SEQUENTIAL PEAK-LOAD PRICING: THE CASE OF AIRPORTS AND AIRLINES

Leonardo J. Basso
Department of Civil Engineering, Universidad de Chile
Casilla 228-3, Santiago, Chile, Ph. (56 2) 978 4380, Fax: (56 2) 689 4206
E-mail: lbasso@ing.uchile.cl

Anming Zhang
Sauder School of Business, The University of British Columbia
2053 Main Mall, Vancouver BC, Canada V6T 1Z2,
E-mail: anming.zhang@sauder.ubc.ca

ABSTRACT

This paper investigates airport peak-load pricing using a vertical structure of airport and airlines. We consider a private, unregulated airport and a public airport that maximizes social welfare. We find that compared to the public airport which may or may not be budget-constrained, a profit-maximizing airport would charge higher peak and off-peak runway prices, as well as a higher peak/off-peak price differential. Consequently, airport privatisation would lead to both fewer total air passengers and fewer passengers in the peak period. Although peak-traveling passengers benefit from fewer delays, overall it is not efficient to have such a low level of peak congestion, suggesting that airport privatization cannot be judged based on its effect on congestion delays alone. We also examine pricing behaviour of a public airport that is constrained to charge a time independent price, finding that it would actually charge the (optimal) off-peak price throughout the day.

Keywords: Peak-load pricing, vertical airport-airline structure, Airport privatization

RESUMEN

Investigamos, usando una estructura vertical aeropuerto-aerolíneas, las características que tendrían sistemas de peak-load pricing si fuesen usados por aeropuertos. Consideramos un aeropuerto privado des-regulado, y un aeropuerto público que maximiza bienestar social. Comparado con un aeropuerto publico, que puede tener o no una restricción de presupuesto, el aeropuerto que maximiza utilidades cobrara precios mas altos tanto en hora punta como en hora valle, al mismo tiempo que tendrá una mayor diferencia entre precios de hora punta y hora valle. Como consecuencia, la privatización del aeropuerto llevaría a una disminución en la cantidad total y en hora punta de vuelos y pasajeros. Aun cuando los pasajeros que permanezcan viajando en hora punta se beneficiarían de menores niveles de congestión, esta menor congestión no es eficiente, lo que sugiere que la evaluación de la privatización de aeropuertos no puede estar basada solo en su efecto en la congestión. También examinamos el comportamiento en precios de un aeropuerto público que esta restringido a cobrar tarifas independientes de la hora del día, encontrando que cobraría el precio de hora valle durante todo el día.

Palabras clave: Peak-load pricing, Estructura vertical aeropuerto aerolíneas, Privatización de aeropuertos

1. INTRODUCTION

During the last several years airport delays have become a major public policy issue. Since the early seventies (e.g. Carlin and Park, 1970), economists have approached runway congestion by calling for the use of price mechanism, under which landing fees are based on a flight's contribution to congestion, but this has not really been practiced. The existing landing fees depend on aircraft weight. Airports have traditionally been owned by governments, national or local. This is changing, however. Starting with the privatization of seven airports in the UK to BAA plc. in 1987, many airports around the world have been, or are in the process of being, privatized.[1] One of the leading arguments for airport privatization is that privatised airports might well shift toward peak-load congestion pricing of runway services they provide to airlines, thus reducing delays in peak travel times. For example, Gillen (1994) argues that privatization does a better job of producing efficient runway pricing mechanisms compared to public ownership.

Taken together, today's shortage of airport capacity has revived much of the recent discussions about peak-load congestion pricing and airport privatization. In this paper we carry out an analysis of peak-load congestion pricing for a private, profit-maximizing airport, for a public airport that maximizes social welfare, and for a public, welfare-maximizing airport that is subject to a financial break-even constraint. The comparison then allows us to shed some light on their pricing policies and traffic allocations to the peak and off-peak periods. We further investigate the case of a public airport that is constrained to charge a time independent landing fee.

Note that the present paper investigates airport peak-load pricing (PLP) in contrast to the majority of airport pricing studies which did not address inter-temporal pricing across different travel periods. In these *congestion pricing* studies (e.g. Pels and Verhoef, 2004) since time-varying congestion is absent, there is only one way for either the airport or the airlines to internalize congestion: raising prices to suppress the demands. In a PLP framework, on the other hand, excess demand problems arise because of the variability of demands during the reference times of the day. If the same price was charged throughout the day, there would be peak periods at which the demand would be much higher than at off-peak periods. PLP looks at the optimal time-schedule of prices so as to flatten the demand curve and make better use of existing capacity.

Another major feature of our analysis lies in the model structure used. Here an airport, as an input provider, makes its price decisions prior to the airlines' output decisions. This vertical structure gives rise to *sequential* PLP: The PLP schemes implemented by the downstream airlines induce a different periodic demand for the upstream airport, with the shape of that demand depending, among other things, on the number of downstream carriers and the type of competition they exert. The airport then would have an incentive to use PLP as well, which in turn affects the way the downstream firms use PLP. This sequential peak-load pricing case, be it for public or private utilities, has not yet been analyzed in the airport pricing literature nor in the extensive general peak-load pricing literature.

[1] For example, in Europe, Australia, New Zealand and Asia. In the U.S. the airports that are used by scheduled airlines are virtually all publicly owned facilities run by the local (city) government or by an agency on behalf of the local government. Canada may represent a middle-of-the-road case in which airports are now managed by private not-for-profit (but subject to cost recovery) corporations.

2. THE MODEL

We consider a two-stage model of airport and airline behavior, in which N air carriers service a congestible airport. In the first stage the airport decides on its runway charges on airlines, and in the second stage each carrier chooses its output in terms of the number of flights. We shall consider a discrete choice model in which the consumer chooses between three mutually exclusive alternatives, namely: h=p, travel during peak hours of a day; h=o, off-peak period travel; and h=n, not traveling. There is a continuum of consumers labelled by θ. We denote $B_h(\theta)$ the gross benefit for consumer θ from traveling in period h and D_h the flight delay associated with travel in period h. Letting α be a consumer's value of time, and t_h the ticket price (airfare) of traveling in period h, the conditional indirect utility function for a quasilinear direct utility is given by:

$$V_h(\theta) = B_h(\theta) - \alpha D_h - t_h \tag{1}$$

The flight delay at period h, for h=p,o, is $D_h = D(Q_h; L_h, K)$, where Q_h is the total number of flights in the period, L_h is the length of the pricing period, and K is the airport's runway capacity. We consider that K and L_h are exogenously given[2] and assume L_o is sufficiently long so that $D(Q_o; L_o, K) = 0$ throughout the relevant range of our analysis. In other words, whilst the narrow peak period is congestible, congestion never arises in the broader off-peak period.[3] For the peak delay function, we make the standard assumption that $D_p = D(Q_p)$ is differentiable in and

$$D_p^{'} = \frac{dD}{dQ_p} > 0, \qquad D_p^{''} = \frac{d^2 D}{dQ_p^2} \geq 0 \tag{2}$$

To obtain the consumer demands for peak and off-peak travel, we first follow Brueckner (2002) in assuming that consumers' benefits functions fulfill $B_p^{'}(\theta) > B_o^{'}(\theta) > 0$. These three conditions say that no two passengers have the same peak or off-peak benefits, that consumers are ordered (according to θ) in increasing order of benefits, and that the peak benefit function is steeper than the off-peak benefit function everywhere. The latter is a *single crossing property* which holds if, for example, θ is seen as an index of the passenger's tendency to travel in business (Brueckner, 2002). From (1), these conditions directly imply that $V_p^{'}(\theta) > V_o^{'}(\theta) > 0$; thus, setting $B_n = 0$, in the case of an interior solution it is easy to show that $\underline{\theta} < \theta^f < \theta^* < \overline{\theta}$, where θ^* denotes the consumer who is indifferent between traveling in the peak and off-peak periods, and θ^f denotes the consumer who is indifferent between flying and not flying.

[2] The case of variable and endogenous capacity is examined in Basso (2005) and Zhang and Zhang (2006) in a congestion-pricing framework.

[3] This is similar to the two-period (peak/off-peak) formulation developed in Brueckner (2002). If the off-peak period is also congestible (but not too serious to cause a "peak reversal"), the analysis will become more complicated although our main insights will continue to hold. We discuss the issue further in the concluding remarks.

For simplicity, we assume θ (>0) is distributed uniformly on $\left[\underline{\theta},\bar{\theta}\right]$ and normalize the number of total consumers to $\bar{\theta}-\underline{\theta}$, so the number of passengers with type belonging to $[\theta_1,\theta_2]$ is directly given by $\theta_2-\theta_1$. We further assume that the benefit functions follow the simple linear form $B_h(\theta)=B_h\cdot\theta$, with $B_p>B_o>0$. The inequalities say that if travel were free and without congestion, the consumer would always prefer traveling to non-traveling. Furthermore, with identical airfares and delays, consumers would always prefer traveling in the peak period to off-peak traveling. Thus, peak travel and off-peak travel are vertically differentiated.

Using q_h to denote the total number of passengers in period h, then $q_p=\bar{\theta}-\theta^*$ and $q_o=\theta^*-\theta^f$. As in Brueckner (2002) and Pels and Verhoef (2004), we make a "fixed proportions" assumption, i.e., $S\equiv$ Aircraft Size × Load Factor, is constant and the same across carrier. It then follows immediately that $q_p=Q_pS=\bar{\theta}-\theta^*$ and $q_o=Q_oS=\theta^*-\theta^f$, or equivalently,

$$\theta^*=\bar{\theta}-Q_pS,\qquad \theta^f=\theta^*-Q_oS \tag{3}$$

The indifferent flyer θ^* is determined by $\theta^*(B_p-B_o)=(t_p-t_o)+\alpha D_p$ (recall that $D_o=0$). The final flyer θ^f is determined by $\theta^f B_o=t_o$. Replacing θ^* and θ^f in (3) we obtain:

$$t_o(Q_o,Q_p)=B_o\bar{\theta}-B_oSQ_o-B_oSQ_p \tag{4}$$

$$t_p(Q_o,Q_p)=B_p\bar{\theta}-B_oSQ_o-B_pSQ_p-\alpha D(Q_p) \tag{5}$$

Equations (4) and (5) are the (inverse) consumer demand functions faced by the airlines for the off-peak and peak periods respectively. As for airlines, they have identical cost functions:

$$c_A^i(Q_h^i,\mathbf{Q}_h^{-i},P_h)=\sum_{h=p,o}[c+P_h+\beta D(Q_h)]Q_h^i \tag{6}$$

where Q_h^i is the number of airline i's flights in period h, $\mathbf{Q}_h^{-i}$ denotes the vector of flights of airlines other than i, c is the airline's operating cost per flight, and P_h is the airport landing fee in period h. Further, parameter β (>0) measures the delay costs to an airline per flight, which may include wasted fuel burned while taxiing in line or holding/circling in the air, extra wear and tear on the aircraft, and salaries of flight crews. Airlines' profit functions can then be written as:

$$\phi^i(Q_h^i,\mathbf{Q}_h^{-i},P_h)=\sum_{h=p,o}[t_h(Q_o,Q_p)Q_h^iS-c_A^i(Q_h^i,\mathbf{Q}_h^{-i},P_h)] \tag{7}$$

3. ANALYSIS OF OUTPUT-MARKET EQUILIBRIUM

To solve for the subgame perfect equilibrium we start with the second-stage airline competition. Given the airport's runway charges P_p and P_o, the N carriers choose their quantities to maximize profits, and the Cournot equilibrium is characterized by the first-order conditions, $\partial \phi^i / \partial Q_h^i = 0$, $h=p,o$.[4] Imposing symmetry, $Q_h^i = Q_h / N$, and re-arranging, the first-order conditions lead to :

$$(B_o \bar{\theta} S - c - P_o) - Q_o [B_o S^2 (N+1)]/N - Q_p [B_o S^2 (N+1)]/N = 0 \tag{8}$$

$$Q_p \frac{(B_p - B_o) S^2 (N+1)}{N} + (\alpha S + \beta)\left(D + \frac{Q_p}{N} D' \right) + (P_p - P_o) - \bar{\theta} S (B_p - B_o) = 0 \tag{9}$$

Since equation (9) depends on Q_p but not on Q_o, it implicitly defines Q_p as a function of P_o, P_p and N. Substituting this function into (8), we obtain Q_o as a function of P_o, P_p and N, leading to:

$$Q_p = Q_p(P_o, P_p; N), \qquad Q_o = Q_o(P_o, P_p; N) \tag{10}$$

Equations (10) are the derived *airport*'s demands for the use of its peak and off-peak periods, respectively (different from $t_o(Q_o, Q_p)$ and $t_p(Q_o, Q_p)$ which capture the *final* consumer demands for air travel). To characterize the airport's demands $Q_p(P_o, P_p; N)$ and $Q_o(P_o, P_p; N)$ we use comparative statics on (8) and (9). We obtain:

$$\begin{aligned}
&\frac{\partial Q_p}{\partial P_p} < 0, && \frac{\partial Q_p}{\partial P_o} = -\frac{\partial Q_p}{\partial P_p} > 0, \\
&\frac{\partial Q_o}{\partial P_p} = -\frac{\partial Q_p}{\partial P_p} = \frac{\partial Q_p}{\partial P_o} > 0, && \frac{\partial Q_o}{\partial P_o} = -\frac{\partial Q_p}{\partial P_o} - \frac{N}{B_o S^2 (N+1)} < 0, \\
&\frac{\partial (Q_o + Q_p)}{\partial P_p} = 0, && \frac{\partial (Q_o + Q_p)}{\partial P_o} = -\frac{N}{B_o S^2 (N+1)} < 0 \;, \qquad \frac{\partial Q_p}{\partial \Delta P_{p-o}} = \frac{\partial Q_p}{\partial P_p} < 0
\end{aligned} \tag{11}$$

Both the above results and straightforward comparative statics with respect to N lead to:

Remark 1: The airport's demands $Q_p(P_o, P_p; N)$ and $Q_o(P_o, P_p; N)$ have the following properties:

(i) They are downward-sloping in own prices;
(ii) The peak and off-peak periods are gross substitutes;

[4] Brander and Zhang (1993) found empirical evidence that airlines compete in Cournot fashion.

(iii) The off-peak runway charge (P_o) determines the amount of total traffic, while the difference between the peak and off peak charges (ΔP_{p-o}) determines the partition of that traffic into the two periods, with peak traffic declining with the charge differential.
(iv) The number of peak-period passengers increases with N;
(v) The number of total passengers increases with N;

Notice that Part (ii) of Remark 1 shows that the airport has the room to “spread the flights” across the peak and off-peak periods by using peak-load landing fees. Therefore, our vertical airport-airline structure gives rise to a possible *sequential PLP*: the PLP schemes implemented by the downstream airlines (higher peak airfare) induce a different periodic demand for the upstream airport. On the other hand, parts (iv)-(v) show that the shape of the demands depend on the number of downstream carriers.
The final ingredient to characterize the Cournot equilibrium in the output market is related to the important issue of airfares: For given airport charges, how do the peak and off-peak airfares compare with each other? From (4) and (5) it follows that

$$\Delta t_{p-o} \equiv t_p - t_o = \bar{\theta}(B_p - B_o) - Q_p S(B_p - B_o) - \alpha D(Q_p) \tag{12}$$

From (9) we obtain an expression for $\bar{\theta}(B_p - B_o)$. Replacing that expression in (12) gives rise to the following airfare-differential formula, evaluated at the Cournot equilibrium:

$$\Delta t_{p-o}\Big|_{\text{Cournot eq}} = \frac{P_p - P_o}{S} + \frac{\beta}{S} D(Q_p) + \frac{\beta}{S}\frac{Q_p}{N} D' + \alpha \frac{Q_p}{N} D' + Q_p \frac{(B_p - B_o)S}{N} \tag{13}$$

It is clear from (13) that if $P_p \geq P_o$, then $\Delta t_{p-o} > 0$, that is, if the airport uses peak-load pricing, airlines will also use PLP (i.e., higher peak airfares) in equilibrium. More interesting perhaps is the fact that, even if the airport prices the periods *backwards*, i.e., $P_p < P_o$, the airlines may still use peak-load pricing in equilibrium, because the remaining four terms in (13) are all positive.

To further interpret (13), first note that holding P_p and P_o constant, $\partial \Delta t_{p-o} / \partial N$ is negative, which can be seen by differentiating (12) and recalling, from Remark 1, that sub-game equilibrium Q_p and Q_o increase in N. This implies that a monopoly airline would have the largest airfare differential. Since, $\partial t_o / \partial N$ is also negative, the lower the N, the larger the off-peak fare. Next, it can be seen that for very large N, the airfare differential approaches to the difference between an airline’s peak and off-peak per-passenger average costs, i.e., the first and second terms on the right-hand side (RHS) of (13). When there is an oligopoly, however, three extra terms are added. Specifically, the third term on the RHS of (13) is the cost of extra congestion on an airline’s own flights and caused by an additional passenger flying in the peak period. Thus, the first three terms on the RHS of (13) represent the difference between an airline’s peak and off-peak marginal costs. The fourth term represents the money value of extra congestion to an airline’s passengers when a new passenger chooses to fly in the peak period, whereas the fifth term is the mark-up term that arises from the carriers’ exploitation of market power. Hence, as it is now known, oligopoly airlines only internalize (charge for) the congestion they impose on their own flights, which has two cost components: extra operating costs for the airline, and extra delay costs for its passengers (Brueckner, 2002). When there is a monopoly airline, congestion is perfectly internalized but exploitation of market power is at its highest degree. When N is large, exploitation of the market power is small but un-internalized congestion is large.

These points can be made more clearly if the Cournot case is compared to the case in which a social planner maximizes total surplus in the second-stage game. The planner maximizes, for given airport charges, the sum of consumer surplus, and airline profits: $CS + \Phi \equiv CS + \sum_{i=1}^{N} \phi^i$, where Φ denotes the aggregate airline (equilibrium) profits. Given the linearity of our conditional indirect utility function in (1), CS is easy to calculate. Then, tedious yet straightforward algebra allows us to get:

$$\Delta t_{p-o}\Big|_{\substack{\text{efficient}\\ \text{output}}} = \frac{P_p - P_o}{S} + \frac{\beta}{S} D(Q_p) + \frac{\alpha S + \beta}{S} Q_p D'(Q_p) \tag{14}$$

Conditional on the airport charges and the airline market structure, (14) gives the socially efficient difference between the peak and off-peak airfares. This fare differential is equal to the difference between an airline's peak and off-peak average costs (the first and second terms on the RHS of (14)), plus all the external costs associated with a new flyer in the peak period, with the latter being the extra congestion cost of *all* the airlines and passengers, not just that of the airline that carries the new peak passenger. Obviously, the last two terms represent the portion of the optimal airfare differential that is not directly affected by the airport's pricing practices.

4. AIRPORT PRICING, TRAFFIC, DELAY AND WELFARE COMPARISONS

When deciding its runway charges in the first stage the airport will take the second-stage equilibrium output into account. These decisions may in reality be set by a public airport or a privatized airport. Consequently, the objective of an airport may be to maximize welfare or to maximize profit. In this section, we first compare airport charges and consequent airfares for these two airport types. We then discuss two extensions: a budget-constrained public airport, and, the case of a public airport that is constrained to charge a time independent fee.

4.1. Maximization of social welfare

Consider first a public airport that chooses P_p and P_o to maximize welfare. With three agents (airport, airlines, and passengers) social welfare (SW) is the sum of their payoffs: $SW(P_o, P_p; N) = \pi(P_o, P_p; N) + CS + \Phi$, where the airport's profit, π, is given by

$$\pi(P_o, P_p; N) = P_o Q_o + P_p Q_p - C \cdot (Q_o + Q_p) \tag{15}$$

In (15), $Q_o = Q_o(P_o, P_p; N)$ and $Q_p = Q_p(P_o, P_p; N)$ are the airport's peak and off-peak demands respectively while C is the unit runway operating cost of the airport.[5] Derivation of the pricing

[5] Note that we have assumed that the marginal operating cost is constant, since the estimation of cost functions has shown that airport runways have relatively constant return to scale.

formulas then follows from the first-order conditions (details are available upon request from the authors). Letting P_o^W, P_p^W denote the welfare-maximizing runway charges, we get:

$$P_o^W = C - \frac{Q_o S^2 B_o}{N} - \frac{Q_p S^2 B_o}{N} \tag{16}$$

$$\Delta P_{p-o}^W = \frac{N-1}{N}(\alpha S + \beta) Q_p D'(Q_p) - \frac{Q_p S^2 (B_p - B_o)}{N} \tag{17}$$

The above welfare-maximizing airport pricing may be seen as if the fees were determined in two phases. First, choice of an off-peak price P_o^W induces the (socially) right amount of total traffic; as can be seen from (16), P_o^W is below the airport's marginal cost. This is needed because exploitation of market power in the airline market would induce allocative inefficiencies by producing too little output. A welfare-maximizing airport fixes this inefficiency by providing a "subsidy" to the airlines and hence lowering their marginal costs in the off-peak period. The exact amount of the subsidy depends in part on the extent of market power, which here is captured by *N*. Once the total traffic is set to its optimal level, the next phase is concerned with the optimal allocation of this traffic to the peak and off-peak periods, which is, as indicated earlier, determined by ΔP_{p-o}. In particular, the public airport sets the peak/off-peak price differential to ΔP_{p-o}^W that will induce the optimal airfare differential downstream. Hence, the outcome is the same as if the airport were to set $P_o = P_p$, which is optimal because there are no differences in airport costs, and then social welfare is maximized in the airline market.

Brueckner (2002) identified the first term in (17) as the per-flight toll that should be charged by the airport authorities to address the problem of un-internalized congestion (note that when *N*=1, this toll is equal to zero). Pels and Verhoef (2004), Basso (2005) and Zhang and Zhang (2006) pointed out that the optimal toll should also include the second term, the market-power effect; they did this, however, using models of congestion pricing (one period), while Brueckner (2002) and the present paper use models of peak-load pricing. This distinction is important because a toll equal to the two terms, thereby capturing both the congestion and market power effects, will not be optimal unless it is charged on top of the optimal charge in the off-peak period, *which is not the marginal cost*. In other words, restricting the analysis to the toll that should be charged during the peak hours offers only a partial view of the problem.

Notice further that the charge differential, ΔP_{p-o}^W, given in (17), is not signed *a priori*. Hence, *it may happen that the airport charge is smaller in the peak period than in the off-peak period*. More specifically, the airport charge differential will be negative for small *N*. This is so because a "tight" airline oligopoly has an airfare differential that is too large due to strong market power, while congestion is largely internalized. As a consequence, the airport price differential is driven predominantly by the market-power effect. When *N* is large, on the other hand, the airport price differential will be positive. This is so because a "loose" oligopoly would have an airfare differential that is too small due to un-internalized congestion, whereas market power is relatively weak. The airport charge differential is then driven by the congestion effect. Final passengers will, nevertheless, *always* pay higher peak airfare than off-peak airfare. The above discussion may be summarised in the following proposition:

Proposition 1: For a public, welfare-maximizing airport, (i) the off-peak runway charge is below its marginal cost; (ii) for small N, the off-peak runway charge may be *greater* than its peak runway charge; in this sense, it appears that the airport does not use peak-load pricing; (iii) although the airport's peak charge may be less than its off-peak charge, final passengers will nevertheless always pay higher peak airfare than off-peak airfare.

4.2. Maximization of airport profit

Next, consider a private, unregulated airport which chooses P_p and P_o to maximize its profit (given by eq. 15). First-order conditions and (11) lead to (P_o^π, P_p^π denoting the profit-maximizing airport charges):

$$P_o^\pi = C + \frac{Q_o S^2 B_o (N+1)}{N} + \frac{Q_p S^2 B_o (N+1)}{N} \tag{18}$$

$$\Delta P_{p-o}^\pi = \frac{\alpha S + \beta}{N} Q_p \left[(N+1) D'(Q_p) + Q_p D''(Q_p) \right] + \frac{Q_p S^2 (B_p - B_o)(N+1)}{N} \tag{19}$$

The RHS of (19) is positive and hence $P_p^\pi > P_o^\pi$: The private airport charges higher runway fees in the peak period than in the off-peak period, and this is true for any N. Thus, a profit-maximizing airport has an incentive to use peak-load pricing. Furthermore, since $(\alpha S + \beta) Q_p (N-1)/N$ is the extra cost each airline induces by not fully internalizing congestion, the first term on the RHS of (19) shows that the private airport will overcharge for congestion. Moreover, notice from (18) that the off-peak charge, which determines the amount of total traffic, is above marginal cost. This is a result of monopoly power on the part of the airport. There is, therefore, a "double marginalization" problem, which is typical of an uncoordinated vertical structure. The discussion leads to the following proposition:

Proposition 2: A private, profit-maximizing airport would use peak-load pricing but would charge more than the cost of un-internalized congestion. Further, it would charge an off-peak runway fee that is above its marginal cost.

4.3. Performance comparisons between the private outcome and first-best

Having derived and characterized the pricing structures for both the public and private airports, we now want to compare them. To have a clearer picture about their performance differences, we shall compare not only the off-peak runway fees and the peak/off-peak fee differentials, but also the induced traffic levels, delays and total surplus. Moreover, we want to assess how these differences (if any) change with the number of airlines, N, which is exogenously given and can be considered as a proxy for airline market structure. We summarize our findings in the following proposition (proofs are available upon request):

Proposition 3: Comparisons of airport pricing, traffic, delay and welfare between the private and public airports are as follows:

(i) $P_o^W < P_o^\pi$ and $\frac{dP_o^W}{dN} > \frac{dP_o^\pi}{dN} = 0$;

(ii) $\Delta P_{p-o}^W < \Delta P_{p-o}^\pi$ and $\frac{d\Delta P_{p-o}^W}{dN} > 0$. If the delay function is linear, then $\frac{d\Delta P_{p-o}^\pi}{dN} = 0$;

(iii) $Q_p^W > Q_p^\pi$ and $\frac{dQ_p^\pi}{dN} > \frac{dQ_p^W}{dN} = 0$;

(iv) $Q_t^W > Q_t^\pi$ and $\frac{dQ_t^\pi}{dN} > \frac{dQ_t^W}{dN} = 0$, where $Q_t \equiv Q_p + Q_o$ is total traffic volume;

(v) $D_p^W > D_p^\pi$ and $\frac{dD_p^\pi}{dN} > \frac{dD_p^W}{dN} = 0$;

(vi) $SW^W > SW^\pi$ and $\frac{dSW^\pi}{dN} > \frac{dSW^W}{dN} = 0$.

From Proposition 3 we see that a private, profit-maximizing airport would induce too small total traffic as compared to the first-best outcome, thereby resulting in allocative inefficiencies. Additionally, a private airport has a greater peak/off-peak runway charge differential than a public airport. Hence, with a private airport, the peak period would be underused not only because the airport has smaller total traffic, but also because its charge differential is too large. Although those passengers who still use the peak period benefit from less delays as part (v) enounces, overall it is not economically efficient. Note that part of the welfare loss arises if the consumers (or some of them, with the number depending on γ) denied from peak travel view traveling in the peak times as a higher quality product than traveling in the off-peak times. To help better understand this proposition, we also offer a schematic representation of the findings in Figure 2.

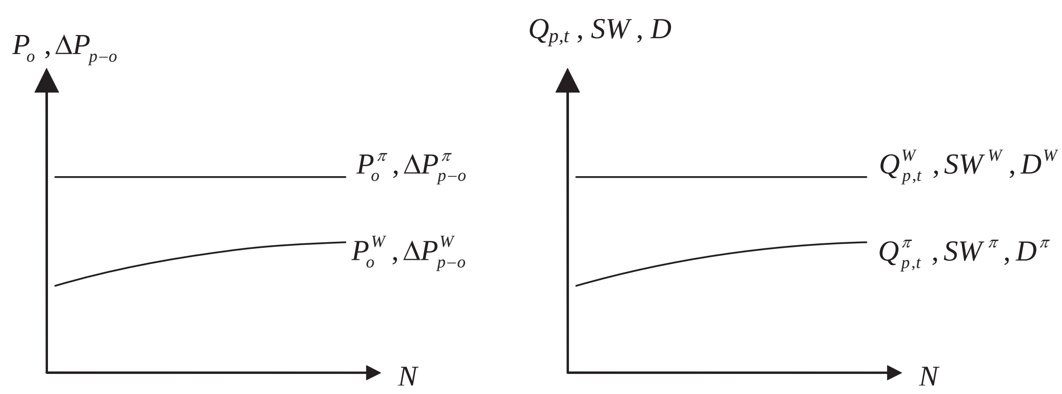

Figure 2: Schematic representation of the results in Proposition 3

This discussion highlights an important issue: one of the main ideas behind airport privatization has been that it would allow airports to use peak-load pricing and thus help solve the congestion problems. But if privatization is measured solely by its effect on congestion delays, it may be seen as a better idea than it actually is and important deadweight losses may be overlooked. This result, which holds here for a fixed capacity–peak-load pricing model, was also found by Basso (2005) in a congestion pricing model with variable (endogenous) capacity.

We have seen that the public airport is indifferent between values of *N* –although Basso (2005) showed that this may not be the case if airlines are not homogenous or if passengers are affected by schedule delay cost. Given that the (welfare) performance of a private airport improves as the number of airlines rises (see Figure 2), it seems important to know what would be the preferred *N* of a private airport itself. From (15) we have:

$$\left|\frac{d\pi}{dN}\right|_{P_o^\pi, P_p^\pi} = \left|\frac{\partial \pi}{\partial N}\right|_{P_o^\pi, P_p^\pi} = \left(P_o^\pi - C\right)\frac{\partial Q_o}{\partial N} + \left(P_p^\pi - C\right)\frac{\partial Q_p}{\partial N} > 0$$

where the first equality follows from the envelope theorem and the inequality follows from Remark 1 and the fact that prices are above marginal costs. Thus, the private airport prefers a large *N*, which is a desirable property, given the findings of Proposition 3.

4.4. Constrained public airport: the financial break-even case and the uniform pricing case

In the above analysis of public airport's pricing behaviour, we have not included a financial break-even constraint on the airport, which may represent a more realistic case nowadays. The unconstrained first-best solution may lead to budget inadequacy. One possible solution for this would be to use two-part tariff, that is, to charge a fixed fee in addition to the marginal (per flight) charge. However, the use of a fixed-fee may not be feasible for a number of reasons. One of them is the absence of symmetry at the airline level; as a consequence, the airport would need to charge differentiated fixed fees (depending on the airline) in order to achieve the first-best, something that may encounter strong opposition and may even be unlawful. If lump-sum transfers are not possible, then Ramsey-Boiteaux prices should be considered. In general, as demonstrated analytically in Basso (2005) and Zhang and Zhang (2006), the pricing formula of a budget-constrained public airport varies between the formula for an unconstrained welfare-maximizing airport and the formula for a profit-maximizing airport. Likewise, in terms of social welfare this *second-best* situation would fall in between the first-best and the private outcome, and would move towards the latter when the severity of the budget constraint rises. Analytically, there is little more to say regarding this issue. A rudimentary numerical simulation shows that for *N*=4 (for example) whilst the private outcome would attain 71% of the first-best welfare level, the budget-constrained public airport would attain 99%, very close to the first-best outcome.[6]

Another major concern of our public-private comparison in Section 4.3 is that such comparison may not be the most relevant one. As indicated in the introduction, public airports have not really practised peak-load pricing. For whatever reason, most public airports currently charge landing fees that are undifferentiated by time of day. We now consider pricing behaviour of a

[6] Details of this and others illustrations are available upon request.

public airport that is constrained to use such a uniform pricing scheme. Formally, the airport's problem is the maximization of social welfare, subject to the constraint $P_p = P_o$. Derivation of the pricing rules follows from maximization of the corresponding Lagrangean function, yielding:

$$P_o = C - \frac{Q_o S^2 B_o}{N} - \frac{Q_p S^2 B_o}{N} = P_o^W$$
$$P_p = P_o$$

Hence, if the public airport is constrained to charge a flat landing fee, it would not choose a fee that is in between the peak and off-peak prices –as the *a priori* intuition may have suggested– but would charge the off-peak price P_o^W throughout the day! This implies that the airport would be doing nothing regarding congestion, irrespective of how acute the problem is. In particular, when N is large and hence un-internalized congestion is severe (while airlines' market power is weak), the airport would still charge below marginal cost throughout the day, rather than charging for congestion. In other words, if the airport charges a flat fee, it would not be the case that it distorts the charging and meets "in the middle" of prices P_o^W and P_p^W; it is actually not taking congestion into account whatsoever. As a result, congestion would certainly worsen as the number of airlines increases.

Now, because P_o is below the marginal cost, in this case the airport would always run a deficit, even for large N, unless two-part tariff is feasible. However, adding a budget constraint to the problem does not change things much. From what we have just found, if the airport needs to break even but charges a flat fee, it would obviously raise the (uniform) price until it can cover its costs, something that happens when that the price equals marginal cost: $P_o = C = P_p$ (this is indeed easy to show formally). So, again, the airport would not really be doing anything to deal with the congestion problem.

These observations are important: on one hand, if by external reasons a public airport cannot use PLP but a private airport can, then privatization may indeed do a better job at solving the congestion problem. In terms of social welfare, the comparison of the two cases would obviously depend on several parameter values. For example, for N=50 in our numerical example, the private outcome attains 80% of the first-best welfare level, while a budget-constrained public airport charging a uniform price attains 88%, a quite smaller gap than before. More generally, if the problem of congestion is sufficiently important and if N is large, the gain from reduced congestion could analytically outweigh the welfare loss from a privatized airport's exploitation of market power. On the other hand, if public airports have no institutional reasons to avoid peak-load pricing, moving public airports toward the use of PLP is something that is worthwhile and urgent to do.

5. CONCLUDING REMARKS

We found that privatization would not induce efficient PLP schemes as it has been argued in some studies. While a private airport always has an incentive to use PLP –higher runway fees in the peak than off-peak periods– irrespective of the number of airlines servicing the airport and even when the airlines have used PLP themselves, it would overcharge for congestion and its pricing structure would induce insufficient total traffic and peak traffic as compared to the socially optimal levels or the levels associated with a budget-constrained public airport. Somewhat surprisingly, depending on the degree of carriers' market power, a public airport may choose a peak charge that is lower than the off-peak charge, so as to offset the market power downstream at the airline level. Here, the public airport, on the surface, is not practicing the peak-load pricing, but such pricing structure is nevertheless socially optimal. Another surprising new result is related to the case of a public airport that is constrained to charge a time independent landing fee. Such airport would not choose a fee that is in between the peak and off-peak prices – as the *a priori* intuition may have suggested– but would charge the off-peak price. Thus if by external reasons a public airport cannot use PLP but a private airport can, privatization may indeed do a better job at solving the congestion problem. Further, if the problem of congestion is sufficiently important, the gain from reduced congestion might even outweigh the welfare loss from a privatized airport's exploitation of market power. This suggests that if public airports have no institutional reasons to avoid peak-load pricing, moving public airports toward the use of PLP would be worthwhile.

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