sum_{j=A,B} C_j(X_i+Y_j)\right] + f_i X_i)\\ &+ \sum_{j=A,B}\left[(f_j - \gamma_j - \eta^*_j(X+Y_j) - t_j)\right]Y_j\\ &+ \sum_{i=1,2}\left[(f_i - \gamma_i - \sum_{j=A,B}(\eta^*_j(X+Y_j) - t_j)\right]X_i\\ &+ \sum_{j=A,B}\left[(t_j-\mu_j)Y_j + X(t_j-\mu_j) - \frac{\kappa_j}{R_j}\right]\end{aligned} \tag{20}$$

Using the approach leading to (18), the first-order conditions along with (11) lead to the following expressions for the full price, airfare and airport charge for domestic flights (we show only expressions for airport A):

$$\begin{aligned}P(Y_A) &= \alpha_A + \beta^*_A Y_A + \mu_A + \gamma_A + (\beta^*_A + 2\eta^*_A)(Y_A+X)\\ f_A &= \gamma_A + \eta^*_A(Y_A+X) + t_A\\ t_A &= \mu_A + (\beta^*_A + \eta^*_A)(Y_A+X)\end{aligned} \tag{21}$$

For the intercontinental flights, we assume the planner can force the airlines to charge a perfectly competitive airfare, allowing use of the same airport tax for domestic and intercontinental flights. We again assume identical variable costs for the two carriers, so that $\gamma_1 = \gamma_2 = \gamma$. We have:

$$
\begin{aligned}
&P(X)=\alpha_A+\alpha_B+(\beta*_A+\beta*_B)X+\mu_A+\gamma+\mu_B+(\beta*_A+2\eta*_A)(Y_A+X)+(\beta*_B+2\eta*_B)(Y_B+X)\\
&f_X=\gamma+\eta*_A(Y_A+X)+\eta*_B(Y_B+X)+\tau_A+\tau_B\\
&\tau_A=\mu_A+(\beta*_A+\eta*_A)(Y_A+X)\\
&\tau_B=\mu_B+(\beta*_B+\eta*_B)(Y_B+X)
\end{aligned}
\tag{22}
$$

The optimal airfare f_x covers the per-passenger operating cost of the airline (equal to $\gamma+\eta*_A(Y_A+X)+\eta*_B(Y_B+X)$) plus the airport charges. The airport charge needed for optimal pricing of international flights covers the airport operating cost plus the marginal external congestion costs for international and domestic airlines and passengers ($(\beta*_A+\eta*_A)(Y_A+X)$ for airport A). The optimal capacities satisfy a condition that generalizes (19) to include both types of traffic:

$$
(\beta_A+\eta_A)(Y_A+X)^2=\frac{\kappa_A}{R_A^2} \tag{23}
$$

4. The airport game

In this section, we focus on the analysis of strategic behavior by airport regulators. Since it is in general difficult to obtain an explicit solution for equilibrium flows as functions of airport capacity, we therefore focus on explicit expressions of the transport equilibrium as a function of the airport charges, holding capacity constant. For more complete and complementary results we refer to the numerical illustrations in the next section. We first construct the “reduced” demand functions, which allow analysis of the airport charging game.

The reduced total demand functions

As in DBDP (2007), the study of the game between airport regulators is more tractable when reduced demand functions can be used. The reduced demand functions characterize the equilibrium travel flows as functions of the control variables of both governments (airport charges and capacity) and as a function of the market regime on the international air transport market.

Furthermore, to obtain more readable analytical expressions we assume symmetry for all demand and cost parameters of consumers and firms in both countries:

$$e_A = e_B = e \ ; \ d_A = d_B = d \ ; \ \alpha_A = \alpha_B = \alpha \ ; \ \beta_A^* = \beta_B^* = \beta^*$$
$$\gamma_A = \gamma_B = \gamma_L \ ; \ \eta_A^* = \eta_B^* = \eta^*$$

We start with the perfect competition case. Using (8) and (11), the perfectly competitive equilibrium can be written as follows (the parameters w_j^i correspond to the parameters in (8) and (11)) :

$$\begin{aligned} Y_A &= w_1^L + w_2^L X^p + w_3^L t_A \\ Y_B &= w_1^L + w_2^L X^p + w_3^L t_B \\ X^p &= w_1^X + w_2^X (Y^A + Y^B) + w_3^X \left(\tau_A + \tau_B\right) \end{aligned} \qquad (24)$$

Solving for X^P, we have:

$$\begin{aligned} X^p &= \frac{1}{m}\left[(w_1^X + 2w_2^X w_1^L) + (w_2^X w_3^L)\,(t_A + t_B) + w_3^X\,(\tau_A + \tau_B)\right] \\ &\text{with } m = 1 - 2\,w_2^X w_2^L \\ X^p &= r_1^p + r_2^p (t_A + t_B) + r_3^p (\tau_A + \tau_B) \\ &\text{where } r_2^p \geq 0 \text{ and } r_3^p < 0 \end{aligned} \qquad (25)$$

Solving for equilibrium local traffic levels then gives:

$$\begin{aligned} Y_A^p &= (w_1^L + w_2^L r_1^p) + (w_3^L + w_2^L r_2^p) t_A + (w_2^L\ r_2^p) t_B + (w_2^L r_3^p)(\tau_A + \tau_B) \\ Y_B^p &= (w_1^L + w_2^L r_1^p) + (w_2^L\ r_2^p)\ t_A + (w_3^L + w_2^L r_2^p) t_B + (w_2^L r_3^p)(\tau_A + \tau_B) \\ &\text{where it can be shown that } (w_3^L + w_2^L r_2^p) < 0 \quad (w_2^L\ r_2^p) > 0 \quad (w_2^L r_3^p) > 0 \end{aligned} \qquad (26)$$

For the imperfect competition case (index "d") we can make use of the property in (16). If we define $M = \dfrac{N}{N+1}$, we find that

$$\begin{aligned} X^d &= M\left[r_1^p + r_2^p (t_A + t_B) + r_3^p (\tau_A + \tau_B)\right] \\ Y_A^d &= (w_1^L + M\ w_2^L r_1^p) + (w_3^L + M\ w_2^L r_2^p) t_A + (M\ w_2^L\ r_2^p) t_B + (M\ w_2^L r_3^p)(\tau_A + \tau_B) \\ Y_B^d &= (w_1^B + M\ w_2^B r_0^p) + (M\ w_2^L\ r_2^p)\ t_A + (w_3^L + M\ w_2^L r_2^p) t_B + (M\ w_2^L r_3^p)(\tau_A + \tau_B) \\ &\text{where we have that: } (w_3^L + M\ w_2^L r_2^p) < 0 \quad (M\ w_2^L\ r_2^p) > 0 \quad (M\ w_2^L r_3^p) > 0 \end{aligned} \qquad (27)$$

These last results follow directly from (25) and (26), recognizing that the *r* parameters in (25) are each multiplied by M. With these reduced demand expressions, we can analyse a strategic tax game between airport regulators.

The airport charges game for fixed capacities with local and intercontinental trips and perfect competition

Assume now that airports are interested in the welfare of their country's own passengers, equal to domestic passengers plus half the intercontinental passengers. As intercontinental passengers pay airport charges in both airports, we need to derive first the airport charge for each airport independently and then solve for the Nash equilibrium.

We maximize first the objective function of the local airport regulator, using as controls t_A and τ_A and treating the quantity of trips $Y_A(t_A, \tau_A)$ and $X(t_A, \tau_A)$ as functions of those two control variables. The result will be airport charges for local traffic and for intercontinental traffic at airport A that are functions of output and cost parameters. For the airport in the other region, we can carry out the same analysis.

We assume the following objective function: consumer surplus of domestic passengers (first three terms), plus half of the surplus of international passengers (the expression in braces), plus the profits of the local airlines and one of the two intercontinental airlines (we assume that one international airline is located in each country), plus tax revenue minus airport costs:

$$\begin{aligned} SW_A = & \int_0^{Y_A} P_A(y)dy - Y_A C_A(Y_A + X) - f_A Y + 0.5\left\{\int_0^X P(x)dx - \sum_{i=1,2}(X_i\left[\sum_{j=A,B} C_j(X_i + Y_j)\right] + f_i X_i)\right\} \\ & + Y_A(f_A - \gamma_L - \eta^*(X + Y_A) - t_A) \\ & + (f_1 - \gamma - \sum_{j=A,B}(\eta^*(X + Y_j) - \tau_j)X_1 \\ & + (t_A - \mu_A)Y_A + X(\tau_A - \mu_A) - \frac{\kappa_A}{R_A} \end{aligned} \tag{28}$$

Imposing zero profits and using the demand assumptions at the beginning of section 3, we can simplify the objective function to:

$$SW_A = 0.5\, d\, Y_A^2 + 0.5\left(0.5\, b\, X^2\right) + (t_A - \mu_A)Y_A + X(\tau_A - \mu_A) - \frac{\kappa_A}{R_A} \tag{29}$$

Using the definitions of (25) and (26), the first-order conditions for t_a and τ_A are

$$\begin{aligned} & Y_A + (r_2^p\, w_2^L + w_3^L)(t_A + d\, Y_A - \mu_A) + r_2^p(0.5\, b\, X - \mu_A + \tau_A) = 0 \\ & X + (r_3^p\, w_2^L)(t_A + d\, Y_A - \mu_A) + r_3^p(0.5\, b\, X - \mu_A + \tau_A) = 0 \end{aligned} \tag{30}$$

We can solve this system of equations and fill in the r and w definitions to obtain the following solution:

$$t_A = \mu_A + (\beta^* + \eta^*)(Y_A + X)$$
$$\tau_A = \mu_A + (\beta^* + \eta^*)(Y_A + X) + 0.5b\,X + \frac{d(\beta^* + \eta^*)}{(d + \beta^* + \eta^*)} X \qquad (31)$$

Note that since X and Y_A are themselves functions of the tax rates, these solutions give tax "rules" rather than closed-form solutions for the taxes. Analogous results hold for country B. We see that a country will apply optimal congestion pricing for domestic flights but will charge a mark-up for international flights. This mark-up consists of two terms:

- the airport regulator acts as a monopolist and charges half of the monopoly mark-up as he neglects half of the CS (first term).
- but the airport regulator also recognizes that he can favor the local travellers by decreasing the international flights (second term).

The effect of imperfect intercontinental airline competition

Imperfect competition will affect the derivation of optimal taxes in two ways: first we need to take the reduced demand functions from equation (27). Second, a government will now take into account some intercontinental airline profits in its objective function as they are positive (third term):

$$SW_A = 0.5\,d\,Y_A^2 + 0.5\left(0.5\,b\,X^2\right) + mX\left(\frac{X}{N}\right)(b + 2(\beta^* + \eta^*)) + (t_A - \mu_A)Y_A + X(\tau_A - \mu_A) - \frac{\kappa_A}{R_A},$$

(32)

where we define m as the total market share of the domestic firms with $m \in [0,1]$: the higher this market share, the more a government will take into account total airline profits in its welfare function. Using the same derivations as in the previous section, we formulate the first order conditions for country A:

$$Y_A + (r_2^d\, w_2^L + w_3^L)(t_A + d\,Y_A - \mu_A) + r_2^d\,((0.5B + 2m\,(b + \beta^* + \eta^*)/N)\,X - \mu_A + \tau_A) = 0$$
$$X + (r_3^d\, w_2^L)(t_A + d\,Y_A - \mu_A) + r_3^d\,((0.5B + 2m(b + \beta^* + \eta^*)/N)X - \mu_A + \tau_A) = 0 \qquad (33)$$

The results with imperfect airline competition are very similar to the previous solutions:

$$t_A = \mu_A + (\beta^* + \eta^*)(Y_A + X)$$
$$\tau_A = \mu_A + (\beta^* + \eta^*)(Y_A + X) + 0.5bX + \frac{d(\beta^* + \eta^*)}{(d + \beta^* + \eta^*)} X + \frac{1 - 2m}{N}\left[b + 2(\beta^* + \eta^*)\right] X \qquad (34)$$

The fourth term in (33) is new and captures the additional effect of imperfect competition among intercontinental airlines. Both the sign and magnitude of the additional mark-up depend on the total number of international airlines (N) and the total market share of domestic airlines on the international market ($m \leq 1$). As a consequence, the fourth term of equation (34) represents a 'double marginalization' effect between companies and countries: as long as airlines in both countries have an equal market share (m=0.5), the fourth term drops out and no additional effects occur because profits of home firms have the same weight as government revenue. However, for a country without international airlines (m=0), the government has to use the tax instrument to extract revenues and the fourth term is an extra mark-up. So when only foreign companies sell on the international market, a government sets an extra mark-up in order to tax away foreign profits. When the countries' international airlines have a market share larger than 50% (m>0.5), the fourth term becomes negative and the tax on international trips decreases. The government with the dominant international airlines knows that its airlines will charge a mark up and that the country will benefit from these profits. Under these conditions, it can as well avoid the double marginalization effect with respect to its own international airlines and decrease its tax.

The effect of uniform charges for national and intercontinental flights

So far, countries are allowed to differentiate between local and international flights. We now analyse the optimal tax when the same tax is required for all flights. For simplicity, we assume perfect competition for intercontinental flights. When equalizing tax levels, we need to reformulate the reduced demand functions:

$$\begin{aligned} X^p &= r_1^p + (r_3^p + r_2^p)(\tau_A + \tau_B) \\ Y_A^p &= (w_1^L + w_2^L r_1^p) + (w_3^L + w_2^L (r_2^p + r_3^p))\tau_A + w_2^L(r_2^p + r_3^p)\tau_B \\ Y_B^p &= (w_1^L + w_2^L r_1^p) + (w_3^L + w_2^L (r_2^p + r_3^p))\tau_B + w_2^L(r_2^p + r_3^p)\tau_A \end{aligned} \tag{35}$$

Now, we can again solve the game in the same way as before. We maximize the welfare function of both countries with respect to the tax.

$$SW_A = 0.5\, d\, Y_A^2 + 0.5\left(0.5\, b\, X^2\right) + (X + Y_A)(\tau_A - \mu_A) - \frac{\kappa_A}{R_A} \tag{36}$$

Only one first order condition for each country determines the solution. We have:

$$(Y_A + X) + (w_3^L + w_2^L(r_2^p + r_3^p))(\tau_A + d\,Y_A - \mu_A) + (r_3^p + r_2^p)(0.5b\,X - \mu_A + \tau_A) = 0 \qquad (37)$$

Solving the system of first order conditions gives us the following result:

$$\tau_A = \mu_A + (\beta^* + \eta^*)(Y_A + X) + \left[0.5bX + \frac{d(\beta^* + \eta^*)}{(d + \beta^* + \eta^*)}X\right]\frac{1}{1+C}$$
$$Where\ C = \frac{b}{d} + \frac{(\beta^* + \eta^*)}{(d + \beta^* + \eta^*)} \qquad (38)$$

The optimal tax resembles the international airline tax from equation (31). As parameter C is always positive, the mark-up set by the government will always be smaller to protect the consumer surplus of the domestic passengers. The less price sensitive are the local passengers, the larger will be the mark up for all airport users because a higher mark up costs less in terms of local consumer surplus (lower d decreases C and therefore the mark-up).

5. Numerical illustrations

The aim is to illustrate the theoretical results but also to show the relative magnitudes of the effects for those cases where the theory is too complex to show clear-cut results. We first calculate the first-best solution that will serve as the reference case. The first best can be reached with perfect airline competition combined with proper congestion pricing. After the study of the reference case, we introduce the role of imperfect competition between airlines and the role of strategic airport regulators.

A. The calibration of the reference scenario

An overview of all air transport costs is given in Table 1. Consumers have a fixed cost per flight of 4 €, airlines have a fixed cost of 10 € per passenger for local flights and a cost of 20 € per passenger for international flights. The average waiting cost for passengers and airlines (per passenger) is assumed to be 15 € per hour. The airports have a fixed cost of 5 € per passenger and a rental cost of capital of 50 € per unit.

For the reference case, we calibrated the model with a point price elasticity of demand of -0.6, which is in correspondence with existing literature (Gillen, Morrison, Stewart (2008)). This calibration to the first best equilibrium gives the following hourly linear demand functions for local and international traffic:

$$P^X\{X\} = 510 - 0.09X$$
$$P^Y_{A/B}\{Y_{A/B}\} = 255 - 0.03Y_{A/B}$$

Table 1. Cost parameters: all cost parameters for the reference case are assumed symmetric between countries and airlines.

Cost parameters numerical example		
Consumer cost	fixed cost (α)	4 €/trip
	waiting cost (β)	15 €/h
Airline cost	fixed local (γ)	10 €/trip
	fixed international (γ)	20€/trip
	waiting (η)	15 €/h
Airport cost	fixed cost (μ)	5 €/trip
	rental (κ)	50 €/ inst cap.

We can decentralise the first-best equilibrium with perfectly competitive intercontinental and domestic airlines using airport taxes that internalize the external congestion costs. For simplicity, we assume that the charges on intercontinental flights in the two countries must be equal. Demand for intercontinental flights only reacts to the total charge, so we introduce this constraint in the reference case to make the reference equilibrium more comparable with the results to come.

In our illustrative reference equilibrium, the total flight demand during peak hours in each airport is 8807, of which 40% are international travellers. Each airport can transport 6822 consumers per hour, which corresponds to a total per year of approximately 30 million passengers. According to European Commission (2010), this is the number of passengers leaving on a yearly basis at London Heathrow Airport. With the capacity and flight demand, we can calculate that the average waiting time for a local flights is approximately 40 minutes, and that for an international flight it is 1h 20 minutes. Aggregated costs, prices and other indicators for the reference equilibrium are given in Table 2 .

Table 2: Results for the first-best reference case

Airport volumes, objective value for regulator and firms			
capacity	6822	welfare in each region	698195
number of local flights	5285	total welfare[4]	1396391
number of international flights	3523	profit for each firm	0

Airline costs	Local traffic	Int. Traffic	Consumer costs	Local traffic	Int. Traffic
airport tax	43.7	43.7	ticket price	73.1	146.2
waiting time	19.4	38.7	waiting cost	19.4	38.7
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**73.1**	**146.2**	**total**	**96.5**	**192.9**

Assuming a duopoly in the market for intercontinental travel does not lead to welfare loss: as long as the central planner controls the airport taxes, the first best can be achieved by reducing the tax on international traffic, as this compensates for the higher ticket price set by the international airlines.

B. The effect of strategic airport regulators

Instead of one intercontinental planner, we now have a separate airport regulator in each continent, deciding on taxes and capacity. In this second simulation we start from the reference case and approach the problem in two steps:

- What is the effect if airports can decide strategically on charges, for given (first-best) capacity?
- What is the effect if the airports can freely choose both capacity and airport charges?

We address these questions for both imperfect and perfect competition.

Each airport regulator maximizes its own welfare function, which takes into account the consumer surplus of domestic traffic, airline profits and half of the consumer surplus of international travellers. In the case of perfect competition between international airlines, no profits are generated by the firms. The results are shown in Table 3. As expected, strategic interaction leads to a strong increase in intercontinental airport taxes. The intercontinental flights are overtaxed for two reasons:

[4] The total surplus generated by the welfare function is 1 400 000 €.

• The consumer surplus of intercontinental flights is not fully taken into consideration by the regulator, while an increase in taxes results in extra airport revenues.

• By increasing the charge for intercontinental flights, the regulator can reduce congestion for domestic passengers. With lower congestion, a lower domestic charge can be levied.

Table 3. Results from strategic airport interaction on charges only and with perfect airline competition

Airport volumes, objective value for regulator and firms			
capacity	6822	welfare in each region	622495
number of local flights	5672	total welfare	1244989
number of international flights	1813	profit for each firm	0

Airline costs	Local traffic	Int. Traffic	Consumer costs	Local traffic	Int. Traffic
airport tax	37.9	126.5	ticket price	64.4	305.9
waiting time	16.5	32.9	waiting cost	16.5	32.9
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**64.4**	**305.9**	**total**	**84.8**	**346.8**

The higher international charges, which reflect double marginalization in the choices of airport regulators, reduce international traffic by approximately 50%. With double marginalization at work, the ticket price for an international flight more than doubles in comparison with the reference case. Since capacity is fixed at the level of the reference equilibrium, the reduced intercontinental traffic volume implies a reduction in congestion and thus lower domestic airline charges. As a result, local traffic slightly increases, so that total traffic is reduced only by 11%. Finally, total welfare decreases by 12% as a result of strategic behavior.

The contrast between these numerical solutions and the "rule" given in (31) for determining the domestic airport charge should be noted. Although the domestic charge follows the first-best rule, being set equal to variable airport cost plus external congestion costs, the level of traffic is lower than in the first-best solution. As a result, the level of the domestic charge falls in moving from the first-best to the strategic case, even though it is computed using the first-best rule.

Combining strategic behavior with imperfect competition on the intercontinental market means that both the regulator and the airlines will try to maximize profits by increasing the ticket price for intercontinental flights. The results for this case are shown in Table 4. Although the charge for intercontinental flights decreases in comparison to the perfect-competition case, the consumer price for intercontinental flights increases further due to the duopoly. The resulting decline in congestion allows lower charges on domestic flights.

Comparing the results in Tables 3 and 4, an important lesson is that the effect of adding imperfect airline competition to the already-strategic behavior of the airport regulators is limited. With perfectly competitive airlines, the welfare loss from strategic regulators was 12%. This loss rises only slightly to 16% with imperfect competition. The additional effect is limited because both airport regulators behave as Stackelberg leaders with respect to the intercontinental airlines, which means they take into account the duopoly mark-ups that will be charged.

Table 4. Results with strategic interaction on airport charges with imperfect airline competition

Airport volumes, objective value for regulator and firms			
capacity	6822	welfare in each region	587540
number of local flights	5753	total welfare	1175079
number of international flights	1456	profit for each firm	52365

Airline costs	Local traffic	Int. Traffic	Consumer costs	Local traffic	Int. Traffic
airport tax	36.7	107.8	ticket price	62.6	339.3
waiting time	15.9	31.7	waiting cost	15.9	31.7
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**62.6**	**267.3**	**total**	**82.4**	**379.0**

C. Strategic choice of both airport charges and capacities

If airports can decide both on charges and capacity, they will tend to lower their capacity because the higher charges on intercontinental flights mean that less capacity is needed. Table 5 shows that the regulators reduce airport capacity by 25% compared to the first-best outcome. A similar effect emerges with imperfect competition on the intercontinental market, and total airport profit is approximately the same in both cases.

Table 5. Results with strategic interaction on airport charges and capacities with perfect airline competition

Airport volumes, objective value for regulator and firms			
capacity	5146	welfare in each region	618529
number of local flights	5204	total welfare	1237059
number of international flights	1646	profit for each firm	0

Airline costs	Local traffic	Int. Traffic	Consumer costs	Local traffic	Int. Traffic
airport tax	44.9	127.0	ticket price	74.9	314.0
waiting time	20.0	39.9	waiting cost	20.0	39.9
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**74.9**	**314.0**	**total**	**98.9**	**361.9**

D. The effect of a non-discrimination rule for airport charges between domestic and intercontinental flights

We have found that the Nash game between the two airport regulators leads to inefficiently high charges for intercontinental flights and important welfare losses. An ideal, though unrealistic, solution is to allow an international aviation authority or intercontinental agreement to enforce marginal social cost pricing. But a second-best strategy that may be easier to enforce is to require both airports to apply the same airport charges for domestic and intercontinental flights. We analyse only 2 cases. First, airport regulators set charges while capacity is kept fixed at the reference level, with perfect competition on the intercontinental market. Second, we add both capacity choices and imperfect competition. Table 6 shows the results for the first case.

Table 6. Results with strategic interaction on airport charges with a non-discrimination rule and perfect airline competition

Airport volumes, objective value for regulator and firms			
capacity	6822	welfare in each region	674780
number of local flights	4491	total welfare	1349560
number of international flights	2994	profit for each firm	0

Airline costs	Local traffic	Int. Traffic	Consumer costs	Local traffic	Int. Traffic
airport tax	73.3	73.3	ticket price	99.8	199.6
waiting time	16.5	32.9	waiting cost	16.5	32.9
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**99.8**	**199.6**	**Total**	**120.3**	**240.5**

The requirement of uniform charges greatly reduces the welfare losses from strategic behavior. Compared to the first best, the welfare loss is now only 4%, compared to 11% with discriminatory charges. Since increasing the intercontinental airport charge now raises the domestic charge in step, the result is a decrease in both domestic and intercontinental flights of 15%. As expected, uniform charges force the airport regulators to limit domestic air traffic in order to gain higher revenue from intercontinental flights. As can be seen in Table 7, these results continue to hold when we add imperfect competition along with endogenous airport capacity.

Table 7. Results with strategic interaction on airport charges and capacities with a non-discrimination rule and imperfect airline competition

Airport volumes, objective value for regulator and firms			
capacity	5181	welfare in each region	641367
number of local flights	4706	total welfare	1282735
number of international flights	2006	profit for each firm	102160

Airline costs	Local traffic	Int. Traffic	Consumer costs	Local traffic	Int. Traffic
airport tax	60.9	60.9	ticket price	90.4	282.6
waiting time	19.4	38.9	waiting cost	19.4	38.9
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**90.4**	**180.8**	**total**	**113.8**	**329.5**

E. Multiple airport regulators on one continent

The model we have analysed up to now has only one airport regulator on each continent deciding on airport charges and airport capacity. However, on some continents, multiple airports governed by separate regulators compete with each other for intercontinental traffic (Heathrow, Charles de Gaulle and Frankfurt). In the next simulation, we consider the extreme case where one continent (A) has only one regulator while the other continent (B) has two airports and two regulators that behave perfectly competitively. On continent B, airport charges are set equal to the marginal congestion costs, and capacity is set according to the first-best rule, at a level where savings in congestion costs for passengers and airlines equal the cost of capacity expansion. On continent A, where there is only one regulator, the regulator sets airport charges and capacity strategically (there is no uniformity rule on charges). Perfect airline competition is assumed.

The results are given in table 8. The overall welfare decrease compared to the first best outcome is 7%, but it is only country B that faces a welfare loss. In country A, the extra margins on intercontinental flights increase welfare by 6%.

Table 8. Results with competitive regulators on continent B and a strategic regulator on continent A

Volume, profits and objective value for EACH airport					
	Region A	Region B		Region A	Region B
capacity	5913	2956	welfare per airport	791288	271520
number of local flights	5285	2642	total welfare		1334329
number of international flights	2349	1174			

Airline costs A	Local traffic	Int. Traffic	Consumer costs A	Local traffic	Int. Traffic
airport charge	43.7	149.4	ticket price	73.1	251.9
waiting time	19.4	38.7	waiting cost	19.4	38.7
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**73.1**	**251.9**	**total**	**96.5**	**298.6**

Airline costs B	Local traffic	Int. Traffic	Consumer costs B	Local traffic	Int. Traffic
airport charge	43.7	43.7	ticket price	73.1	251.9
waiting time	19.4	38.7	waiting cost	19.4	38.7
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**73.1**	**251.9**	**total**	**96.5**	**298.6**

We can also compare this case to the one with a strategic regulator in country B (Table 5). Having only one airport regulator acting strategically rather than two increases overall welfare, illustrating the point that one monopoly is better for society than two. So it can beneficial for airports on the same continent to cooperate, thus acting strategically, even if they have a strong revenue objective.

F. Asymmetric cost structures.

So far, all of our numerical examples have assumed symmetry in cost structures between all airports, airlines and consumers. We can relax this assumption and let intercontinental airports have cost differences. Only the case where the variable cost per consumer differs between airports is analysed. Such a difference can be the result of immigration procedures, wages, or tradable emission permit schemes that are specific to one continent.

Assume that the airport in country B has a variable cost per consumer of 10 €, double the cost of the airport in country A. We recalculate the first best, in which both capacity and airport charges now differ between countries. The consequence of the higher cost is a welfare decrease of 3%, as seen in Table 9. Which country faces the welfare loss depends on constraints imposed on international charges in the two countries. As in the previous reference case, we assume that each country must levy the same international charge. In this case, the planner does not allow the airport regulator facing the higher cost to offset this burden with a higher charge.

Table 9: Results with strategic interaction, asymmetric airport costs, and perfectly competitive airlines

Volume, profits and objective value for each airport					
	Region A	Region B		Region A	Region B
capacity	6779	6650	welfare per airport	698126	654781
number of local flights	5285	5118	total welfare		1352908
number of international flights	3468	3468	firm profits	0	0

Airline costs A	Local traffic	Int. Traffic	Consumer costs A	Local traffic	Int. Traffic
airport charge	43.7	46.2	ticket price	73.1	151.2
waiting time	19.4	38.7	waiting cost	19.4	38.7
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**73.1**	**151.2**	**total**	**96.5**	**197.9**

Airline costs B	Local traffic	Int. Traffic	Consumer costs B	Local traffic	Int. Traffic
airport charge	48.7	46.2	ticket price	78.1	151.2
waiting time	19.4	38.7	waiting cost	19.4	38.7
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**78.1**	**151.2**	**total**	**101.5**	**197.9**

We now assume strategic behavior by airport regulators, with results shown in Table 10. A first case investigates the effect of higher costs when capacity is held fixed at a level of 6822 and international airlines are perfectly competitive. Airport regulators set both domestic and intercontinental charges as before. The results do not differ much from those of previous exercises. We learn that the airport with higher costs (B) increases its charge relative to the reference case by more than airport A. However, with strategic interaction, the airport that does not face extra costs is forced to bear part of the welfare loss. In total, the increase in costs creates a welfare loss of 3.5%. Country A, which does not face the higher cost, bears 13% of the total welfare loss.

Table 10: Results for the first-best reference case with asymmetric airport costs

Volume, profits and objective value for each airport					
	Region A	Region B		Region A	Region B
capacity	6822	6822	welfare per airport	617315	587221
number of local flights	5676	5548	total welfare		1204536
number of international flights	1794	1794	firm profits	0	0

Airline costs A	Local traffic	Int. Traffic	Consumer costs A	Local traffic	Int. Traffic
airport charge	37.9	125.5	ticket price	64.3	308.0
waiting time	16.4	32.6	waiting cost	16.4	32.6
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**64.3**	**308.0**	**total**	**84.7**	**348.5**

Airline costs B	Local traffic	Int. Traffic	Consumer costs B	Local traffic	Int. Traffic
airport charge	42.3	129.9	ticket price	68.4	308.0
waiting time	16.1	32.6	waiting cost	16.1	32.6
fixed cost	10.0	20.0	fixed cost	4.0	8.0
total	**68.4**	**308.0**	**total**	**88.6**	**348.5**

It is possible to run multiple variations with this asymmetric cost structure, but the overall effect of cost differences is not affected by imperfect competition or by the choice of capacity. The results suggest that extra costs in one country will always reduce welfare in the other country, as long as strategic pricing or capacity choices are allowed.

6. Conclusions

In this paper, we focus on the strategic interaction of airport regulators on different continents when determining their optimal airport charges and capacities. We analyze international airport competition in a simple setting with only two countries, perfect competition in the local airline markets and both imperfect and perfect competition in the intercontinental market.

We see that strategic airport pricing and capacity choices by regulators lead to a welfare loss: the regulators both behave as monopolists in the market for international flights, charging a mark-up and decreasing capacity. This welfare loss even overshadows possible negative effects from imperfect competition within the intercontinental airline market. Secondly, we show in a numerical example that the welfare loss created by this strategic interaction can be reduced by a domestic/intercontinental non-discrimination clause for airport charges. The effect of this second-best policy depends on the relative weights of both the local and intercontinental markets within the welfare function of the regulator.

Furthermore, we looked at an asymmetric situation in which only one airport regulator was capable of acting strategically. We find that reducing the number of monopolist regulators increases overall welfare. However, consolidating regulatory authority for multiple airports on a continent can improve welfare for its own residents. As a consequence, each continent has an incentive to centralize regulatory authority, which results in the suboptimal strategic equilibrium.

Finally, we study the effect of intercontinental cost differences under strategic behavior of airport regulators. We find that only a small part of a continent's cost increase will be shifted toward the other continent.

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