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Airport deregulation: Effects on pricing and capacity

Leonardo J. Basso *

Department of Civil Engineering, Universidad de Chile, Casilla 228-3, Santiago, Chile

Abstract

We use a model of vertical relations between two congestible airports and an airline oligopoly to examine, both analytically and numerically, how deregulation may affect airports prices and capacities. We find that: (i) unregulated profit-maximizing airports would overcharge for the congestion externality and, compared to the first-best, would induce large allocative inefficiencies and dead-weight losses. They would restrict capacity investments but, overall, would induce fewer delays; (ii) Welfare maximization subject to cost recovery performs quite well, achieving congestion levels similar to a private-unregulated airport but without inducing such large traffic contraction; this puts a question mark on the desirability of deregulation of private airports; (iii) Increased cooperation between airlines and airports provides some improvements, but the resulting airport pricing strategy leads to a downstream airline cartel; (iv) When schedule delay costs effects are strong and airline differentiation is weak, it may be optimal to have a single airline dominating the airports, but this happens only when airports' pricing schemes render the number of airlines irrelevant for competition.
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1. Introduction

In the literature nowadays, congestion is often mentioned as the most important problem major airports face. In the last decades, some authors have argued in favor of airport privatization because, among other things, private airports would charge efficient congestion prices and would respond to market incentives for capacity expansions (see *e.g.* Craig, 1996). Following the example of the UK, many countries moved – or are moving – towards privatization of some of their public airports[1] but, out of the concern that the privatized airports would exert market power, most of the newly privatized airports have been subject to economic regulation (such as price cap in London Heathrow or rate-of-return in Amsterdam). Lately, however, many authors have argued that privatization has not been as successful as expected because the regulation mechanisms would misplace the incentives regarding capacity.[2] Moreover, it has been argued that *ex-ante* regulation could be unnecessary altogether so it could be either completely discarded or replaced by *ex-post* price monitoring. Why? Some of the reasons that have been put forward are (see *e.g.* Beesley, 1999; Condie, 2000; Forsyth, 1997, 2003; Starkie,

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* Tel.: +56 2 978 4380; fax: +56 2 689 4206.

E-mail address: lbasso@ing.uchile.cl.

[1] In 1987, the three airports in the London area and four other major airports in the UK were privatized. Following this example, airports in Austria, Denmark, New Zealand, Australia, Mexico and many Asian countries have been, or are being, privatized.

[2] Price caps would lead to under-investment in capacity, while rate-of-return would lead to over-investment in capacity. For a list of papers that discuss country-specific experiences with regulation see Oum et al. (2004).

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; and (iii) alternatively, most of the problems would be solved if deeper collaboration between airlines and airports was allowed and encouraged.

The move towards dismantlement of regulation or the less-stringent price monitoring has already started in some countries (*e.g.* New Zealand and Australia) yet "the content and likely impact of monitoring has yet to be determined" (Forsyth, 2003). What we attempt on this paper is to shed light on the potential impact of deregulation on pricing practices and capacity decisions of airports. For this, we compare the performances of profit-maximizing airports to first-best and second-best airports, that is, airports that maximize social welfare (with and without a budget constraint). Indeed, as a referee pointed out, what we analyze here are somewhat theoretical extremes: a private-unregulated airport does not necessarily behave as a pure profit-maximizing airport and, certainly, a public airport does not necessarily maximize social welfare. Yet, we see this analysis as a reasonable first approach to the issue.

There are many papers that have examined optimal airport pricing. For example Brueckner (2002, 2005) and Pels and Verhoef (2004) look for the optimal toll that airport authorities should charge for the use of a fixed-capacity airport, in order to maximize social welfare. Zhang and Zhang (2003) and Oum et al. (2004) on the other hand, look in addition into the decisions of an unregulated profit-maximizing airport, including capacity decisions. They do this, however, without formally modeling the downstream airline market, something achieved by assuming that the airport's demand is a function of a full price – which includes airport charges and congestion costs – and measuring *consumer surplus* through the integration of the airport's demand. In this paper instead, 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. The differences in terms of airports' pricing schemes and capacity investments are material. This is so because, as it is analytically shown, only if the airline market is perfectly competitive, the integration of the derived demand for the airport provides a correct measure of consumer surplus.

We find that unregulated profit-maximizing airports would overcharge for the congestion externality. Analytical and numerical results showed that, when compared to the first-best, these airports would induce large allocative inefficiencies and dead-weight losses. They would restrict capacity investments but, nevertheless, would induce fewer delays. Airports that maximize social welfare but subject to a budget constraint would perform fairly well, both in terms of allocative efficiency and congestion management. We also find that two features that we include in our airline oligopoly model and that have not been considered before – namely, schedule (frequency) delay cost and demand differentiation – play an important role on the incentives an airport has with respect to the dominance by a single airline. Finally, we provide a few extensions by looking into maximization of joint profits of airports and airlines (a benchmark for collaboration between these agents) and independent profit maximization of two airports.

The plan of the paper is as follows: Section 2 contains formal modeling of the downstream airline market. We use the derived demand for airports services obtained here to compare the performance of first-best and second best airports against profit-maximizing airports in Section 3. Section 4 contains extensions to the models presented, while Section 5 summarizes and integrate our findings. Proofs of some propositions and details on the numerical examples are provided in the Appendix. However, for space reasons, some other proofs, derivations and results have been omitted from the paper but are available in a supplementary appendix.[3]

2. The airline market

2.1. The airline oligopoly model

The oligopoly model presented here is used to obtain the derived demand for airports and to characterize it. We consider two airports, where round trips are serviced by N airlines with identical cost functions, which face (horizontally) differentiated demands in a non-address setting.[4] We analyze a three-stage game: first, airports choose capacities, K_h; second, they choose the charge per flight, P_h;[5] finally, airlines choose their quantities. We

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[3] The supplementary appendix can be requested from the author and can be found, in the online version, at doi:10.1016/j.ijindorg.2007.09.002.

[4] Brueckner (2002), Zhang and Zhang (2003) and Oum et al. (2004) considered an airport in isolation; Pels and Verhoef (2004) considered two airports. Brueckner considered homogenous airlines while Pels and Verhoef considered a homogenous duopoly.

[5] A per-flight charge may not be a reflection of actual practice. Many airports actually have weight-based charges, but this has been starkly criticized on efficiency grounds by economists for at least three decades (*e.g.* Carlin and Park, 1970). Per-flight charges have been assumed in most analytical airport pricing papers.

look for sub-game perfect equilibria through backward induction, so we focus first, in this section, on the Nash equilibria of the airlines' sub-game. Each airline's demand is dependent on the vector of full prices, $\boldsymbol{\theta}$:

$$q_i(\boldsymbol{\theta}) = q_i(\theta_i, \boldsymbol{\theta}_{-i})$$
$$\theta_i = t_i + G(\tau_i) + \alpha(D(Q, K_1) + D(Q, K_2)) \qquad (1)$$

where q_i is the demand faced by airline i, θ_i is its full price, Q is the total number of flights of all airlines, t_i is the ticket price for the round trip, $G(\tau_i)$ is schedule delay cost,[6] τ_i is the expected gap between passengers' actual and desired departure time, $D(Q, K_h)$ represents flight delay (of both take-off and landing) because of congestion at airport h and α represents the passengers' value of time.[7] Note that τ_i depends on the frequency chosen by airline i: the higher the frequency, the smaller the gap. Thus, schedule delay cost can be written as $g(Q_i) \equiv G(\tau_i(Q_i))$ where Q_i is 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[8]

$$D^h(Q, K_h) = \frac{Q}{K_h(K_h - Q)}. \qquad (2)$$

Assuming linear symmetric demands and substitute outputs we get $q_i(\boldsymbol{\theta}) = a - b\theta_i + \sum_{j \neq i}^N e\theta_j$, where a, b

and e are positive. Inverting the system and re-labeling we get

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

where A, B and E are fixed positive numbers and we assume that $B > E$, that is, outputs are imperfect substitutes (it is easy to verify that $B > E$ is equivalent to $b > (N-1)e$). We assume that airlines behave as Cournot oligopolists in that they choose quantities (see Brander and Zhang, 1990; Oum et al., 1993, for some empirical evidence). Note that homogeneity in the Cournot competition – the usual case in airline oligopoly models (*e.g.* Oum et al., 1995; Brueckner, 2002) – is a special case of our model; it suffices to replace E by B in the results. This enables an assessment of the importance of (horizontal) airline differentiation in airport decisions. Two more comments about the demand model are important. First, we incorporated the schedule delay cost, an important aspect of service quality which has sometimes been considered in pure airline oligopoly models but never in airport markets analysis.[9] Second, we chose to have N as an exogenous parameter because airports may have preferences regarding N that are different than the pure free entry equilibrium, and they may indeed have a sizeable influence in the number of active firms. Airports' preferred N under different ownership and pricing schemes is analyzed in Sections 3 and 4 (airlines' free entry equilibrium is described in the supplementary appendix).

Using Eqs. (3) and (1), the system of *inverse demands* faced by the airlines can be obtained as $t^i = A - B \cdot q_i - \sum_{j \neq i}^N E \cdot q_j - g(Q_i) - \alpha(D(Q, K_1) + D(Q, K_2))$. This can be simplified though, by recognizing that $q_i = Q_i \times$ Aircraft Size $\times$ Load Factor. Here, we assume that the

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[6] Schedule delay cost represents the monetary value of the time between the passenger's desired departure time and the actual departure time. It was introduced by Douglas and Miller (1974) as the addition of two components: frequency delay cost and stochastic delay cost. The former is a cost induced by the fact that flights do not leave at a passengers' request but have a schedule. Stochastic delay has to do with the probability that a passenger cannot board her desired flight because it was overbooked. Overbooking arises in the presence of stochastic demands, which is not the case here. Hence, our schedule delay cost corresponds only to frequency delay cost.

[7] In parallel but independent work, Zhang and Zhang (2006) analyzed a vertical structure of airlines and airports somewhat similar to the one proposed here. However, our work considers a number of model features – such as airline differentiation, two airports, schedule delay cost – and different analyses – such as characterization of the derived demand for airports, analysis of second best capacities, optimal number of airlines, independent *versus* system privatization, vertical integration/two part tariffs and numerical simulations – that are not considered in their work. The main overlap is in Propositions 1 and 2.

[8] This convex function of Q was proposed by the US Federal Aviation Administration (1969) and is further discussed in Horonjeff and McKelvey (1983). It has been used by Morrison (1987), Zhang and Zhang (1997) and Oum et al. (2004). Pels and Verhoef (2004) considered delay functions that were linear on Q.

[9] Douglas and Miller (1974) and Oum et al. (1995) considered schedule delay cost in analytical models, while Morrison and Winston (1989) measured it empirically in their estimation of an airline choice model. The fact that the schedule delay cost is airline dependent – rather than depending on the overall frequency Q of the industry – can be supported by two model features: first, airlines are differentiated and thus their frequency is seen as an individual attribute (as in the discrete choice framework of Morrison and Winston, 1989). Second, passengers take round trips and have to take the same airline for their return flight; thus, what matters for a passenger is the frequency of each particular airline, even if the differentiation is not too strong. If one were to consider homogeneity and unidirectional trips such that, in effect, passengers would board the first flight they can, then a more reasonable model would have airlines choosing departure times and then competing in prices. An example, for a duopoly, of this airline scheduling competition can be found in Shipper et al. (1998).

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.[10] Thus

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

Note that the inverse demand system is not linear in output, as D is not and there is no reason to think that g is. In fact, we make the following useful assumptions about 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. Hence, under Assumptions (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.[11] With this, the residual inverse demand is negative and upward sloping first; it then becomes positive, and then downward sloping, when the linear part of the function starts dominating schedule delay cost effects. Finally, for higher values of Q_i, congestion starts to kick and t^i decreases faster than linearly. The explanation of the shape of the demands is quite intuitive: schedule delay cost put by itself, and regardless of other technological considerations such as a fixed cost, a limit to the number of airlines that can be active in the industry. This minimum scale of entry though, stems from a feature that is particular to transport services and implies that perfect competition between airlines, as the limit case when $N \rightarrow \infty$, is not consistent with this model.

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

$$C_A^i(Q_i, \mathbf{Q}_{-i}, P_h, K_h) = Q_i \Big[c + \sum_{h=1,2} (P_h + \beta D(Q, K_h)) \Big]. \quad (5)$$

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.[12] Thus, airline i's profits, ϕ^i, are obtained from Eqs. (4) and (5), and the fact that revenues are $t^i q_i = t^i Q_i S$. We get

$$\phi^i(Q_i, \mathbf{Q}_{-i}, P_h, K_h)$$
$$= \Big[AS - BQ_iS^2 - \sum_{j \neq i} EQ_jS^2 - c - \sum_{h=1,2} P_h \Big] Q_i$$
$$- SQ_ig(Q_i) - (\alpha S + \beta) \sum_{h=1,2} Q_iD(Q, K_h). \quad (6)$$

2.2. The derived demand for airports and its characteristics

To obtain the derived demand for airports, we solve for the equilibrium of the airline market. Using Eq. (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 should always hold.[13] Thus, $\partial\phi^i/\partial Q_i = 0$ gives us the unique and symmetric Cournot–Nash equilibrium of the game. Calculating this and imposing symmetry, we obtain the following important equation

$$\Omega(Q, P_h, K_h, N)$$
$$= (\alpha S + \beta) \sum_{h=1,2} \Big(D^h(Q, K_h) + \frac{Q}{N} D_Q^h(Q, K_h) \Big)$$
$$+ S\Big(g\Big(\frac{Q}{N}\Big) + \frac{Q}{N} g'\Big(\frac{Q}{N}\Big) \Big) + S^2(2B + (N-1)E)\frac{Q}{N}$$
$$+ c + \sum_{h=1,2} P_h - AS = 0. \quad (7)$$

Eq. (7) implicitly defines a function $Q(P_h, K_h; N)$, i.e. airports' demand as a function of airport charges, capacities and airline market structure, N (the implicit function theorem holds). Note that under Assumptions (a) and (b), $g(x) + xg'(x) = 0$ and the second term would be zero. Also, defining $P = P_1 + P_2$, one can explicitly obtain the airports' inverse demand $P(Q, K_h; N)$.

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[10] This assumption was also made by Brueckner (2002) and Pels and Verhoef (2004). A variable proportions case arises if, before a change in airport charges, airlines decide to change S (aircraft size, load factor or both). As pointed out by a referee, with fixed load factors *and* aircraft size, prices per passenger and per flight are equivalent.
[11] If passengers' desired departure time is uniformly distributed, then Assumption (b) holds and $\eta = 1/4$.

[12] Using the expression for delay in Eq. (2), it can be verified that marginal costs are strictly increasing and larger than average cost (except at $Q_i = 0$). Cost, marginal cost and average cost functions are strictly convex. Given that aircrafts sizes are assumed constant, this cost function may represent a short-run.
[13] See the supplementary appendix for proofs and a discussion of Cournot (or *tatonnement*) stability.

We now characterize the demand for airports. We are interested first in learning how airports' demand $Q(P_h,K_h; N)$ changes with P_h, K_h and N or, alternatively, how the inverse demand changes with Q, K_h and N. Consider first changes of Q with P. If Assumptions (a) and (b) hold,

$$
\frac{dQ}{dP} = -\frac{\Omega_P}{\Omega_Q}
$$

$$
= -\frac{N}{(\alpha S + \beta)\sum_h((N+1)D_Q^h + Q^2 D_{QQ}^h) + S^2(2B + (N-1)E)}.
$$

$$(8)$$

All other derivatives are easily obtained by using the same comparative statics techniques on Eq. (7). Below, we summarize the results. The first two rows of Eq. (9) require Assumptions (a) and (b) regarding schedule delay cost, while those in the third row do not. In summary

$$
\frac{\partial P}{\partial Q} < 0, \quad \frac{\partial P}{\partial N} > 0, \quad \frac{\partial^2 P}{\partial Q \partial N} > 0, \quad \frac{\partial^2 P}{\partial Q^2} < 0, \quad \frac{\partial Q}{\partial N} > 0,
$$

$$
\frac{\partial Q}{\partial P_h} < 0, \quad \frac{\partial Q}{\partial K_h} > 0, \quad \frac{\partial^2 Q}{\partial P_h^2} < 0, \quad \frac{\partial^2 Q}{\partial P_h \partial K_h} > 0 \quad \frac{\partial P}{\partial K_h} > 0,
$$

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

$$(9)$$

Having characterized the shape of the demand function, we can now compute the surpluses (in sub-game equilibrium) of airlines and passengers. Passenger surplus is given by $PS = \int_{\theta(P,K,N)}^A \sum_i^N q_i(\boldsymbol{\theta}) d\theta_i$. Since $\partial q_i/\partial\theta_j = \partial q_j/\partial\theta_i$, the line integral has a solution that is path independent (PS is equal to both Hicksian measures). Using a linear integration path, straightforward calculations lead to

$$
PS(P_h, K_h, N) = (B + (N-1)E)S^2 Q(P_h, K_h, N)^2/2N.
$$

$$(10)$$

The aggregate (equilibrium) profit for carriers, Φ, is easily obtainable from an individual carrier's profit Eq. (6) and the imposition of symmetry, that is, $Q_i = Q(P,K_h,N)/N$. We obtain:

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

$$(11)$$

We turn now into an important question, which we frame as follows: the airline market model was useful to

derive and characterize the demand for airports (Eqs. (7) and (9)). It would be simple if we could directly use this demand function to fully analyze the airports markets, because this function may be estimated only with airport level information. Indeed, we would directly use this demand function to setup a maximization of airports' profits problem. But things are less obvious in the maximization of social welfare case though. What is needed is a measure of *consumer* surplus but as it is clear from this vertical setting, *consumers* of airports are both final consumers (passengers) and airlines. What we need then is a measure of the sum of passenger surplus and airlines profits. What has been assumed in previous papers where the airline market is not formally incorporated (Zhang and Zhang, 1997; Oum et al., 2004), is that the airport demand does carry enough information so that its integration gives this total *consumer* surplus. We investigate now under which conditions this is true. In Zhang and Zhang (1997) and Oum et al. (2004), the demand for the airport, Q, is assumed to be dependent on a full price ρ, which includes flight delay costs and the airport charge. Using the notation of this paper, the demand for the airport would be $Q \equiv Q(\rho)$, where:

$$
\rho = \sum_{h=1,2} P_h + (\alpha S + \beta)\sum_{h=1,2} D^h(Q, K_h) \equiv P
$$
$$
+ (\alpha S + \beta)\sum_h D^h.
$$

$$(12)$$

Other charges to passengers, such as the flight ticket, are assumed to be exogenous as far as the airport is concerned. However, when one considers the full vertical structure and the associated sub-game equilibrium, $Q^i(P_h, K_h; N) = Q(P_h, K_h; N)/N$, both delays (Eq. (2)) and ticket prices (Eq. (4)) will directly depend on airport charges and capacities, which are the decision variables of the airports. So, the first question that arises is: is it reasonable to use the full price idea at the airport, rather than at the airline market level? An answer can be obtained by looking at Eq. (7). Using Eq. (12) to form ρ, and abstracting from schedule delay cost effects (*i.e.* making $g=0$) so that we can take $N \to \infty$, Eq. (7) can be written as:

$$
QS^2\left(\frac{2B}{N} + \frac{(N-1)}{N}E\right) + \rho + c - AS
$$
$$
+ (\alpha S + \beta)\frac{Q}{N}\sum_h D_Q^h = 0.
$$

$$(13)$$

Hence, Q would not depend only on ρ but also on D_Q and N; the (implicit) demand for airports should be $Q \equiv Q(\rho, D_Q, N)$. Note, however, that in the perfect

competition case, *i.e.* when $N \to \infty$, Eq. (13) leads to $Q(N \to \infty) = \frac{AS-c-\rho}{S^2 E}$, which implies that $Q(\rho, D_Q, N \to \infty) \equiv Q(\rho)$. Thus, under perfect competition, a full price as defined by ρ, can in fact be used directly at the airport market level: $Q(\rho)$ summarizes well the equilibrium of the downstream market.

Next, what has been (implicitly) assumed before, is that the integration of the airport demand with respect to ρ would capture the full *consumer* surplus. Let us study this, using the general (implicit) demand function $Q \equiv Q(\rho, D_Q, N)$. We are thus interested in unveiling how

$$\int_\rho^\infty Q(\rho, D_Q, N) \mathrm{d}\rho \tag{14}$$

is related to airlines profits and passenger surplus. Regrouping terms in Eq. (11) to form ρ, and considering again $g = 0$, we can write the aggregate (equilibrium) profit for carriers as:

$$\Phi(Q, \rho) = QS\left[A - \frac{QS}{N}(B + (N-1)E)\right] - Q[c + \rho]. \tag{15}$$

Consider now the total derivative of Φ with respect to ρ. From Eq. (15) the following results

$$\frac{\mathrm{d}\Phi}{\mathrm{d}\rho} = -Q(\rho, D_Q, N) - \frac{(N-1)ES^2 Q}{N}\frac{\partial Q}{\partial \rho}$$
$$- (\alpha S + \beta)\frac{Q}{N}\sum_h D_Q^h \frac{\partial Q}{\partial \rho}. \tag{16}$$

Reordering, integrating from ρ to ∞, and using Eq. (13) we finally get[14]

$$\int_\rho^\infty Q(\rho, D_Q, N)\mathrm{d}\rho = \Phi + \mathrm{PS} - \frac{BS^2 Q^2}{2N}$$
$$- \frac{1}{N}(\alpha S + \beta)\int_\rho^\infty Q \sum_h D_Q^h \mathrm{d}\rho. \tag{17}$$

Eq. (17) shows that integration of the airports demand with respect to the full price, delivers a correct measure of consumer surplus if and only if the airline market is perfectly competitive ($N \to \infty$). This was in fact the maintained assumption of Zhang and Zhang (2003) and Oum et al. (2004) so we have provided theoretical support for their modeling. When the airline market is imperfectly competitive though, the integral of Q with respect to ρ,

does not capture airlines profits plus passenger surplus because market power induces losses of consumer surplus and partial internalization of congestion — third and fourth terms in Eq. (17) respectively.[15]

The main conclusion of the previous analysis is that to analytically examine the airport markets, one cannot abstract from the airline market if competition is imperfect there. Formal modeling is required to adequately set up the social welfare maximization problem. The simplest way to do this is by considering directly the three actors involved (which is the method we use), although one could also add the missing terms to the integral of airport's demand. At the practical level, the conclusion is bad news for managers of public airports or airport regulation authorities: optimal pricing and capacity investments would 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, implying that we would need to search for regulation mechanism that work (*i.e.* are feasible), yet which are not optimal.

3. The airports market

3.1. System of welfare-maximizing airports

In this section, we look at the first two stages of the game – airports' capacities and prices – taking as known the equilibrium in the third stage, and compare the performance of airports under different objective functions. We do this both analytically and through numerical examples; details on these numerical simulations (such as the parameters used) are presented in the Appendix. So, consider first a system of airports maximizing social welfare. This case will be denoted by W and has been the case usually studied in the airport pricing literature that considers airlines' market power, *e.g.* Brueckner (2002, 2005) and Pels and Verhoef (2004). In those papers however, capacity was fixed while here it is a decision variable. As discussed in Section 2, with imperfect competition in the airline market the social welfare (SW) function is not simply the integral of airports' demand plus airports' profits. The correct SW function can be obtained by adding the two airports' profits (total profits denoted by π), passenger surplus in Eq. (10) and the sum of airlines' profits in sub-game equilibrium in Eq. (11); that is: SW$=\pi+$PS$+\Phi$. Decision variables are Q, P (which is the sum of P_1 and P_2), K_1 and K_2, but Q and P

---

[14] Here, we used the fact that $Q(\rho=\infty, D_Q, N)=0$ and therefore $\Phi(\rho=\infty, D_Q, N)=0$.

[15] For more on the general relation between input and output market surplus see Basso (2006). Among other things, he shows that, in a case like this, the integral of the input demand with respect to P – as opposed to ρ – would never adequately capture downstream firms' profits plus final consumer surplus, not even under perfect competition.

are related through the demand function. We use P and K_h as decision variables – *i.e.* we use the inverse demand function $P(Q,K_h;N)$ rather than the direct demand function $Q(P_h,K_h;N)$ – but obviously results do not change if we choose otherwise. In this setup, the three-stage game is identical to a two-stage game where Q and K_h are chosen simultaneously. As it is usual in the literature, we assume that an airport costs are separable and given by $C(Q)+rK$. Hence, the problem of the welfare maximizing airports is

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

$$+\left\{\frac{(B+(N-1)E)S^2Q^2}{2N}\right\}$$

$$+\left\{QS\left[A - \frac{QS}{N}(B+(N-1)E) - g\left(\frac{Q}{N}\right) - \alpha\sum D^h\right]\right.$$

$$\left. -Q[c+P+\beta\sum D^h]\right\}. \tag{18}$$

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

$$P = 2C' + \frac{(N-1)}{N}(\alpha S + \beta)Q\sum_h D_Q^h - \frac{QS^2B}{N} \quad, \tag{19}$$

$$-Q(\alpha S + \beta)\frac{\partial D(Q,K_h)}{\partial K_h} = r, \qquad h=1,2. \tag{20}$$

Second-order conditions do not hold globally but simulations showed that they do hold for a large range of parameter values, particularly for the numerical examples. A necessary condition though, is that C is not *too* concave.[16] It is also easy to prove that at the optimum, $K_1=K_2=K$. The pricing rule has three components: (i) airports marginal cost. (ii) A charge that increases price and is equal to the uninternalized congestion of each carrier. This efficient 'congestion toll' was first described by Brueckner (2002). It has the important feature that it diminishes with airlines' market shares (the larger the N, the larger the toll), showing that the scope for congestion pricing would be narrower that in the 'road case' where users do not have market power. (iii) A term that decreases price and which amounts to a subsidy to firms with market power in order to increase social welfare. This term, which was first identified by Pels and Verhoef (2004), attempts to diminish allocative inefficiency through an external decrease in airlines' marginal cost. Pels and Verhoef considered only a duopoly, but it is easy to see from Eq. (19) that the subsidy decreases with the number of airlines as expected.

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[16] Airports' operational economies of scale would be exhausted at fairly small traffic levels (*e.g.* Doganis, 1992).

As for capacity, Eq. (24) shows that capacity is added until the costs of doing so equate the benefits in saved delays to passengers and airlines. This capacity decision is essentially the same as the one found by Oum et al. (2004), even though they did not consider the airline market formally. The importance of considering the airline market will become clear when comparing this capacity rule to the one used by profit-maximizing airports.

As can be seen, the final charge Eq. (19) will be above or below marginal cost depending on whether the congestion toll or the subsidy dominates. If K is fixed, the congestion toll increases as N grows while the subsidy decreases. When capacity is a decision variable however, optimal K changes with N and, therefore, it is not necessarily true that the congestion toll increases and the subsidy decreases as N increases. In fact, the signs of dQ^W/dN, dK^W/dN, and dP^W/dN cannot be determined *a priori*. In the numerical examples shown in the Appendix however, we found that traffic, capacities and price increase with N. When N is small, prices are indeed negative because internalized congestion is large and hence the congestion toll is small, while subsidies need to be large. In fact, in the numerical examples, the price reaches marginal cost only when $N \geq 9$. But with capacity costs, price equal marginal cost would not lead to cost recovery; budget adequacy only occurs when N is over 200. These results speak of two things: First, that it will be important to look at the more realistic second best case, in which airports maximize social welfare subject to a budget constraint. This is done in Section 3.3. Second, and perhaps more importantly, that 'solving' the problem of airlines' market power through airport pricing does not seem to be, on one hand desirable and, on the other hand feasible (see Brueckner, 2005, for more on this).

Since both Q and K increases with N, it is reasonable to ask what happens with delays as the number of airlines increase. Numerically, it can be seen that delay slightly decreases with N, showing that the airports would keep up with traffic growth induced by more air carriers. 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:

$$\frac{d\mathrm{SW}}{dN} = \frac{\partial \mathrm{SW}}{\partial N} = \frac{(B-E)S^2Q^2}{2N^2} + Sg'\left(\frac{Q}{N}\right)\frac{Q^2}{N^2}. \tag{21}$$

The first term on the right hand side (RHS) is non-negative while the second is negative. It can be seen that when differentiation is weak, *i.e.* $B \approx E$, Eq. (21) may be negative which would imply that it would be better, in a social welfare sense, to have one airline. This may appear surprising but the explanation is simple: these 'first-best' airports solve not only the congestion externality but they

also solve airlines' market power through subsidies. Hence, having a monopoly airline would not produce allocative inefficiencies. But a monopoly airline provides a higher frequency than each airline in oligopoly because the number of flights of individual airlines decreases with N. And larger frequencies mean smaller schedule delay cost (recall this was assumed to be airline dependent) which increases demand. Indeed, this result abstracts from the fact that the airport itself would require subsidies to operate. In the opposite case, when differentiation is strong, *i.e.* $B \gg E$, Eq. (21) 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.[17]

3.2. System of profit-maximizing airports

We now examine the decisions of a system of airports which maximize profits, which can be roughly understood as private-unregulated airports. We denote this case by SPA. The problem the SPA faces is given by

$$\max_{Q,K_1,K_2} \pi(Q, K_h; N) = P(Q, K_h; N)Q - 2C(Q)$$
$$- (K_1 + K_2)r. \qquad (22)$$

First-order conditions on Q lead to the well-known pricing rule $P = 2C' + P/\varepsilon_P$ – where ε_P is the (positive) price elasticity of airports' demand – but this does not tell us much in this case. Using Eq. (8), however, we can calculate an explicit expression for ε_P from where we get:

$$P = 2C' + \frac{(N+1)}{N}(\alpha S + \beta)$$
$$\times Q\sum_h \left(D_Q^h + \frac{Q}{N+1}D_{QQ}^h \right)$$
$$+ \frac{QS^2(2B + (N-1)E)}{N}. \qquad (23)$$

Just as in the first-best, the pricing rule has three components. The second component is related to congestion. Comparing this to Eq. (19), it can be easily seen that profit-maximizing airports would overcharge for congestion: their congestion charge is proportional to $(N+1)/N$, which is larger than an airline's market share, and the expression also includes a term related to the second derivative of the delay function, which further increases the congestion charge. This shows that,

just in terms of delays, deregulation may lead to traffic levels that are too small to be efficient, although the overcharge for congestion becomes less important as the number of airlines grow. The airports' price is further increased by the third term in Eq. (23), which is pure market power from the part of the airports: Profit-maximizing airports would certainly not subsidize the airlines but instead would try to capture part of their profits by increasing the price. We discuss the relative importance of each of these two terms (congestion and market power charges) below.

As for capacity, first-order conditions lead to

$$Q\frac{\partial P}{\partial K_h} = r, \qquad h = 1, 2. \qquad (24)$$

Eq. (24) shows that the airports would increase capacity until marginal revenue equals the marginal cost of providing the extra capacity. Clearly, the capacity rule of profit-maximizing airports in Eq. (24) is different than that of welfare-maximizing airports in Eq. (20). 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 which led them to conclude that private airports set capacity levels efficiently for the traffic they induced through pricing. The divergence is caused by the fact that their set-up only holds for a perfectly competitive airline market, as discussed in Section 2.2. Indeed, if one replaces in the private airport capacity rule Eq. (24), the marginal value of capacity by its full expression, *i.e.* $\frac{\partial P}{\partial K_h} = -(\alpha S + \beta)$ $\left(\frac{Q}{N}D_{QK}^h + D_K^h \right)$, one can see that, if $N \to \infty$, then the capacity rules (20) and (24) do coincide. In general, however, this would not be the case: the marginal revenue perceived by the airport is not necessarily a measure of the social benefit of an increase in capacity (Spence, 1975, provided this insight for a monopolist selling a *final* good, and who had to choose price and quality rather than price and capacity).

We would like now to compare the performances of profit- and welfare-maximizing airports. Comparisons are complex though, because quantity (prices) and capacities are chosen simultaneously. A way to make comparisons feasible is to assume first that capacities are fixed and to compare just prices. As expected, profit maximization would lead to allocative inefficiencies in the form of reductions in traffic (the proof is in the Appendix):

Proposition 1. *For given capacities, the profit-maximizing airports charge a higher price than welfare-maximizing airports and consequently, they induce less traffic.*

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[17] These results were not obtainable in Pels and Verhoef's model because they did not have N as a variable and had no schedule delay cost. Brueckner did consider N firms, but Eq. (21) would have always been zero in his case because his model featured homogeneity and no schedule delay cost.

How can capacity decisions be compared? Since quantity and capacity are defined simultaneously in a system of equations, two cases can be distinguished. First, we can compare actual capacities and quantities. Second, we can examine what distortions, if any, arise on the capacity side when the monopoly pricing distortion is taken into account; in other words, whether capacity distortions are mere byproducts of monopoly pricing or not. To analyze these two questions, we first examine what happens with K when Q is given (*e.g.* the airline market is frequency regulated).[18] A proof in the Appendix shows that:

Proposition 2. *For a given Q, the system of profit-maximizing airports (SPA) will oversupply capacity with respect to the first-best airports (W).*

Thus, regarding actual capacities and quantities, from Proposition 2 it is clear that, if for a given capacity the output restriction of the system of profit-maximizing airports is not too important, *i.e.* $Q^{SPA}(K) \approx Q^W(K)$ (these denote quantity rules for given K), then these airports' capacities will be higher than the W ones and delays would be smaller. If the output restriction is severe, $Q^{SPA}(K) \ll Q^W(K)$, then SPA capacities would be smaller than W capacities. The second question regarding capacity is, what distortions, if any, arise on the capacity side when the 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? To analyze optimal social welfare capacities under monopoly pricing, consider the following constrained SW function, $CSW(K) \equiv SW(Q^{SPA}(K))$, and maximize it with respect to K (recall that $K_1 = K_2 = K$). How does the second constrained social welfare capacity, K^{CW}, compare to K^{SPA}? Differentiating and evaluating at K^{SPA} we get

$$\left.\frac{dCSW}{dK}\right|_{K^{SPA}} = \left.\frac{\partial SW}{\partial Q}\right|_{Q^{SPA}(K^{SPA}),K^{SPA}} \cdot \left.\frac{\partial Q^{SPA}(K)}{\partial K}\right|_{K^{SPA}}$$
$$+ \left.\frac{\partial SW}{\partial K}\right|_{Q^{SPA}(K^{SPA}),K^{SPA}}. \quad (25)$$

We are interested on the sign of Eq. (25). If it is positive, then constrained social welfare capacities are larger than the SPA ones. The first derivative on the RHS is always

positive by Proposition 1; the second one also is.[19] The third derivative is negative because Proposition 2 shows that, for any given Q (including Q^{SPA}), SPA airports oversupply capacity with respect to social-welfare maximizing airports. Therefore, the sign of (25) is not determined *a priori*: we cannot say whether K^{CW} is below or above K^{SPA}. However, if $Q^{SPA}(K) \approx Q^W(K)$, then $K^{SPA} > K^{CW}$ because the first derivative on the right hand side of Eq. (25) would be close to zero by first-order condition in the (unrestricted) max SW case, and Eq. (25) would be negative. Of course, we would also have $K^{SPA} > K^W$. So, if it was true that unregulated profit-maximizing airports induce small allocative inefficiencies, as it has been argued, this would mean that private capacities would be too large, even in a second best sense. If $Q^{SPA}(K) \ll Q^W(K)$, then the positive terms in Eq. (25) are more likely to dominate the negative one, and K^{CW} may be above K^{SPA}. Hence, overall, we can only say that, probably, the monopoly of private airports does induce distortions in capacity, which are in addition to pricing distortions. But, whether this distortion is under or over-investment strongly depends on the size of the allocative inefficiencies, something that we can unveil through numerical examples.

Our fixed-capacities simulations show that the SPA output restriction is severe, that is $Q^{SPA}(K) \ll Q^W(K)$, because profit-maximizing airport charges are fairly large and way above marginal cost. For fixed capacity and $N=3$, output is diminished by 56% as compared to the first-best. Hence, given the discussion above, the actual SPA capacities would be smaller than the first-best capacities and the second-best capacities, that is $K^{SPA} < K^W$ and $K^{SPA} < K^{CW}$. In fact, when chosen freely, SPA capacities range between 31% and 48% of the first-best capacities, when N goes from 1 to 10. And this, together with their large prices, makes the SPA traffic to be between 24% and 44% of the first-best traffic level.[20] Now, by construction, profit-maximizing airports

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[18] This analysis may seem similar to Spence (1975)'s examination of the provision of quality by a monopolist, since under the current modeling K can be seen as a measure of quality. However, Spence's insights – although pervasive – do not apply directly because, here, the firm that has to choose *quality* provides an input to a downstream oligopoly, rather than a final product. Moreover, in the downstream (final) market, there are externalities in both production and consumption.

[19] We have that $\partial Q^{SPA}(K)/\partial K = -\pi_{QK}/\pi_{QQ}$, but $\pi_{QK} = P_{QK}Q + P_K > 0$ (see Eq. (9)) and $\pi_{QQ} < 0$.

[20] A large profit-maximizing airport charge is in line with a previous result: Morrison and Winston (1989) found that the difference between the monopoly and the *efficient* per-passenger landing fee was $498.4. Multiplying this by the aircraft size we use in the numerical examples, lead to a difference of $49,840 dollars per flight. Since Morrison and Winston did not formally consider the airline market, their results are valid only for perfect competition in the airline market. In our case, the difference between SPA and W when $N=10$ is $43,505 per landing (recall that P is the sum of charges at both airports), as can be seen in the Appendix. This airport charge is comparable to theirs, 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.

induce dead-weight losses. The numerical examples put these between 60% and 32% when N goes from 1 to 10. Yet, for all values of N, the profit-maximizing airports have smaller delays (from 34% to 5% smaller) which, as it is now clear, are achieved at the cost of important reductions in traffic. This may be seen as a warning sign: congestion has been one of the main drivers of research in this area and proponents of privatization and/or deregulation have argued that private airports would charge efficient congestion prices and would respond to market incentives for capacity expansion. But measuring the result of such policies only by its effects on congestion, may lead to the wrong conclusions.

Finally, because dead-weight losses decrease with the number of airlines, it is interesting too see whether the SPA would prefer to have a large number or a small number of airlines servicing the market. To examine this, we totally differentiate profits with respect to N and then apply the envelope theorem: $\mathrm{d}\pi/\mathrm{d}N = \pi_Q Q_N^{\mathrm{SPA}} + \sum \pi_{K_h} K_N^{\mathrm{SPA}} + \pi_N = \pi_N = Q^{\mathrm{SPA}} P_N > 0$. Hence, as N increases, profits increases: the SPA would prefer to have many airlines in the market.

3.3. Cost recovery of social welfare maximizing airports

The comparison between profit-maximizing and first-best airports is useful as a benchmark, yet airport budget adequacy is evidently important for policy making. The issue of budget adequacy was explicitly considered by Zhang and Zhang (1997) and Oum et al. (2004), but in models that only looked at the airport market, with social welfare functions that are valid only if the airline market is perfectly competitive. On the other hand, in the airport pricing literature that takes into account the vertical relation between airports and airlines, airports profits are usually not considered in the social welfare function. For example, Brueckner (2002) and Pels and Verhoef (2004) were interested in the toll that some airport authority has to charge to make efficient use of installed capacity, so whether airport revenues would cover costs or not was not examined.

The analysis in Section 3.1 shows that for N small, first-best airports would run deficits because it would be optimal to subsidize the airlines (the market power effect

dominates the congestion effect). Pels and Verhoef (2004) argued that when subsidies are optimal but unfeasible, then the *toll* should be set to zero, which in this model is equivalent to airports charging marginal cost. However, this would not be enough to cover airports costs here – even if the marginal cost function is flat – because airports have to pay for the capacity. To ensure cost recovery, the restriction $\pi \geq 0$ needs to be considered. This case, which we denote CRL (Cost Recovery with Linear prices), is characterized by the following pricing and capacity rules:

$$P^{\mathrm{CRL}} = 2C' + \frac{1}{1+\lambda} P^W + \frac{\lambda}{1+\lambda} P^{\mathrm{SPA}} \quad , \qquad (26)$$

$$-\frac{Q(\alpha S + \beta)}{1+\lambda} \frac{\partial D(Q, K_h)}{\partial K_h} + \frac{\lambda}{1+\lambda} Q \frac{\partial P}{\partial K_h} = r, \quad h = 1, 2 \qquad (27)$$

where $\lambda \geq 0$, the Lagrange multiplier of the restriction, captures the severity of the constraint by balancing the charge between the efficient first-best price and the SPA price. Since the CRL case lies in between the W and SPA cases, it is evident that actual prices and capacities will lie in between as well. The numerical examples show that CRL capacities would be approximately 40% larger than SPA capacities, while the CRL price would be less than a third of the SPA price. The CRL traffic level would then be approximately 2 times the SPA traffic level, inducing a total social welfare that is between 74% to 44% larger than in the SPA case, when N goes from 1 to 10. Importantly, flight delay levels in the CRL case and the SPA case are very close, with a 2% maximum difference for different values of N. These results show that second-best airports (budget constrained) perform quite better than their profit-maximizing counterparts, both in terms of level of traffic and in terms of congestion, showing that the large traffic contraction that a private-unregulated airport would induce is not really needed to manage congestion.

We saw before that the SPA price would be too high because of two effects, overcharge for congestion and market power. Given what we have just shown, and that in the literature, some authors have argued that privatization would be a way of handling increasing congestion problems, it seems now reasonable to explore

Table 1
Division of SPA and CLR prices into congestion and market power components

Type	Q	K	P	Congestion charge (CC)	Market power charge (MP)	CC/MP
SPA	42.55	81.31	84,249	819	79,430	0.01
CRL	71.11	81.31	26,867	18,473	4394	4.20

what percentage of the total SPA price, corresponds to the congestion overcharge, and how does that compare to the CLR case. To do this we use an example with $N=3$, and divide the CLR and SPA prices, for given optimal CLR capacities, into its two components (Table 1).

As can be seen, the total congestion charge of SPA airports is a fairly small part of its total price. Hence, the congestion overcharge is even smaller. This shows that profit-maximizing airports would achieve low congestion levels not because they 'solve congestion' *per se*, but just because they would exert market power. A possible lesson of all this is that if private airports can be considered as profit-maximizers, they would need to be regulated. The problem of course would be how to regulate price while getting the incentives for capacity expansions right. This question, which may not seem to be new at all (*e.g.* Spence, 1975), has in this context the added complexity of the downstream (airlines) market and seems to be an urgent area of further research. On the other hand, the performance of CLR airports indicate that as long as a non-subsidized public airport maximizes social welfare, or a non-for profit organization has the incentives to do so, it is possible to balance budget adequacy, good congestion management and allocative efficiency.

4. Extensions

In this section, we look at other possible objective functions airports may have, and which have potentially important policy implications. We are brief for space reasons, but some proofs and derivations may be found in the supplementary appendix.

4.1. Maximization of joint profits: airlines and airports

Consider first the joint maximization of airlines' and airports' profits (we denote this case by JP). Two reasons why it is interesting to look at this case are: 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, deeper collaboration between airlines and airports was allowed and encouraged or, on the other hand, if airlines had enough countervailing power (Beesley, 1999; Condie, 2000; Forsyth, 1997, 2003; Starkie, 2001, 2005; Productivity Commission, 2002; Civil Aviation Authority UK, 2004). The maximization of joint profits emerges as an obvious first approach to analyze these assertions. A second reason why it is interesting to look at joint-profits maximization is two part tariffs. With two-part tariffs, airports not only charge a per-flight price but they also charge a fixed-fee to each airline.

Airlines then compete as in Section 2 but with this fee added to the cost function, which does not affect their quantity decisions but only whether they operate or not. The outcome is exactly that of maximization of the sum of profits but obtained in a non-cooperative fashion.[21] Pricing and capacity rules in this joint-profits case are:

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

(28)

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

(29)

The second term on the RHS of Eq. (28) shows that in this case there is no overcharge for congestion yet, the third term increases the price above the full marginal cost of each flight. This component is put in place by the airports to countervail the *business-stealing effect*, *i.e.* that airlines do not take into account profits lost by competitors when they expand their output. By increasing airlines' marginal cost, the airports induce a total output contraction that leads to a final outcome identical to cooperation between competitors in the airline market. The intuition of this result (which has not been obtained in the airport pricing literature before), depends on why the maximization of joint profits was the relevant case. With two-part tariffs, the 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 'capture' an input provider to run a cartel for them. The upstream firm is rewarded with a share of the profits.[22] Now, despite the fact that the result

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[21] 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 two-parts tariff setting is that, here, the upstream company has a quality (capacity) that matters.

[22] This idea of an upstream firm running the cartel for the downstream firms has been discussed in the vertical control literature and, particularly, in the input joint-venture case. For example, Shapiro and Willig (1990) conjecture that input joint-ventures can facilitate collusion and push a market toward the monopoly outcome. Chen and Ross (2003) formalize this. If airport provision was seen as an input joint-venture by the airlines, our results show two things in addition to what Chen and Ross found. First, that if there are externalities, the input price is, additionally, used to force their internalization by downstream competitors. Second, that when marginal costs are not constant downstream, the outcome is not as in monopoly or a downstream merger, but as in a cartel.

is as if airlines collude, this is not worse for social welfare than the system of profit-maximizing airports charging linear prices (SPA) because, here, vertical double marginalizations are avoided. This shows up in the fact the both the second and third terms in Eq. (28) are smaller than their SPA counterparts, and that the capacity rule (29) is the same as in the social-welfare maximizing case. Analytical comparisons with previous cases are summarized in the following proposition.

Proposition 3.

1) *For a given K the JP airports will: (i) induce fewer flights than the W ones (ii) induce more flights than the SPA ones*
2) *For a given Q, the JP airports will: (i) have the same capacity as W airports (ii) have less capacity than SPA airports.*
3) *As for actual capacities and quantities, JP airports will induce fewer flights and will have smaller capacities than W airports.*
4) *The JP airports undersupply capacity with respect to second-best social welfare capacities under JP pricing (despite having the same capacity rule).*[23]

Together with Proposition 3, the numerical examples in the Appendix show that the proposal of increased collaboration between airports and airlines could indeed be an improvement. JP airports induce higher joint profits and consumer surplus – and therefore social welfare – more traffic, higher capacities and smaller airfares than SPA airports. But, since JP airports manage to induce an airline cartel, while in the first-base case *W* airlines, market power is disabled through subsidies, JP airports' performance still fall far away from the first-best. Yet, for small values of *N*, their performance social-welfare wise is quite close to CLR airports. This comparison however, is not necessarily fair because, if airlines were asymmetric, implementing collaboration or two part-tariffs would be fairly complex. On the other hand, if the symmetry of airlines can be exploited, then, JP airports should be compared with airports that are budget constrained, but that are also allowed to use two part tariffs. In that case the airports may, in principle, establish negative marginal

prices while covering their costs through the fixed fee.[24] This case, which in the numerical examples in the Appendix is denoted by CRT (Cost Recovery with Two-parts tariff), achieves, practically, the same result as the first-best.

In equilibrium, the change of joint profits with *N* is similar to the first-best case (see Eq. (21) and the discussion therein). When substitutability is weak, joint profits are maximized with a monopoly airline and hence 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. 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) warning: "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". His comment is supported by this result but, here, airport domination is not necessarily harmful. With the JP pricing scheme, airline competition is destroyed in any case and irrespective of *N*, but a monopoly offers a higher frequency than the one offered by each airline, thus reducing schedule delay cost (which was assumed to be airline dependent). When airports are relatively indifferent between $N=1$ or higher, implementation problems may play a role: it may be easier for them to coordinate actions with only one airline. With two-part tariffs, however, airports may still prefer to let a single airline dominate, even if it is not the most profitable action, because their pricing becomes simpler: they do not need to estimate the second and third terms of the pricing rule and 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 on the airline market.

4.2. Independent profit-maximizing airports

So far, there has been no apparent need to have two airports in the model. We have them because in many cases the idea is to privatize airports independently and

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[23] It has been argued that a capacity rule such as the one JP airports follow would be efficient because it is identical to the first-best one so, for a given *Q*, capacity would be set efficiently (Oum et al., 2004). The question Proposition 3.4 answers is different: do JP airports induce distortions in capacity that go beyond what is induced only by pricing? This is analogous to what was done when looking at second-best capacities under SPA pricing, in Section 3.2.

[24] This mechanism has been also suggested for the *access* problem to telecommunication networks (Laffont and Tirole, 2000). Since there is no guarantee that two-part tariffs would enable cost recovery – because airlines may not make enough money to actually cover the airports' expenses – the restriction $\pi + \Phi \geq 0$ needs to be considered.

not in a system. We explore this situation by looking at two independent profit-maximizing airports. We take prices (rather than quantities) as tactical variables and look first at the open-loop case in which prices and capacities are chosen simultaneously. We denote this case IPA. Each airport's program is:

$$\max_{P_h, K_h} \pi^h = Q_h(P_1, P_2, K_1, K_2)P_h - C(Q_h) - K_h r,$$
$$h = 1, 2. \tag{30}$$

We look for symmetric equilibrium and calculate the sum of equilibrium airport charges. We get

$$P = 2C' + 2(P/\varepsilon_P). \tag{31}$$

The pricing Eq. (31) clearly shows the *horizontal* double marginalization problem that arises in oligopoly when outputs are complements, which is the case here. In these cases, competition is harmful for social welfare. Capacity rules are the same as in SPA (Eq. (24)), but obviously actual capacities will be different. Hence, IPA airports induce fewer flights and have smaller capacities than the SPA. From Propositions 1–3, 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, $Q^W > Q^{JP}$, $Q^{SPA} > Q^{IPA}$, $K^{JP} < K^W$ and $K^{IPA} < K^{SPA}$.

In the closed-loop game, where airports first choose capacities (simultaneously) and then prices, airports over-invest in capacity with respect to the open loop. Qualitatively (a full derivation is in the supplementary 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.

Finally, if the independent profit-maximizing airports collaborate with the airlines or each charges two-parts tariffs (case denoted by IJP), the horizontal double marginalization also arises (details in the supplementary appendix): the airports jointly overcharge for congestion and the business stealing effect. The numerical examples in the Appendix show that the horizontal double marginalization is quite harmful for social welfare, particularly as N grows.

5. Summary and conclusions

Privatization of airports has been argued for on the grounds that private airports would implement more efficient congestion pricing schemes and would have better incentives to invest in capacity. Privatized airports have been subject to economic regulation though, out of the concern they would exert market power. But 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, and because potential collaboration between airlines and airports – or, alternatively, airlines countervailing power – would put downward pressure on market power. Because most of the literature on airport privatization/deregulation has been essentially descriptive and empirical analysis are unfeasible because of absence of real data, the aim of this paper was to build an analytical model where the potential impact of deregulation on pricing practices and capacity decisions of airports could be examined. We use a model of vertical relations between two congestible airports and an airline oligopoly, to compare the performances of airports under different objective functions. In this model, we explicitly recognize that the demand for airports services is a derived demand. We prove analytically that using the airports demand to obtain a measure of consumer surplus is incorrect if airline competition is not perfect. This is an important result because, on one hand, several papers have calculated consumer surplus by integration of the airports demand and, on the other hand, because it shows that optimal pricing policies require massive amounts of information.

We find that unregulated profit-maximizing airports would overcharge for the congestion externality. Analytical and numerical results showed that, when compared to the first best, these airports would induce large allocative inefficiencies and dead-weight losses. They would also restrict capacity investments but, overall, would induce fewer delays. This triggers a warning: the effects of privatization/deregulation should not be assessed only in terms of the effects on congestion. Next, because first-best policies imply losses, we also compared the performance of profit-maximizing airports against second-best airports, *i.e.* welfare maximization subject to a budget constraint. We found that these airports would perform quite well, achieving congestion levels similar to a private-unregulated airport, but without inducing such large traffic contraction; this puts a question mark on the desirability of deregulation of private airports. We also found that increased cooperation between airlines and airports induce some improvements, as vertical double

marginalizations – such as the congestion overcharge – are avoided. Yet the outcome it is still closer to the profit-maximizing case than to the first-best because the airport adopts a pricing strategy that leads to a downstream airline cartel.

It was also shown that under some objective functions it may be better, social welfare wise, to have a single airline dominating the airports. This case arises when airports maximize the sum of their profits and those of the airlines, or when they maximize social welfare *and* schedule delay costs effects are strong and airline differentiation is weak. However, it would be bold to extract from here unconditional support for airport domination by a single airline. The crux of the matter is that a single airline is optimal only when the pricing practice of the airport renders the number of airlines irrelevant for competition. In the cases we saw, this happened either in the form of elimination of market power through subsidies, or in the form of cartel behavior. But in the more likely case in which, despite the airport pricing, competition is increased with the number of airlines – as in the profit-maximizing case – a large number of firms is still preferable.

We close by discussing what we think are important areas of further research. First, it seems important to examine what would be optimal regulation schemes for profit-maximizing airports. What we need are mechanisms to regulate price and capacity of a congestible upstream facility facing an oligopolistic downstream (carriers') market, a problem which appears complex to solve. Second, it seems urgent to look for practical objective functions for budget-constraint airports, with the specific feature of less information requirements. Third, most of the papers on airport pricing – if not all – have assumed some form of fixed-proportion assumptions, in which aircraft size is fixed rather than being chosen by the airlines. However it seems obvious that the airports' pricing schemes will influence aircraft size decisions, which will have effects both on congestion levels and schedule delay costs. A model that considers aircraft size as decision variable would be an important contribution to the airport pricing literature. Finally, this and other papers exploit symmetry and Cournot behavior at the airline level, yet in a number of airports this is not the case; there

is one large airline competing with a fringe of smaller airlines. These cases may be better analyzed with Stackelberg competition or competitive fringe models. Important developments along these lines are already on their way (see Morrison and Winston, in press; Daniel and Harback, in press; Brueckner and Van Dender, 2007).

Acknowledgments

Appendix A

● **Proof of proposition 1.** From Eq. (18), we can write

$$SW(Q, K_h; N) = \pi + \frac{(B + (N-1)E)S^2Q^2}{2N}$$
$$+ QS\left[A - \frac{QS}{N}(B + (N-1)E) - g\left(\frac{Q}{N}\right) - \alpha\sum D^h\right]$$
$$- Q[c + P + \beta\sum D^h].$$
(A.1)

Differentiate this with respect to Q and evaluate the result at $Q^{SPA}(K)$, the optimal SPA quantity for given K. This makes $\partial\pi/\partial Q$ nil. Using Eq. (7) to replace $AS - c - S\left(g'\left(\frac{Q}{N}\right)\frac{Q}{N} + g\left(\frac{Q}{N}\right)\right)$, we get: $\frac{\partial SW}{\partial Q}|_{Q^{SPA}(K)} = -P_Q Q + \frac{BS^2 Q}{N} - \frac{(N-1)}{N}(\alpha S + \beta)Q\sum_h D_Q^h|_{Q^{SPA}(K)}$ Replacing $P_Q = -(\alpha S + \beta)\sum_h\left(\frac{N-1}{N}D_Q^h + \frac{Q}{N}D_{QQ}^h\right) - \frac{S^2(2B + (N-1)E)}{N}$, we finally get $\frac{\partial SW}{\partial Q}|_{Q^{SPA}(K)} = \frac{Q^2}{N}(\alpha S + \beta)\sum_h D_{QQ}^h + \frac{S^2 Q(3B + (N-1)E)}{N}|_{Q^{SPA}(K)} > 0$, which shows that the SPA induces fewer flights. The equivalence follows from the decreasing monotonicity of P with respect to Q. □

● **Proof of proposition 2.** Eq. (A.1) and the envelope theorem leads to $\partial SW/\partial K_1|_{K^{SPA}(Q)} = -Q(\alpha S + \beta)D_{K_1} - QP_{K_1}$. The first term is positive while the second is negative. Replacing $\frac{\partial P}{\partial K_1} = -(\alpha S + \beta)\left(\frac{Q}{N}D_{QK_1}^1 + D_{K_1}^1\right)$, one finally obtains that $\partial SW/\partial K_1|_{K^{SPA}(Q)} = Q^2(\alpha S + \beta)D_{QK_1}/N < 0$. □

Table A.1
Parameter values for the numerical analysis

Demand					Airlines		Airports	
α	40	A	2000		S	100	r	10,000
β	3000	B	0.15		N	varies	C'	2000
γ	4	E	0.13		c	36,000		

- Numerical analyses

There are three reasons why they are needed. First, dismantlement of regulation has not been implemented at a large scale and, hence, there is no real data to conduct empirical analyses. Second, in this model comparative statics and analytical comparisons are not conclusive in all cases. And third, even when analytical results are obtainable, they are necessarily qualitative. We use the parameter values in Table A.1, and solve numerically the fixed-point system for P and Q, using the first order conditions of each case, *e.g.* Eqs. (18) and (19) for the maximization of social welfare case. All other parameters are then obtained by simple substitution.

While certainly real aviation cases are more complex that what is portrayed in this paper, we did try to be as reasonable as possible with the parameterization, by drawing data and values from other studies: For α,

Morrison and Winston (1989 , p. 90) empirically found a value of $45.55 an hour in 1988 dollars; for γ, they found a value of $2.98 an hour in 1983 dollars (p. 66). For β, Morrison (1987, p. 51 footnote 20), finds that the hourly extra cost for an aircraft due to delays is approximately $1700 (resulting from 3484-18*100) in 1980 dollars. For 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 c, Brander and Zhang (1990) proposed the following formula for the marginal cost per passenger in a direct connection: $\text{cpm}(D/\text{AFL})^{-\theta}D$; 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

Table A.2
Results of numerical analysis

N	Type	Q	K	P	D	t	PS	Φ	π	π+Φ	SW
1	W	92.18	100.18	−134,263	0.115	608	6,372,189	14,599,332	−14,748,019	−148,686	100.00
	SPA	21.92	31.21	93,629	0.076	1665	360,368	798,224	1,340,397	2,138,621	40.15
	CRL	42.92	53.71	29,024	0.074	1350	1,381,798	2,985,054	0	2,985,054	70.17
	JP	45.85	51.48	4000	0.158	1300	1,576,519	4,080,700	−1,029,579	3,051,121	74.36
	CRT	91.09	99.05	−131,008	0.116	624	6,222,620	14,278,419	−14,278,419	0	99.99
	IPA	11.62	17.78	123,352	0.106	1817	101,304	252,124	822,021	1,283,695	22.25
	IJP	45.85	51.48	4000	0.158	1300	1,576,519	4,080,700	−1,029,579	3,051,121	74.36
3	W	101.23	109.62	−33,201	0.110	608	7,001,866	5,800,933	−5,958,055	−157,122	100.00
	SPA	36.10	45.52	93,533	0.084	1500	890,628	719,011	2,321,856	3,040,867	57.44
	CRL	71.11	81.31	26,867	0.086	1021	3,455,375	2,754,159	0	2,754,159	90.72
	JP	50.36	56.27	61,129	0.152	1299	1,733,133	1,606,429	1,751,761	3,358,190	74.38
	CRT	100.08	108.42	−31,065	0.111	623	6,843,847	5,677,648	−5,677,648	0	99.99
	IPA	19.80	26.23	123,174	0.117	1719	267,820	238,905	1,518,049	2,073,541	34.21
	IJP	34.34	39.21	90,607	0.180	1516	805,821	820,940	2,189,990	3,010,930	55.76
10	W	104.83	113.37	6379	0.108	607	7,252,401	1,855,122	−2,017,987	−162,865	100.00
	SPA	46.41	54.67	93,389	0.103	1378	1,421,451	363,240	3,055,011	3,418,251	68.27
	CRL	91.84	100.71	25,934	0.103	779	5,566,250	1,410,818	0	1,410,818	98.41
	JP	52.16	58.17	83,218	0.149	1299	1,795,457	509,499	2,968,472	3,477,971	74.38
	CRT	103.64	112.13	8,121	0.109	623	7,088,606	1,815,514	−1,815,514	0	99.99
	IPA	25.87	31.67	122,926	0.141	1646	441,640	124,213	2,054,761	2,567,223	42.44
	IJP	31.16	35.79	113,528	0.188	1572	640,840	205,027	2,697,114	2,902,142	49.97

Fixed capacity (at the socially optimal level)

N	Type	Q	K	P	D	t	PS	Φ	π	π+Φ	SW
3	W	101.23	109.62	−33,200.87	0.1100	607.66	7,001,866	5,800,933	−5,958,055	−157,122	100.00
	SPA	42.76	109.62	84,054.67	0.0058	1,414.86	1,249,429	914,925	1,230,779	2,145,705	49.60
	CRL	68.31	109.62	36,095.95	0.0151	1,065.09	3,188,313	2,344,470	0	2,344,470	80.83
	JP	58.37	109.62	54,794.35	0.0104	1,201.25	2,328,119	1,708,355	772,470	2,480,825	70.26
	CRT	100.05	109.62	−29,206.49	0.0954	624.85	6,840,677	5,514,806	−5,514,806	0	99.94
	IPA	28.53	109.62	110,686.70	0.0032	1,609.47	556,042	406,238	850,949	1,257,186	26.49
	IJP	44.35	109.62	81,072.63	0.0062	1,393.08	1,344,236	984,543	1,226,018	2,210,560	51.93

W: system of social welfare-maximizing airports. SPA: system of profit-maximizing airports. CRL: welfare maximization with cost recovery (linear pricing). JP: maximization of joint profits: airports and airlines (or two-part tariff). CRT: welfare maximization with cost recovery two-part tariff pricing. IPA: independent profit-maximizing airports. IJP: independent airports maximizing own profit plus airlines' profits (or each airport with two-part tariff). *Q*: traffic. *K*: capacity. *P*: airport charges. *D*: delay. *t*: air ticket. PS: passenger surplus. *Φ*: airlines profits. *π*: airports profits. SW: social welfare.

1981–1988 (see Oum et al., 1993): cpm=$0.12/pax/mile, AFL=775 miles and $\theta=-0.43$. 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. For the schedule delay cost, it is assumed that Assumptions (a) and (b) in Section 2 hold, so that the schedule delay cost function is only defined by γ and η; we impose η equal to one.[25] We consider a constant airport operational marginal cost, implying that economies of scale (if any) arise from the presence of fixed costs. We do not define a value for these so that airports' profits in Table A.2 are net of the fixed costs.

Table A.2 summarizes some of the results obtained. It has both, variable- and fixed-capacity cases. When capacity is fixed, it was set at the socially optimal level but choosing it otherwise does not change the qualitative conclusions. Second order conditions hold in all cases and social welfare is presented in terms of percentages rather than dollars. When airports are independent (IPA and IJP cases), results are for open-loop games. Insights do not qualitatively vary with changes in the value of the parameters, although some numbers do. Specifically, different values for the demand parameters (A, B and E) and for r and for C' were tried, since for these parameters we had less information. It was found that the impact of changes in r and C' are quite small, while demand parameters impact on the levels but not on the order of the results. For example, taking $A=5000$ and $B=1$, as in Pels and Verhoef (2004), and then taking $E=0.8$ and $N=3$, SPA traffic decreases from 36 to 18 and SPA capacity decreases from 45 to 24, while W traffic decreases from 101 to 50 and W capacity decreases from 110 to 56.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ijindorg.2007.09.002.

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