AIRPORT OWNERSHIP AND ITS EFFECTS ON CAPACITY AND PRICE

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Abstract

It has been argued in the literature that privatized airports would charge more efficient congestion prices and would be more responsive to market incentives for capacity expansions. Furthermore, the privatized airports would not need to be regulated since price elasticities are low, so allocative inefficiencies would be small, and collaboration between airlines and airports, or airlines countervailing power, would solve the problem of airports' market power. However, as important as this issue may appear, not much has been done to analytically examine what the outcomes of privatization or divestment of regulation may be. This paper uses a model of vertical relations between airports and airlines to examine, both analytically and numerically, how ownership affects airports prices and capacities. Results show a rather unattractive picture for privatization. We find that: (i) private airports would be too small in terms of both, traffic and capacity and, despite the fact that they may be less congested, they induce important deadweight losses; (ii) the arguments that airlines countervailing power or increased cooperation between airlines and airports may make regulation unnecessary seem to be overstated; and (iii) things may deteriorate further if privatization is done on an airport by airport basis rather than in a system. We also show that two features of air travel demand that have not been incorporated previously in the literature –demand differentiation and schedule delay cost– play important roles on airports' preferences regarding the number of airlines using the airport.

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INTRODUCTION

In the last decades, some industry watchers, commentators and economists have argued in favor of the privatization of airports. They have given many reasons; among others, government revenues, financing aspects and private enterprise creativity and drive. On efficiency grounds, which is the focus of the present paper, it has been argued that private airports would charge more efficient congestion and peak-load prices and that they will respond to market incentives for capacity expansions (see e.g. Craig, 1996). These last points are important because, in the literature, congestion is often mentioned as the most important problem major airports face.

In 1987, the three airports in the London area and four other major airports in the UK were privatized. Following the example of the UK, many countries moved –or are moving– towards privatization of some of their public airports (among others, Austria, Denmark, New Zealand, Australia, Mexico and many Asian countries). Out of the concern that the privatized airports would exert market power –they would be local monopolies by having a captive market– most of the newly privatized airports have been subject to economic regulation, either in the form of price caps (as London Heathrow) or rate-of-return (as Flughafen Düsseldorf). Lately, however, many authors have argued that the regulation mechanisms fell short of being optimal; in particular, privatization has not been as successful as expected because the regulation mechanisms would misplace the incentives regarding capacity: price caps would lead to underinvestment while rate-of-return would lead to overinvestment in capacity.[1] Moreover, some authors and government agencies have argued that *ex-ante* regulation could be unnecessary altogether so it should be either completely divested or replaced by *ex-post* price monitoring. Why? Some of the reasons that have been put forward are the following (see e.g. Beesley, 1999; Condie 2000; Forsyth, 1997, 2003; Starkie, 2000, 2001, 2005; Productivity Commission, Australia, 2002; Civil Aviation Authority UK, 2004): (i) airports have low price elasticity of demand so price levels will not have large implications for allocative efficiency; (ii) airlines have countervailing power that will put downward pressure on airport prices; (iii) alternatively, most of the problems would be solved if deeper collaboration between airlines and airports was allowed and encouraged; and (iv) demand complementarities between aviation and concession activities would induce the airport to charge below monopoly prices on the aeronautical side (particularly when concession revenues are larger than airside revenues). In fact, the move towards divestment of regulation or the less-stringent price monitoring has already started in some countries (examples are New Zealand and Australia).

However, as important as this may appear, there have been, to our knowledge, only two papers that have analytically examined what the outcomes of privatization or divestment of regulation may be (Zhang and Zhang, 2003; Oum et al., 2004). And, although there are many analytical papers that examine optimal pricing of public airports, most of the papers that do deal with privatization and divestment of regulation issues are fairly descriptive. Forsyth (2003) acknowledges this: “The shift to price monitoring has been a response to these problems [the problems with regulation], though the content and likely impact of monitoring has yet to be determined”. What this paper does is analyze the effects of airport ownership on prices and capacities, using formal modeling to enable an analytical examination of some of the assertions that have been put forward in the literature regarding privatization and regulation of airports, and to gain insights about other issues that have yet been discussed.

What makes this paper different from the previous two though, is the way the airline market enters the picture. Zhang and Zhang (2003) and Oum et al. (2004) essentially abstract from it, assuming that an airport's demand is directly a function of a full price, which includes airport charges and congestion costs. In this paper, we formally model the airline market as an oligopoly, which takes airport charges and capacities as given, recognizing that this is a vertical setting: airports provide an input –airport service–, which is necessary for the production of an output –movement– that is sold at a downstream market. Hence, the demand for airports services is a derived demand. Indeed, other authors have used a vertical setting as well (Brueckner, 2002; Pels and Verhoef; 2004; Raffarin, 2004), but they used it only to study optimal congestion pricing. Optimal capacity or the effects of privatization have not been analyzed.

Our airline oligopoly model expands on previous work; here, airlines' demands are sensitive to schedule (frequency) delay cost in addition to flight delay caused by congestion at the airport, airlines services are not necessarily perfect substitutes, and the impact of the number of firms on airport demand is highlighted. We show that schedule delay and substitutability play important roles on the incentives an airport has with respect to the dominance by a single airline. At the airport market level, the most obvious differences from the previous papers is that we look into private ownership and allow capacity to be a decision variable. We consider both system and individual privatization of airports, and the case of joint maximization of airports' and airlines' profits. Analytical and numerical simulations show a rather unattractive picture for privatization in the model considered. First, the idea that low elasticities of demand for airports would induce small allocative inefficiency would be true only if the elasticity was constant, something rather improbable and that does not consider the fact that capacity decisions will be different. What is obtained here is that important allocative inefficiencies may well arise. Results worsen when privatization is done on an airport by airport basis rather than in a system because when airports are both origin and destinations of trips, their demands are perfect complements and therefore 'competition' between airports induces a horizontal double marginalization problem. On the other hand, the maximization of joint profits benchmark shows that the arguments regarding airlines countervailing power or an increased scope for cooperation between airlines and airports are probably overstated. The outcome does improve but still falls far off from the first best.

The plan of the paper is as follows: first, we formally –yet briefly– model the downstream airline market to derived and characterize the demand for airports. We then use these results to analyze airport pricing, capacity and incentives under private and public ownership. Since these analyses rely on comparative statics, we provide numerical simulations to better assess the differences.[2]

THE AIRLINE MARKET

The oligopoly model

We present here the airline oligopoly model, which is used to obtain the derived demand for airports and to characterize it. We consider two national airports and demand for round trips.[3] We analyze a three stage game: first, airports choose their capacities, K_h; second, they choose the charge per flight, P_h; finally, airlines choose their quantities. We look for sub-game perfect equilibria, so we focus first, in this section, on the Nash equilibria of the airlines' sub-game. We consider N airlines with identical cost functions, facing horizontally differentiated demands (nonaddress setting). N is exogenous and represents the main airline industry structure indicator in the model. Each firm's demand is dependent on the vector of full prices, $\boldsymbol{\theta}$:

$$\begin{aligned} & q_i(\boldsymbol{\theta}) = q_i(\theta_i, \boldsymbol{\theta}_{-i}) \\ & \theta_i = t_i + G(\tau_i) + \alpha\big(D(Q, K_1) + D(Q, K_2)\big) \end{aligned} \tag{1}$$

where q_i is the demand of airline i, θ_i is its full price, Q is the total number of flights of all airlines, t_i is the round trip ticket price, $G(\tau_i)$ is schedule delay cost,[4] τ_i is the expected gap between passengers' actual and desired departure time, $D(Q,K_h)$ is flight delay caused by congestion at airport h, and α is passengers' value of time. Since τ_i depends on the frequency chosen by airline i (the higher the frequency, the smaller the gap), schedule delay cost can be written as $g(Q_i) \equiv G(\tau_i(Q_i))$, with Q_i the number of flights of airline i, $g'(Q_i) < 0$ while $g''(Q_i)$ has no evident sign a priori. The delay function considered is[5]

$$D^h(Q, K_h) = Q / \big[K_h (K_h - Q)\big] \tag{2}$$

where D^h is the total delay of both take-off and landing at airport h. We assume that demands are linear, symmetric and airlines' outputs are substitutes. Inverting the system of demands we get

$$\theta_i = A - B \cdot q_i - \sum_{j \neq i}^{N} E \cdot q_j \tag{3}$$

A, B and E are positive, and $B \geq E$, that is, outputs are imperfect substitutes. We assume that airlines behave as Cournot oligopolists in that they choose quantities, an assumption that is backed by some empirical evidence (Brander and Zhang, 1990; Oum et al., 1993). Note that homogeneity in the Cournot competition, the usual case in airline oligopoly models[6], is a special case of our model (just replace E by B in the results).

Using (3) and (1), the following system of *inverse demands* faced by the airlines can be obtained: $t^i = A - B \cdot q_i - \sum_{j \neq i}^{N} E \cdot q_j - g(Q_i) - \alpha\big(D(Q, K_1) + D(Q, K_2)\big)$. This can be simplified though, by recognizing that $q_i = Q_i \times$ Aircraft Size $\times$ Load Factor. Here, we assume that the product between aircraft size and load factor, denoted by S, is constant and the same across carriers, making the vertical relation between airports and airlines of the fixed proportions type.[7] Thus

$$t^i(Q_i, \mathbf{Q}_{-i}) = A - SBQ_i - \sum_{j \neq i}^{N} SEQ_j - g(Q_i) - \alpha\big(D(Q, K_1) + D(Q, K_2)\big) \tag{4}$$

Note that linear demands in full prices do not lead to *inverse demands* that are linear in output, as D is not linear and there is no reason to think that g is. In fact, we make now the following useful assumptions regarding schedule delay costs: (a) The monetary cost of the gap between the actual and desired departure times, τ, is proportional to its length; (b) τ is inversely proportional to the frequency of flights. Assumption (a) is similar to what has been already assumed regarding congestion delay costs; (b) is equivalent to say that τ is directly proportional to the interval between flights (inverse of the frequency). Hence, under (a) and (b) we get $g(Q_i) = G(\tau_i(Q_i)) = \gamma \cdot \tau_i(Q_i) = \gamma \cdot \eta \cdot Q_i^{-1}$, where γ is the constant monetary value of a minute of schedule delay and η is a constant. Thus, residual inverse demand is negative and upwardsloping first; it then becomes positive, and then downward sloping, when the linear part of the function dominates schedule delay cost. Finally, for larger values of Q_i, congestion kicks in and t^i decrease faster than linearly. This feature of this demand system is not troublesome though: the insight is that schedule delay cost put by itself, and regardless of other technological considerations such as a fixed cost, a limit to the number of firms that can be active in the industry; perfect competition is not consistent with this model.

The final ingredient necessary before analyzing equilibria is costs. Airline costs are

$$C_A^i(Q_i, \mathbf{Q}_{-i}, P_h, K_h) = Q_i \left[c + \sum\nolimits_{h=1,2} (P_h + \beta D(Q, K_h))\right] \tag{5}$$

The term in square brackets is the cost per flight, which includes pure operating costs c, airports charges P_1 and P_2, and congestion delay costs. Airline i's profits are then obtained from (4), (5) and the fact that revenues are $t^i q_i = t^i Q_i S$.

$$\begin{aligned}\phi^i(Q_i, \mathbf{Q}_{-i}, P_h, K_h) = &\left[AS - BQ_i S^2 - \sum_{j \neq i} EQ_j S^2 - c - \sum_{h=1,2} P_h\right] Q_i - SQ_i g(Q_i) \\ &- (\alpha S + \beta) \sum_{h=1,2} Q_i D(Q, K_h)\end{aligned} \tag{6}$$

The derived demand for airports is obtained from the equilibrium of the airline market. Using (6), it can be shown that under assumptions (a) and (b) there exists a unique, interior and symmetric Cournot-Nash equilibrium of the sub-game, as long as N is smaller than the free-entry number of firms (which always hold). Thus, $\partial \phi^i / \partial Q_i = 0$ gives us the Nash equilibrium of the game. Calculating this and imposing symmetry, we obtain the following important equation

$$\begin{aligned}\Omega(Q, P_h, K_h, N) = &(\alpha S + \beta) \sum_{h=1,2} \left(D^h(Q, K_h) + \frac{Q}{N} D_Q^h(Q, K_h) \right) + S\left(g(\frac{Q}{N}) + \frac{Q}{N} g'(\frac{Q}{N}) \right) \\ &+ S^2 \left(2B + (N-1)E\right) \frac{Q}{N} + c + \sum_{h=1,2} P_h - AS = 0\end{aligned} \tag{7}$$

Equation (7) implicitly defines a function $Q(P_h, K_h; N)$, which is airports' demand as a function of airport charges, capacities and airline market structure, N (the implicit function theorem holds). Also, one can define, without loss of generality, $P = P_1 + P_2$; if airports were to be priced jointly then an explicit expression of the airports' inverse demand $P(Q, K_h; N)$ is obtainable.

We now characterize airports' demand. Consider first changes of Q with N. Under (a) and (b),

$$\frac{dQ}{dN} = -\frac{\Omega_N}{\Omega_Q} = \frac{Q}{N} \left(\frac{(\alpha S + \beta) \sum D_Q^h + S^2 (2B - E)}{(\alpha S + \beta) \sum D_Q^h + S^2 (2B - E) + (\alpha S + \beta) \sum (N D_Q^h + Q D_{QQ}^h) + S^2 EN} \right) \tag{8}$$

It can be checked that $dQ/dN > 0$, $d^2Q/dN^2 < 0$ and $dQ^i/dN < 0$ $\forall E \in (0, B]$. All other derivatives are obtained in a similar fashion as above. In summary

$$\frac{\partial Q}{\partial N}>0,\quad \frac{\partial Q}{\partial P_h}<0,\quad \frac{\partial Q}{\partial K_h}>0,\quad \frac{\partial^2 Q}{\partial P_h^2}<0,\quad \frac{\partial^2 Q}{\partial P_h \partial K_h}>0, \frac{\partial P}{\partial Q}<0,\quad \frac{\partial P}{\partial N}>0,$$
$$\frac{\partial^2 P}{\partial Q \partial N}>0,\quad \frac{\partial^2 P}{\partial Q^2}<0,\quad \frac{\partial P}{\partial K_h}>0,\quad \frac{\partial^2 P}{\partial Q \partial K_h}>0,\quad \frac{\partial^2 P}{\partial K_h^2}<0,\quad \frac{\partial^2 P}{\partial K_1 \partial K_2}=0,\quad \frac{\partial^2 P}{\partial K_h \partial N}<0 \tag{9}$$

Finally, we look at how much information about the downstream market is captured by the derived demand for airports. This is important because in the maximization of social welfare case, what we need is a measure of *consumer* surplus. Since *consumers* of airports are both final consumers (passengers) and airlines, what we need is a measure of the sum of passenger surplus and airlines profits. What has been (implicitly) assumed in literature about privatization is that the integration of the airport demand function captures this *consumer* surplus. Adding airports profits to the integral would give a social welfare function. Under which conditions is this true? Recall that $P=P_1+P_2$; we are thus interested in how the following equivalent expressions

$$\int_P^{\infty} Q(P, K_h, N)\, dP \quad \text{or} \quad \int_0^{Q} P(Q, K_h, N)\, dQ - P(Q, K_h, N)Q \tag{10}$$

are related to airlines profits and passenger surplus.[8] First, the variation of Marshallian passenger surplus is given by $CS = \int_{\boldsymbol{\theta}(P,K,N)}^{\mathbf{A}} \sum_i^N q_i(\boldsymbol{\theta}) d\theta_i$. Since $\partial q_i / \partial \theta_j = \partial q_j / \partial \theta_i$, the line integral has a solution that is path independent. A linear integration path leads to

$$CS(P_h, K_h, N) = \frac{\big(B+(N-1)E\big)S^2 Q(P_h, K_h, N)^2}{2N} \tag{11}$$

Next, in the sub-game equilibrium, the profit of each airline is obtained by replacing equilibrium $(Q_i, \mathbf{Q}_{-i})$ in equation (6). Since the equilibrium in the downstream game is symmetric, sub-game total profits for the airline industry as a whole, Φ, are easily calculated as $\Phi = N \cdot \phi^1$, that is

$$\begin{aligned}\Phi(P, K_h, N) = QS\left[A - \frac{QS}{N}(B+(N-1)E) - g\left(\frac{Q}{N}\right) - \alpha \sum D(Q, K_h)\right] \\ - Q\left[c + P + \beta \sum D(Q, K_h)\right]\end{aligned} \tag{12}$$

Taking the total derivative of Φ with respect to P, using (7) and (11) and some algebra, we get

$$\int_P^{\infty} Q(P, K_h, N)\, dP = \Phi + CS - \frac{BS^2Q^2}{2N} - \frac{(N-1)}{N}(\alpha S + \beta)\int_P^{\infty} Q \frac{\partial Q}{\partial P}\left(\sum_h D_Q^h\right) dP \tag{13}$$

Hence, if N is 1, integration of the airports' demand captures only the monopoly airline profits, completely leaving out passengers (the second and third terms on the right hand side cancel out). Only if there is no congestion and N goes to infinity (which requires assuming away schedule delay cost), integration of the airports' demand is equal to airlines profits and passenger surplus. In any other case, the integral fails to adequately capture the surpluses of the agents in the downstream market. Thus, the integral of Q does not capture airlines profits plus consumer surplus because of both, market power and uninternalized externalities (third and fourth terms in equation 15 respectively). Hence, to correctly analyze the social welfare maximization problem in airport markets, formal modeling of the airline market is required. One can either directly consider the three actors involved, or add the missing terms to the integral of airport's demand. At the practice level, the conclusion is bad news for managers of public airports or airport regulation authorities: even in a setting of complete information, optimal pricing and capacity require detailed knowledge about the market structure and demand of the airline market; information on costs and demand for airports alone is not enough. This unquestionably complicates the problem.

THE AIRPORTS MARKET

System of private airports

We are first interested in the decisions of a System of Private Airports (SPA). By this, I mean that pricing and capacity decisions at both airports are made by a single entity which maximizes profits; this is truly a monopoly situation. Decision variables are Q, P (which is the sum of P_1 and P_2), K_1 and K_2. Q and P however are related through the demand function. We will use Q and K_h as decision variables –that is, we will use the inverse demand function $P(Q, K_h; N)$– but obviously results do not vary if we choose them otherwise. It is assumed, as is usually done in the literature, that airports' costs are given by $C(Q) + rK$, where C represents operating costs and rK capital costs. The problem the SPA faces is given by

$$\max_{Q,K_1,K_2} \pi(Q, K_h; N) = P(Q, K_h; N)Q - 2C(Q) - (K_1 + K_2)r \tag{14}$$

First order conditions lead to the following pricing and capacity rules:

$$P = 2C' + P/\varepsilon_P \tag{15}$$

$$Q(\partial P/\partial K_h) = r \qquad , \; h = 1,2 \tag{16}$$

where ε_P is the (positive) price elasticity of airports' demand. It can be proved that, at the optimum, $K_1 = K_2 = K$ but it cannot be proved that second order conditions hold globally. Simulation shows that they do hold for a large range of parameter values, though. (15) is the familiar market failure in which monopolies set price above marginal cost. (16) shows that private airports increase capacity until the marginal revenue of doing so equals the marginal cost of providing the extra capacity. The monopoly system of airports only cares about the last *consumer*: increasing capacities by ΔK allow the airport to charge an extra ΔP, without loosing the marginal consumer (recall that a consumer lost for the airport is equivalent to a change in the equilibrium quantity in the downstream market). The extra charge however can be passed to all inframarginal consumers. What is important is that the marginal revenue perceived by the airport is not necessarily a measure of the social benefit of an increase in capacity (Spence, 1975).

Interesting as well, is to see how optimal Q, P and K_h change with N. Unfortunately, comparative statics are not definitive: derivatives cannot be signed a priori so we will need to wait until the numerical simulation to have a better idea (the same goes for final outcomes in the airline market of course). What it is easy to show, however, is that as N increases, profits increases. To see this, simply differentiate profits evaluated at optimal Q and K with respect to N and apply the envelope theorem: $d\pi/dN = \pi_Q Q_N^{SPA} + \sum \pi_{K_h} K_N^{SPA} + \pi_N = \pi_N = Q^{SPA} P_N > 0$.

System of public airports

We now consider a system of public airports that maximizes social welfare. We will denote this case by W. As it is clear now, the social welfare (*SW*) function is not simply the integral of airports' demand plus airports' profits –see (13). The correct *SW* function can be obtained in two ways. First, directly from the expressions for consumers' surplus (11), total airlines' profits in the sub-game equilibrium (12), and airports profits.[9] A second way to obtain *SW* is to use expression (13) for the integral of airports' demand in order to find Φ+*CS*, then use $\int_P^{\infty} Q\, dP = \int_0^Q P\, dQ - PQ$ to simplify, and then add airports profits. We get:

$$\max_{Q,K_1,K_2} SW(Q,K_h;N) = \int_0^Q P(Q,K_h,N)\, dQ - 2C(Q) - (K_1+K_2)r + \frac{BS^2Q^2}{2N} + \frac{(N-1)}{N}(\alpha S+\beta)\int_P^{\infty} Q\frac{\partial Q}{\partial P}\left(\sum_h D_Q^h\right)dP \tag{17}$$

Note that as discussed, no value of N reduces (17) to airports profits plus the integral of airports' demand. First-order conditions lead to

$$P = 2C' + \frac{(N-1)}{N}(\alpha S+\beta)Q\sum_h D_Q^h - \frac{BS^2Q}{N} \tag{18}$$

$$-Q(\alpha S+\beta)(\partial D/\partial K_h) = r, \qquad h = 1,2 \tag{19}$$

Again, second-order conditions do not hold globally but do in the numerical simulation, at the optimum $K_1 = K_2 = K$, and results do not change if P and K_h were taken as the decision variables. The reader may have noted that we did not impose a budget constraint so budget adequacy is not ensured; this discussion is delayed. The public airports' total charge has three components: marginal cost, a charge that increases price and is equal to the uninternalized congestion of each carrier, and a term that decreases price, which countervails airlines' market power. In fact, this system of public airports' manages to induce the outcome of social welfare maximization in the airline market. As can be seen, the final charge will be above or below marginal cost depending on whether the congestion effect or the market power effect dominates. For the monopoly airline case, congestion is perfectly internalized and airports charges will be below marginal cost (and probably below zero). The third term in fact amounts to subsidize firms with market power in order to increase social welfare by diminishing allocative inefficiency. The implicit assumption is, evidently, that there is no other mechanism in place to control this market power. Note that if K is fixed, as N grows the market power effect decreases while the congestion effect increases. When K is not fixed, this is expectable but not clear cut, because K will change with N as well. In fact, the signs of dQ^W/dN, dK^W/dN and dP^W/dN cannot be determined a priori.

The congestion term was first found by Brueckner (2002). Pels and Verhoef (2004) later pointed out that the market power term was also needed. The differences between Pels and Verhoef's result and the result here are: (i) in their model (and in Brueckner's), a regulator would charge a toll equal to the second and third terms in (18). Here, is the public airports that distort marginal cost pricing by an amount equal to that toll; (ii) they considered a duopoly in a homogenous Cournot setting , here there are *N* firms in a differentiated Cournot setting; (iii) they assumed a delay function that was linear in traffic while here it is not; (iv) they assumed a fixed capacity while here capacity is a decision variable.

As for capacity, public airports will add capacity until the extra costs equate the benefits in saved delays to passengers and airlines. Clearly, this capacity decision is different from the decision (a system of) private airports make, as they care about extra revenues and not extra social benefits (Spence, 1975, provided this insight). This result differs from what was obtained by Oum et al. (2004) as they found that private and public airports followed the same capacity rule, and hence it was concluded that private airports set capacity levels efficiently for the traffic they induced through pricing. The divergence is undoubtedly caused by the fact that there, the *social welfare function* was not completely capturing the surpluses of all agents in the market.

How does social welfare change with *N*? Differentiating *SW* evaluated at optimal *Q* and *K* with respect to *N*, and applying the envelope theorem we get:

$$\frac{dSW}{dN} = \frac{\partial SW}{\partial dN} = \frac{(B-E)S^2Q^2}{2N^2} + Sg'\left(\frac{Q}{N}\right)\frac{Q^2}{N^2} \tag{20}$$

The first term on the right hand side is non-negative while the second is negative. It can be seen that when differentiation is weak, (20) may be negative implying that it would be better for the society to have one airline. The explanation is simple: here both market power and the congestion externality are controlled, and a monopoly airline provides a higher frequency than each airline in oligopoly, thus diminishing schedule delay cost and increasing demand. When differentiation is strong, (20) would probably become positive. In that case, the expansion of demand generated by a new firm will overweight the increased schedule delay cost due to reduced frequencies. What is notable is that, with 'enough homogeneity', a monopoly airline is optimal but there is no need to regulate it: the public airports system would subsidize the airline to induce the optimal quantity (but there is still the issue of budget adequacy). These results were not obtainable by Pels and Verhoef because they only considered a homogenous duopoly. Brueckner did considered *N* firms, but (20) would have always been zero in his case because he considered homogeneous firms and no schedule delay cost.

We compare now the system of private airports and the system of public airports. We know the SPA price will be above marginal cost; the W price may be above or below marginal cost depending on whether the congestion effect or the market power effect dominates. May it happen that private airports charge less than public airports, actually inducing more traffic? The problem is that comparisons are complex because quantity (prices) and capacities are chosen simultaneously. A way to make comparisons feasible is to assume first fixed capacity.[2]

Proposition 1: For a given *K*, the system of private airports will induce fewer flights than the system of public airports or, equivalently, it will charge a higher price.

Proposition 1 indicates that allocative inefficiency will always be in the form of restricted output. As explained before, it has been argued that this inefficiency would not be too important because the price elasticity of airports' demand is low. So, even if the price increases importantly, the actual quantity would not decrease as much. This assertion cannot be confirmed or negated with proposition 1, but something can be said even at this point: observed price elasticities are not necessarily good forecasts of the value the price elasticity will attain under other circumstances. The contention would be true only if the price elasticity of demand is constant, something rather unlikely. For example, the efficient pricing rule in (18) has probably not been implemented in any airport, so we can hardly know what price elasticity value it would induce. More importantly, monopolies price in the elastic range of the demand. Thus, while it may be true that the price elasticity is low under the current pricing system (say, pure marginal cost, which as seen is *not* the efficient price), the system of private airports would price so to get into the elastic range of the elasticity, something that may indeed induce important allocative inefficiency. This issue will be further discussed under the light of the numerical simulation.

The reasoning regarding the price elasticity and the allocative inefficiency, also fails to take into account that a private airport would choose a different capacity than a public airport would. How can capacity decisions be compared? Various cases can be distinguished. First, quantity and capacity are defined simultaneously in a system of equations. We could therefore compare actual capacities and quantities. A second more interesting question is, what distortions, if any, arise on the capacity side when the (well known) monopoly pricing distortion is taken into account. How would the SPA capacity compare to constrained social welfare maximization where monopoly pricing is taken as given (2^{nd} best case)? Is the distortion in capacity a mere byproduct of monopoly pricing? To analyze these two cases, we first examine the transposed of proposition 1, i.e. what happens with K when Q is given (e.g. the airline market is frequency regulated). In these analyzes, the reader will find strong similarities with Spence (1975) examination of the provision of quality by a monopolist. Indeed, under the current modeling, K can be seen as a measure of quality. However, Spence's insights, although pervasive, do not apply here directly due to the congestion externality and the vertical characteristic of the airport-airline markets, as it is shown in the proof of proposition 2.

Proposition 2: For a given Q, the system of private (SPA) airports will oversupply capacity with respect to the system of public airports (W).

As for actual capacities and quantities, from proposition 2 it is clear that, if for a given capacity the output restriction of the system of private airports is not too important, i.e. $Q^{SPA}(K) \approx Q^{W}(K)$ (these denote quantity rules for given K), then private airports' capacities will be higher than the W ones. If the output restriction is severe, $Q^{SPA}(K) << Q^{W}(K)$, then the result is reversed. The *low price elasticity* reasoning then is still important here because it has a counterpart in terms of capacity.

To analyze the 2^{nd} best social welfare capacity, we consider the following second best SW function: $\widetilde{S}W(K) \equiv SW(Q^{SPA}(K))$ –which is social welfare subject to SPA (monopoly) pricing–, and maximize it with respect to K (recall K_1=K_2=K). How does the second best social welfare capacity, $\widetilde{K}^{W}$, compare to K^{SPA}? Unfortunately, we cannot say much analytically here; if

$Q^{SPA}(K) \approx Q^{W}(K)$, then $K^{SPA} > \tilde{K}^{W}$. If $Q^{SPA}(K) << Q^{W}(K)$ then $\tilde{K}^{W}$ may be above K^{SPA}. Numerical simulations showed that, in fact, the latter is the relevant case; if the system of private airports restrict output severely, and therefore has smaller capacities, the public airports, if forced to price as the private system, would increase its capacity departing from K^{SPA}, as this directly benefits airlines and passengers..

Maximization of joint profits: airlines and airports

There are at least two reasons why this case is interesting. First, it has been argued that regulation may be unnecessary –in that airport charges may be kept down and capacity investments may be more efficient– if, on one hand, airlines were allowed to have a stake at the airport or if deeper collaboration between airlines and airports was allowed and encouraged, or, on the other hand, if airlines had enough countervailing power. The maximization of joint profits emerge then as an obvious way to analyze these assertions. It would be the best that can be achieved if collaboration was allowed, while countervailing power would have an effect only on the division of profits. There might be a myriad of implementation problems though, as recognized in the literature (e.g. Condie, 2000; Starkie, 2005). We do not intend to model these problems here but, instead, to use the maximization of joint profits as a benchmark. A second reason why it is interesting to look at the maximization of joint profits is because through a simple pricing scheme –two part tariffs–, that outcome is obtained in a non-cooperative fashion: the system of private airports tries to maximize profits of the chain and then captures airlines' profits through the fixed fee. This is well-known in the vertical control literature and is somewhat surprising that almost no author has mentioned it (the only exception we are aware of is Borenstein, 1992). The difference with the usual setting is that here the upstream company has a quality (capacity) that matters.

This case is denoted JP, for joint profits. As in the W case, there are two ways to write the joint profits function. Directly using (12) and airport profits, or using the integral of airports' demand as before. Some manipulations lead to:

$$\max_{Q,K_1,K_2} \pi + \Phi = \int_0^Q P(Q,K_h,N)\,dQ - 2C(Q) - (K_1+K_2)r - \frac{(N-1)ES^2Q^2}{2N} + \frac{(N-1)}{N}(\alpha S+\beta)\int_P^{\infty} Q\frac{\partial Q}{\partial P}\left(\sum_h D_Q^h\right)dP \tag{21}$$

Inspection of (21) gives a third reason to analyze this case: when the airline market is monopolized (N=1), the last two terms vanish, leading exactly to what would have been called *social welfare* has the airline market not been incorporated. We now know that in that case, passenger surplus is in fact out of the picture. Thus, previous results are nested within this case. First-order conditions yield

$$P = 2C' + \frac{(N-1)}{N}(\alpha S+\beta)Q\sum_h D_Q^h + \frac{(N-1)ES^2Q}{N} \tag{22}$$

$$-Q(\alpha S+\beta)(\partial D/\partial K_h) = r\,, \qquad h = 1,2 \tag{23}$$

Again, second-order conditions do not hold globally and $K_1=K_2=K$ at the optimum. The price charged by the system of private airports –the variable part in the case of two-part tariffs–, has three components, each one related to a different *externality*. First, it has marginal cost to avoid the vertical double marginalization problem –a vertical externality to the vertical structure–, which arises in the SPA case. Second, it adds a charge equal to the uninternalized congestion cost of each carrier, a horizontal externality. Third, it adds a term to fight the *business-stealing effect*, a horizontal externality typical of oligopoly: firms do not take into account profits lost by competitors when expanding their output. The first two components are on line with maximization of social welfare while the third moves in the opposite direction; it destroys competition downstream instead of attacking airlines' market power. The final outcome is indeed that of cooperation between competitors in the airline market.

This result, which has not been obtained in the airport pricing literature before, has different intuitions depending on why the maximization of joint profits was the relevant case. With two-part tariffs, the private airports use the variable price to destroy competition downstream in order to maximize the profits of airlines, which are later captured through the fixed fee. The process is known: the fixed fee allows the marginal price to act only as an aligner of incentives, relieving it from the duty of transferring surplus as well. When the max joint profits case arises because of collaboration between airlines and airports, what happens is that airlines would like to collude in order to increase profits, but fail to do so because of the incentives to defect on any possible agreement. What they manage to de here, however, is to 'capture' an input provider to run the cartel for them. By increasing the price of the input, the input provider induces the collusion level of output. Here, the price increase takes into account both, the congestion externality and the business-stealing effect. Note that with N=1, there is no business-stealing effect and congestion is perfectly internalized by the monopolist; consequently, the last two terms vanish. Also, if airlines were completely differentiated, i.e. E=0, there would not exist the business-stealing effect but congestion would still need to be internalized. The upstream firm is rewarded with part of the profits, which is where bargaining power enters the picture. Now, despite the fact that the result is as if airlines collude, this is not necessarily worse for social welfare than a system of private airports charging linear prices as in SPA because, here, two other harmful externalities are dealt with, the vertical double marginalization and the congestion externality. The final outcome is indeed closer to the public case as shown below. As for capacity decisions, it can be seen that the rule is the same as in the public case. This happens because this is the capacity that maximizes downstream profits as well (for a given Q).

The signs of dQ^{JP}/dN and dK^{JP}/dN cannot be determined a priori but we can know how, in equilibrium, joint profits change with N. For this, differentiate π+Φ, evaluated at optimal Q and K, with respect to N and apply the envelope theorem:

$$\frac{d(\pi+\Phi)}{dN}=\frac{(B-E)S^2Q^2}{N^2}+Sg'\left(\frac{Q}{N}\right)\frac{Q^2}{N^2} \tag{24}$$

The analysis is similar to the social welfare case. When differentiation is weak, joint profits may be maximized with a monopoly airline: airports would have an incentive to let a single airline dominate. This may be facilitated if airlines and airports are encouraged to collaborate, as the airports may try to deal with only one airline and, together, foreclose entry to other airlines. In the two-part tariff case, the airport would extract all the profits of the monopoly airline through the fixed fee. What is remarkable is that for the SPA case, the larger the *N* the better, irrespective of the degree of substitutability. This was Borenstein's (1992, p.68) insight: he was critic about privatization of airports because, "without competition from other airports, an operator's profits would probably be maximized by permitting dominance of the airport by a single carrier and then extracting the carrier's rents with high facility fees". In this model, however, airport domination by a single airline is not necessarily harmful. Social welfare may actually increase because, for N>1, it is still true that the congestion externality is internalized and that there is no competition, as with monopoly, but a monopoly offers a frequency even higher than the frequency offered by each airline in the coordinated case, reducing schedule delay cost.

When airports are relatively indifferent between N=1 or higher, the implementation problems mentioned before may play a role. In the case of collaboration between airport and airlines, it may be easier for the airports to coordinate actions with only one airline, but it may be also true that this could increase the airline's countervailing power. With two-parts tariff, however, airports may still prefer to let a single airline dominate even if (24) is slightly positive because the pricing rule becomes simpler: (i) airports do not need to estimate the second and third terms of the pricing rule (something indeed difficult); (ii) they would need to worry about assessing the right fixed fee for only one firm. This shows that recognizing the scope for vertical control in airport pricing is important. Two-part tariff is the simplest form of vertical control and even this pricing mechanism has important and rather unexplored consequences for the airline market.

We can now turn to comparisons. They are summarized through the following propositions:

Proposition 3: For a given *K* the JP airports will: (i) induce fewer flights than the W ones (ii) Induce more flights than the SPA ones

Thus, for a given capacity, JP airports induce a smaller allocative inefficiency than SPA airports, showing that the proposal of increased collaboration does improve things. How strong this allocative inefficiency is cannot be unveiled until a parameterization is chosen; however, it can be easily pictured that it may not be small since in this case competition downstream is absent while in the public case, market power downstream is controlled.

Proposition 4: For a given *Q*, the JP airports will: (i) have the same capacity as W airports (ii) Have less capacity than SPA airports.

Proposition 5: As for actual capacities and quantities, JP airports will induce fewer flights and will have smaller capacities than W airports.

Hence, if prices and capacities are decided using the incomplete social welfare function (N=1 in equation 21), the result will be airports that are too small in terms of both, capacity and traffic. As before, whether actual JP capacities are below or above SPA capacities will depend on whether the output restriction of SPA airports, with respect to JP, is severe or not.

Next, it has been argued before that a capacity rule such as the one JP airports follow would be efficient because it is identical to the public one so, for a given *Q*, capacity will be set efficiently (Oum et al. 2004). The question we ask now is different: do JP airports induce distortions in capacity that go beyond what is induced only by pricing? To analyze this we look for 2^{nd} best capacity, maximizing social welfare subject to the restriction of JP pricing. It can be shown that

Proposition 6: The JPT airports undersupply capacity with respect to second best social welfare capacities (despite having the same capacity rule).

Before leaving this section, there is a lesson that can be extracted regarding the budget adequacy of the public airports, which is that it may be achievable through a fixed fee. Lump-sum transfers will not affect marginal decisions of airlines and therefore public airports may use the efficient pricing and capacity rules, which may include actually paying airlines to land, and then collect the money necessary to cover their expenses through a monthly facility fee. This would be a sort of Loeb-Magat mechanism. A less efficient alternative is Ramsey-Boiteaux prices: the Lagrange multiplier, which captures the severity of the budget constraint, will balance the charge between the efficient price (18) and the profit maximizing price (15), enabling cost recovery.

Independent private airports

In many cases, the idea is to privatize airports independently and not in a system; what would be the outcome? We assume first that airports choose linear prices and capacities simultaneously (the open-loop case) in a non-cooperative game. We denote this case IPA, for independent private airports. Each airport's program is

$$\max_{P_h, K_h} \pi^h = Q_h(P_1, P_2, K_1, K_2)P_h - C(Q_h) - K_h r\,, \qquad h = 1,2 \tag{29}$$

A necessary condition for existence of equilibria is that C is not *too* concave, something that has been assumed throughout. If this is the case, it can be shown that prices are strategic substitutes. We look for symmetric equilibrium. Interest lies on the sum of airport charges, P, rather than individual charges. First-order conditions and imposition of symmetry leads to

$$P = 2C' + 2\frac{P}{\varepsilon_P} \tag{30}$$

$$Q\frac{\partial P}{\partial K_h} = r\,, \qquad h = 1,2 \tag{31}$$

(30) is to be compared with the SPA case in (17); clearly $P^{IPA} > P^{SPA}$. This was expected: it is the result of the horizontal double marginalization problem that arises in oligopoly when outputs are complements. In these cases, competition is harmful for social welfare. Capacity rules are the same but obviously actual capacities will be different. Hence, independent private airports induce fewer flights and have smaller capacities than a system of private airports. From propositions 1 to 4, we have that:

- For given K, $Q^W(K) > Q^{JP}(K) > Q^{SPA}(K) > Q^{IPA}(K)$.
- For given Q, we will have that, $K^{JP}(Q) = K^W(Q) < K^{SPA}(Q) = K^{IPA}(Q)$.
- For actual capacities and prices, $Q^W > Q^{TPT}$, $Q^{SPA} > Q^{IPA}$, $K^{JP} < K^W$ and $K^{IPA} < K^{SPA}$.

In the closed-loop game, where airports first choose capacities (simultaneously) and then prices, airports over-invest in capacity par rapport to the open loop. Qualitatively (a full derivation is in the appendix), what happens is that, in the three stage game, investment in capacity makes an airport tough: it leads to an own price increase, which hurts the other airport. Since in addition prices are strategic substitutes, increasing capacity increases own profits. Using the terminology of Fudenberg and Tirole (1984), airports over-invest in capacity following top-dog strategies. This leads to higher prices than in the open loop, but the overall effect on traffic is unclear.

What if the independent private airports collaborate with the airlines? In this case, the relevant problem is each airport maximizing its profit plus the profits of airlines, given that the other airport is doing the same. The outcome of this is the same as if airports, individually, charge two part tariffs (in an open-loop setting). We denote this case IJP. Solving the game, we get the following pricing and capacity rules

$$P = 2C' + 2\frac{(N-1)}{N}(\alpha S + \beta)Q\sum_h D_Q^h + 2\frac{(N-1)ES^2Q}{N} \tag{32}$$

$$-Q(\alpha S + \beta)\frac{\partial D(Q, K_h)}{\partial K_h} = r \qquad , \ h = 1,2 \tag{33}$$

Jointly, individual airports using two part tariffs or collaborating with airlines charge more than a system of private airports using two-part tariffs or collaborating with airlines (except when N=1). The horizontal double marginalization also arises here: each airport tries to correct externalities on their own and, as a result, they jointly overcharge for congestion and the business stealing effect. Capacity rules on the other hand are as in JP, therefore comparisons between this case and the JP case is analogous to the comparison between JP and W. Finally, whether there is over or under-investment in the close-loop cases cannot be determined analytically.

NUMERICAL SIMULATIONS

The need for numerical simulations arises from two facts; first, that in some cases comparative statics and analytical comparisons were not conclusive, second, that even when analytical results were obtainable, they were necessarily qualitative. For example, JP capacities and prices are below W ones, but by how much? We resorted to simulation to shed light on these types of questions. We used the parameter values in table 1.

Table 1: Parameter values for the numerical simulation

Demand				***Airlines***		***Airports***	
α	40	A	2000	S	100	r	10000
β	3000	B	0.15	N	1 to 10	C'	2000
γ	4	E	0.13	c	36000		

For the schedule delay cost, it was assumed that assumptions (a) and (b) in the airline market Section hold, so that the schedule delay cost function was defined by γ and η; we imposed η =1. We considered a constant airport operational marginal cost and looked into both, variable-capacity and fixed-capacity cases; the latter, in order to better see whether the argument that says that allocative inefficiency would be small with privatization holds or not. The fixed capacity was set at the socially optimal level but choosing it otherwise did not change the qualitative conclusions. For independent airports (IPA and IJP cases), we looked into open-loop games. It was not our intention to portray real aviation cases with these parameters but, rather, to obtain insights about what are the consequences of different ownership and pricing schemes. We did try, however, to be as reasonable as possible with the parameterization, by drawing data and values from other studies.[10] Previous results in the literature (discussed below) confirmed the plausibility of the parameterization.

We now summarize the main insights gained from the numerical simulation.

1. We confirmed that second order conditions hold in all cases.
2. In the system of private airports case (SPA), Q, K and the delays increased with N. Airports profits increased with N as analytically showed, but social welfare also did. P was fairly large in all cases and way above marginal cost, but this is on line with a previous empirical result by Morrison and Winston (1989).[11]
2. For public airports (W), Q and K increased with N but delays decreased. P increased with N: as N grows, the congestion effect started dominating the market power effect. The subsidies required when N is small are large but are consistent with (smaller than) Pels and Verhoef (2004) results. We also found that SW increased with N: differentiation dominated the schedule delay cost effect in equation (20). When homogeneity was increased, the result reversed as explained.
3. Regarding the JP case, Q and K increased with N while delays decreased. P increased with N: as N grows, both the uninternalized congestion and the business stealing effects are more important, and they were not countervailed by changes in capacity. When N=1, the monopoly airline perfectly internalizes congestion and it obviously produces at the profit maximizing level so there was no need for corrections from the part of the airports: P was thus equal to marginal cost. Joint profits increased with N: differentiation dominated the schedule delay cost effect in equation (24). More homogeneity though, reversed the result, making it better for the airports to let a single airline dominate. This was not harmful for society however.
4. Actual SPA capacities and quantity were way below social welfare ones. For example, for N=3, we found $Q^{SPA} = 36$, $K^{SPA} = 45$, while $Q^{W} = 101$ and $K^{W} = 110$. Social welfare decreased by 44%. This was confirmed by the fixed-capacity simulations. The main insight here is that the allocative inefficiency of private airports, if capacity is exogenously decided, is by no mean small. The argument was that price elasticities of demand are low, but the problem with that assertion is that it assumed the elasticity is constant. Observed elasticities however, are not the elasticities that would arise under private (unregulated) ownership, or with the efficient prices derived in (21) because efficient prices have not been the rule. In fact, it is true that the price elasticity of demand when P is equal only to marginal cost is fairly low (below 0.1 in absolute value) but, still, the allocative inefficiency is very strong.
5. Comparisons between the SPA and the JP cases were not analytically simple. We found that, in general, JP airports are less harmful for social welfare than SPA airports. For example for N=3, we found $Q^{JP} = 50$, $K^{JP} = 56$, and a decrease in social welfare of 27% (compare to point 4). JP got closer to SPA the larger the N though, because in the JP case, competition downstream is destroyed for every N while in SPA it is not. Now, although these findings support the idea that collaboration between airlines and a system of private airports leads to a better outcome, it would be adventurous, to say the least, to conclude that with privatization and collaboration –or strategic agreements– between airlines and airports, regulation

becomes unnecessary. If anything, the outcome is closer to private unregulated airports rather than optimal ones.

4. When comparing delays of SPA and W airports, we found that delays were smaller in the private case. This issues a warning: congestion has been one of the main drivers of research in this area and proponents of privatization have argued that private airports would charge efficient congestion and peak load prices and would respond to market incentives for expansion. If one measures the result of privatization only by its effects on congestion, privatization may appear as a better idea than it actually is. Despite the smaller delays, we have seen that the private airports themselves would be substantially smaller both in terms of traffic and capacity. More importantly, social welfare would be substantially smaller. JP airports on the other hand, would have larger delays than the public airports.
7. When airports are privatized individually (IPA and IJP cases), the horizontal *double marginalization* problems visibly arose. For N=3, we found $Q^{IPA} = 19$, $K^{IPA} = 26$, and a decrease in social welfare of 67%.
8. Regarding social welfare second best capacities, when N=3, if public airports were forced to price as SPA, they would increase capacity from 45 to 59, which would lead to a traffic of 41 instead of 36. Second best capacity would still be far away from the first best capacity though, which was 109.6. Hence, SPA does induce an extra distortion: given that their restriction of output is severe, they undersupply capacity with respect to the second best.
9. What about budget adequacy of public airports? This has been an important issue in the literature. We argued before that Ramsey-Boiteaux prices may not be necessary because fixed fees may be used. What the simulation showed, in all cases, is that although airports had large deficits, airlines had large profits such that joints profits were actually positive. Thus, achieving budget adequacy through fixed fees may be possible, and would depend on the value of airports' fixed costs.
10. Finally, the insights did not qualitatively change with changes in the value of the parameters.

FINAL COMMENTS

Privatization of airports has been argued for on the grounds that private airports would implement more efficient congestion and peak-load prices, and would have better incentives to invest in capacity. Privatized airports have been subject to economic regulation though, out of the concern that they would exert market power. But this has been changing. It has been argued that regulation may be unnecessary because a private unregulated airport would not induce large allocative inefficiencies since price elasticities are low, because potential collaboration between airlines and airports –or, alternatively, airlines countervailing power– would put downward pressure on market power, and because concession revenues would induce the airports to charge less on the aeronautical side. The aim of this paper was to build an analytical model where these ideas could be tested and other insights gained, since most of the literature on airport privatization has been essentially descriptive.

A vertical setting was used to analyze airport privatization, both analytically and numerically. In the model, airports are input providers for the downstream airline market, in which airlines take airport prices and capacities as given. Our airline oligopoly model expanded on previous models on three aspects: it featured demand differentiation, schedule delay cost was included in the full price perceived by passengers, and had a particular emphasis on the importance of the number of airlines in the market. It was shown that these aspects have an important role on the incentives an airport has with respect to the dominance by a single airline. At the airport level, the results showed a rather unattractive picture for privatization. First, the idea that low price elasticities of demand for airports would induce small allocative inefficiency failed to take into account the fact that observed elasticities may be poor forecasters of elasticities in other settings, and that capacity would be chosen by a private airport in a different way than a public airport. Our results showed that private airports would be much smaller than efficient public airports in terms of both traffic and capacities, which was reflected in important deadweight losses. Second, the arguments that airlines countervailing power or increased cooperation between airlines and airports may make regulation unnecessary are, most likely, overstated. The benchmark of maximization of joint profits showed, on one hand, that airports exerting vertical control on airlines (two-part tariffs in this model is enough) leads to the same outcome. More importantly, while the vertical double-marginalization problem is solved and the incentives for investment in capacities are better aligned, competition at the airline level is destroyed. So, while the outcome is indeed better in terms of traffic, capacities and social welfare, it is still closer to the pure private case than to the public one. It seems bold to conclude from here then, that regulation is unnecessary, especially because any implementation problem, which would only worsen the outcome, was assumed away. Also, it was shown that things deteriorate further when privatization is done on an airport by airport basis rather than in a system, because airports' demand complementarities induce horizontal double marginalization problems. These arise with simple linear prices, two-part tariffs, and when airports strategically collaborate with airlines. Finally, we note that our model and its results are applicable to many other cases such as other transportation terminal (seaports; container terminals), railroad tracks or any vertical setting where upstream quality (here measured by capacity) matters.

We realize that the model presented can be seen as the worst case scenario, social welfare wise, for private airports: the two airports have demands that are perfect complements. Real competition between airports can emerge in two ways though. First, there may be *Geographic Competition*; airports in the same city area –such as the three San Francisco Bay area airports– compete for consumers in the same origin. Second, there may be competition for connecting passengers. When there is a network of airports (three or more distinct origin-destinations pairs), airlines can partly offset airports' market power through routing, something that would be taken into account by private airports when making decisions. Modeling these two types of competition seems to us the most important directions for future research, albeit they are complex ones

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ENDNOTES

[1] For a list of papers that discuss country-specific experiences with regulation see Oum et al. (2004).

[2] For space reasons, propositions will be presented without proofs. Also some derivations and results have been omitted. Details are from the author.

[3] These assumptions are consistent with Pels and Verhoef (2004) and are, in fact, a generalization of Brueckner (2002) and Raffarin (2004), who consider a single airport. Zhang and Zhang (2003) and Oum et al. (2004), also consider an airport in isolation.

[4] Schedule delay cost represents the monetary value of the time between the passenger's desired departure time and the actual departure time and it was first introduced by Douglas and Miller (1974). Morrison and Winston (1989) empirically measured it.

[5] This function is discussed in Horonjeff and McKelvey (1983) and was used by Morrison (1987), Zhang and Zhang (1997) and Oum et al. (2004). Pels and Verhoef (2004) and Raffarin (2004) used functions linear in traffic.

[6] See e.g. Oum et al. (1995), Brueckner (2002), and Pels and Verhoef (2004).

[7] This assumption was also made by Brueckner (2002) and Pels and Verhoef (2004). A variable proportions case arise if, before a change in airport charges, airlines decide to change S (aircraft size, load factor or both).

[8] We restrict attention to P without loss of generality. Any later division of P into its components does not change the value of the expressions in (11).

[9] In the airport pricing literature that considers the vertical relation between airports and airlines, airports profits are usually not considered in the social welfare function (see e.g. Brueckner, 2002; Pels and Verhoef, 2004).

[10] The values of some of the parameter may be justified as follows: For $\boldsymbol{\alpha}$, Morrison and Winston (1989, p. 90) empirically found a value of $45.55 an hour in 1988 dollars; for $\boldsymbol{\gamma}$, they found a value of $2.98 an hour in 1983 dollars (p. 66). For $\boldsymbol{\beta}$, Morrison (1987, p. 51 footnote 20), finds that the hourly extra cost for an aircraft due to delays is approximately $1,700 (resulting from 3,484 – 18*100) in 1980 dollars. For $\boldsymbol{S}$, recall that it reflects the product between aircraft size and load factor. In North America, the average plane size in 2000 was 159 (see Swan 2002, table 2); considering in addition an average load factor of 65% (see Oum and Yu, 1997, p.33) we obtain a value for S of 103.35. Regarding airlines' operational per flight cost $\boldsymbol{c}$, Brander and Zhang (1990) proposed the following formula for the marginal cost per passenger in a direct connection: $cpm(D/AFL)^{-\theta}D$; where cpm is the cost per passenger-mile, D is the origin-destination distance, AFL is the average flight length of the airline and θ is the cost sensitivity to distance. The following were the average values for American and United Airlines in the period 1981-1988 (see Oum et al., 1993): cpm=$0.12/pax/mile, AFL=775 miles and θ=-0.43. If we use AFL=800, cpm=$0.20 and D=1000 (e.g. Chicago-Austin), and multiply the result by 2S to reflect the operational cost of a return flight, we obtain a value for c of $36,340.

[11] This, despite the fact that they used a different delay function (theirs was estimated and homogenous of degree one on Q and K), and that their airport's demand was actually estimated.