

On the relationship between airport pricing models

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Abstract

Airport pricing papers can be divided into two approaches. In the traditional approach the demand for airport services depends on airport charges and on congestion costs of both passengers and airlines; the airline market is not formally modeled. In the vertical-structure approach instead, airports provide an input for an airline oligopoly and it is the equilibrium of this downstream market which determines the airports' demand. We prove, analytically, that the traditional approach to airport pricing is valid if air carriers have no market power, i.e. airlines are atomistic or they behave as price takers (perfect competition) and have constant marginal operational costs. When carriers have market power, this approach may result in a surplus measure that falls short of giving a true measure of social surplus. Furthermore, its use prescribes a traffic level that is, for given capacity, smaller than the socially optimal level. When carriers have market power and consequently both airports and airlines behave strategically, a vertical-structure approach appears a more reasonable approach to airport pricing issues.

Keywords: Airport pricing; Airport congestion; Vertical structure

1. Introduction

Airport pricing has been widely analyzed in the economics literature. Basso and Zhang (2007) present a detailed account of models used and results obtained in analytical papers of airport pricing during the last 25 years. They show, among other things, that the models in the literature can be grouped into two broad approaches. The traditional approach has used a classical partial equilibrium model where the demand for airport services depends on airport charges and on congestion costs of both passengers and airlines; the airline market is not formally modeled. In some cases the assumption has been that airline competition is perfect and hence airport charges and delay costs are completely passed onto passengers. The vertical-structure approach has instead recognized that airports provide an input for the airline market – which is modeled as a rather

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simple oligopoly – and that it is the equilibrium of this downstream market that determines the airports' demand: the demand for airport services is therefore a derived demand.

Basso and Zhang (2007) show that not only the two approaches are different, but also the questions examined with each approach have not perfectly overlapped. This obviously raises questions about the transferability of results, making it important to find the relationship, if any, between airport pricing models of the two approaches. This is the purpose of the present paper.

We prove analytically that the traditional approach to airport pricing is indeed valid if air carriers have no market power (airlines are atomistic or they behave as price takers and have constant marginal operational costs). When there is market power at the airline level, the social surplus measure of the traditional approach will fall short of giving a true measure of social surplus. Furthermore, the traditional approach would prescribe a traffic level that is, for given capacity, smaller than the socially optimal level. Numerical examples further show that, when there is a low degree of competition between air carriers, using the traditional approach to determine the optimal prices and capacity levels may induce large deadweight losses. Therefore, when air carriers have market power and consequently both airports and airlines behave strategically, a vertical-structure approach is needed to analyze airport pricing and capacity issues.

2. Traditional and vertical approaches

This section describes the basic setups of the traditional and vertical-structure approaches. We will be brief here given the recent survey by Basso and Zhang (2007), where details and references may be found. The traditional approach has been used by, among others, Morrison (1987), Zhang and Zhang (1997), Oum et al. (2004) and Lu and Pagliari (2004). The approach may be synthesized in a fairly concise way: in order to provide aviation services, an airport incurs both operating and capital costs. It collects user charges to cover these costs and, for a private airport, to make a return on capital investments. Congestion at the airport induces delays and therefore extra costs on passengers and airlines. In this approach it is assumed, usually implicitly, that airlines fully pass airport charges to passengers; the same is assumed for airlines delay costs. Therefore, passengers will perceive a full price consisting of the airport charge, the flight delay cost, travel-time cost, plus other airline charges (e.g. air ticket). Oum et al. (2004) has argued that since other airline charges are exogenous as far as the airport is concerned, the demand an airport faces may be considered to be a function only of a full price which includes the airport charge P and the flight total delay cost D . The latter includes delay costs to both airlines and passengers. The variables in the model with a single airport would be²

$Q(\rho)$	demand for airport facilities measured by the number of flights, which is a function of the full price ρ perceived by passengers
ρ	$P + D$, the full price that determines the airport's demand
P	airport charge per flight
$D = D(Q, K)$	flight delay cost experienced by each flight, which depends on traffic Q and airport capacity K
K	capacity of the airport
$C(Q)$	operating costs of the airport
r	cost of capital

One of the main issues that have been analyzed using the traditional approach is the nature of the airport's choices of user charge P and capacity K , for cases in which social welfare is maximized (with and without a budget constraint). The public airport objective function is then the following total social surplus function:

$$\max_{P, K} \int_{\rho}^{\infty} Q(\rho) d\rho + PQ - C(Q) - rK \quad (1)$$

² For simplicity, we present a model with no intraday variations in demand, i.e. a 'single period' model. But this approach has been used to analyze the case of many periods. With the exception of Oum and Zhang (1990), all other papers assumed that the demands in each period were independent of each other.

In the vertical-structure approach, on the other hand, airports are viewed as providing an input for the production of an output: travel.³ This output is produced by an oligopolistic airline industry which, taking the airport's price and capacity as given, would reach some equilibrium from where the airport's demand is obtained. In this approach, a passenger faces a full price which is the sum of her delay cost (rather than the airline's) and the air ticket (rather than the airport charge). It follows from here that the equilibrium in the airline market is not only equilibrium traffic but also equilibrium delays and air ticket prices. This would show that: (i) as far as the airport is concerned, its demand will be some direct function of P , K and of the (exogenous) airline-market structure, which in some papers is represented by the number of airlines N . Hence, the airport's derived demand would be $Q(P, K; N)$. Delays enter the picture through the equilibrium of the downstream market. (ii) How airport charges and airlines' delay costs are passed to passengers is built inside the demand faced by the airport and depends on the nature of the equilibrium reached in the airline market. And (iii), that other airline charges are not exogenous to the airport because the downstream equilibrium depends on P and K , which are decided by the airport.

From these brief explanations, it is clear that the two approaches are quite different. In fact, some authors have been somewhat critical of the traditional approach based on the observation that it would not properly consider all actors involved (e.g. Raffarin, 2004). As is obvious, vertical-structure models are more complex and, therefore, they can indeed better account for the interactions between all agents. Hence, unveiling the relationship between the two approaches boils down to find when it is legitimate to take a short-cut by using a traditional approach rather than a vertical-structure approach. In our view, to clarify the connection between the two approaches, there are three questions that need to be answered

1. It would seem that a full price model pertains more to the airline-market stage than the airport-market stage. Under what conditions would it be reasonable to assume that the airport demand can be written as $Q(\rho)$ – with, $\rho = P + D(Q, K)$ – rather than as $Q(P, K; N)$?
2. The vertical-structure approach shows that 'consumers' of airports are both airlines and passengers and, therefore, a total (social) surplus function should include both airlines' profits and passenger surplus. In the traditional approach, however, this is not the case. There, consumer surplus has been obtained through an integration of the airport demand function with respect to the full price, as in Eq. (1). If under some conditions the airport demand can reasonably be written as $Q(\rho)$, would its integration give a correct measure of total surplus, i.e. the sum of airlines' profits and passenger surplus?
3. When the integration of $Q(\rho)$ does not give a correct measure of the sum of airlines' profits and passenger surplus, but a traditional approach is used nonetheless, how do the prescribed traffic and capacity levels compare to the real first-best ones?

3. Relationship between approaches

We build a general vertical-structure model to answer the three questions listed above.⁴ We start by describing the airline market, which takes airport charges and capacities as given. We use this model to derive the demand for the airport. Consider N airlines servicing a congestible airport and producing homogeneous outputs. Let Q_i be airline i 's number of flights, and $Q = \sum_{i=1}^N Q_i$ be total output. Demand for airline services is given by $q(\theta)$, where θ is the full price and q represents the total number of passengers. This full price is the sum of the ticket price, t , and passenger delay costs:

$$\theta = t + \alpha d(Q, K) \quad (2)$$

where α denotes passengers' value of time and $d(Q, K)$ is a flight's delay. The difference between $d(Q, K)$ here and $D(Q, K)$ in Section 2 is that the latter directly represented the time costs of delays, whilst d represents only

³ This approach was initiated by Brueckner (2002) and has been used by, among others, Brueckner (2005), Pels and Verhoef (2004), Basso (in press) and Zhang and Zhang (2006).

⁴ Basso (in press), in a paper with completely different objectives, also examined the first two questions but using a model with restrictive assumptions such as linear demands, Cournot competition and constant marginal operational cost. These restrictions are relaxed in the present paper enabling more robust, general and precise answers.

delay in time units. To transform the demand in terms of passengers into a demand in terms of flights, we simply assume that aircraft size times load factor equals S for all carriers. With this, we have $Q_i S = q_i$, where q_i denotes the output in terms of the number of passengers carried by airline i .⁵ Assuming that airlines' demand is invertible, the inverse demand at the airline-market level is then represented by $\theta(QS)$, with $\theta'(QS) < 0$ (i.e. downward-sloping demand).

An airline's cost function will be given by

$$C^i(Q_i, Q) = c^i(Q_i) + [P + \beta_i d(Q, K)]Q_i \quad (3)$$

where c^i is airline i 's operational cost, P is the airport charge per flight, and β_i is the congestion cost per flight per unit of time that airline i incurs. We now assume, for expositional simplicity, that airlines have identical costs but, as shown in [Appendix](#), our main insights will go through with the type of asymmetry presented in (3). Obtaining t from (2), profits of airline i are then given by

$$\pi^i(Q_i, Q; P, K) = \underbrace{[\theta(QS) - \alpha d(Q, K)]}_{t} SQ_i - c(Q_i) - [P + \beta d(Q, K)]Q_i \quad (4)$$

Each of the N firms chooses its strategy variable to maximize its profit. In equilibrium, this gives rise to the derived demand for airports as a function of the airport's price and capacity, and the number of airlines, i.e. $Q(P, K; N) = \sum_{i=1, \dots, N} Q_i$. Under cost symmetry, this equilibrium is in effect such that $Q_i = Q/N$. What we want to know first is under what conditions this derived demand may be written as $Q(\rho)$. For this, first note that while ρ was defined as $\rho = P + D(Q, K)$ in the traditional approach, here it will be defined as

$$\rho = P + [\alpha S + \beta]d(Q, K) \quad (5)$$

Because d is a flight's delay in time units, $[\alpha S + \beta]d(Q, K)$ corresponds to the flight's total delay costs D . Then, as will be seen below, the answers to our questions are determined by the market structure at the airline level and the nature of airlines' interactions.

Rather than deciding a priori in which particular way airlines interact among one another (including which decision variable they use as the strategy variable), we model interactions between airlines using conjectural variations. The term conjectural variation is defined as a firm's anticipation of the change in industry output as a result of a unit change in its own output. The mathematical expression would be $v_i = dQ/dQ_i$. We assume that airlines have identical conjectures; different conjectures lead to no useful result. Thus, each firm chooses Q_i to maximize (5) while taking into account that $dQ/dQ_i = v$. Using the symmetry in equilibrium, the set of first-order conditions lead to

$$S\theta(QS) - P - (\alpha S + \beta)d(Q, K) + \frac{Qv}{N} \left[S^2 \theta'(QS) - (\alpha S + \beta) \frac{\partial d}{\partial Q} \right] - c' \left(\frac{Q}{N} \right) = 0 \quad (6)$$

What is practical about this model is that many types of airline interaction are nested within it. So, for example, price-taking airlines (perfect competition) is captured by $v = 0$. To see this, note that with $v = 0$, Q is independent of firm i 's output and, hence, so are $\theta(QS)$ and $d(Q, K)$. Eq. (2) then tells us that t is unaffected by firm i 's choice of output. In that case (6) can be written as

$$t = \frac{c'(Q/N) + P + \beta d(Q, K)}{S} \quad (7)$$

That is, each airline sets the ticket price t to be the same as its marginal cost (per passenger), which is what indeed results from the maximization of profits (4), taking t as given. Similarly, Cournot competition – where each firm chooses output assuming its choice will lead to no change in its rivals' outputs – is captured by $v = 1$, while cartel behavior – where firms choose output to maximize their joint profits – is captured by $v = N$. This

⁵ This fixed-proportions assumption is quite common in vertical-structure models; see [Basso and Zhang \(2007\)](#) for details.

can be easily seen by solving the Cournot and Cartel games directly and checking that the first-order conditions coincide with (6) evaluated at these two values of v .⁶

Eq. (6) implicitly defines the airport demand Q . Using the expression for ρ in Eq. (5), we can write (6) as

$$S\theta(QS) - \rho + \frac{Qv}{N} \left[S^2\theta'(QS) - \frac{\partial\rho}{\partial Q} \right] - c' \left(\frac{Q}{N} \right) = 0 \quad (8)$$

Since $\theta(QS)$ is invertible, this equation shows that, in general, Q would depend not only on ρ but also on ρ_Q ($\equiv \partial\rho/\partial Q$), i.e. the derivative of ρ with respect to Q . The (implicit) demand for airports then should in general be $Q \equiv Q(\rho, \rho_Q, N, v)$ and not $Q(\rho)$. However, there are two special cases in which the airport demand can indeed be written as $Q(\rho)$. First, when airlines behave competitively ($v = 0$) and have constant marginal operational cost, $c'(\cdot) = \tilde{c}$. In this case, Eq. (8) becomes

$$S\theta(QS) - \rho - \tilde{c} = 0 \quad (9)$$

From (9) it is easy to see that the airport's demand could be expressed as a function $Q(\rho; \tilde{c}, S)$.

The second case is when $v > 0$ and we let N approach to infinity, $N \rightarrow \infty$, so each firm produces infinitesimal output (yet total output Q is obviously bounded). In this case, Eq. (8) will reduce to (9) by redefining \tilde{c} to be the intercept of the marginal operational cost function, i.e. $\tilde{c} = \lim_{x \rightarrow 0} c'(x)$. Note that this atomistic carriers' case can only exist if airlines have no fixed-costs, and it corresponds to the classical idea of perfect competition being the limiting case of oligopoly when the number of firms is very large.

Hence, from (6) and the two exceptions above we conclude that whenever airlines do not behave competitively, the airport demand cannot be written as $Q(\rho)$. These are the cases in which airlines possess market power, that is, their price is above marginal cost, as can be seen by using (2) and (5) to rewrite (8) as

$$t - \frac{c' + P + \beta d}{S} = \frac{Qv}{NS} [(\alpha S + \beta)d_Q - \theta'(QS)S^2] \quad (10)$$

The left-hand side of (10) is the difference between the (ticket) price and marginal cost per passenger. Under both special cases this difference is zero but in general, since $d_Q (\equiv \partial d/\partial Q) > 0$ (i.e. increasing traffic volume will, for given airport capacity K , increase congestion) and $\theta'(QS) < 0$, oligopoly models with $v > 0$ and finite N will result in price being greater than marginal cost, with the magnitude of the difference capturing the degree of the price distortion. For example, collusion ($v = N$) will lead to a greater price distortion than Cournot competition ($v = 1$).

The above discussions lead to **Proposition 1**:

Proposition 1. *The airport demand can be expressed as $Q(\rho)$ if and only if air carriers have no market power, i.e. if and only if: (i) airlines are atomistic; or (ii) they are price takers and have constant marginal operational costs.*

It is worth pointing out that this result is not necessarily limited to the conjectural-variation version of oligopoly. To see this, define $\delta (\geq 0)$ as the difference between price and marginal cost. We can write

$$t - \frac{c' + P + \beta d}{S} = \delta(Q, N, (\alpha S + \beta)d_Q) \quad (11)$$

⁶ We are aware of the argument that the notion of 'conjectural variations' is logically flawed if interpreted literally. This happens because the model in question is a 'one-shot' game and hence firms do not have an opportunity to respond to changes in output by their rivals. Here we take the approach of taking v 's as market conduct parameters that are used to include, in a single one-shot game, Cournot, cartel and perfect competition models as special cases (see Church and Ware, 2000, p. 273; Brander and Zhang, 1990). That is, by simply replacing v by these three values, we recover the outcomes of these three structures, but v does not need to have any other economic meaning. As is to be seen in the text, while the conjectural-variations model facilitates the discussion, our insights are more general. Also, it is noted that we refer to the case of $v = 0$ as perfect competition rather than as Bertrand competition. Under Bertrand competition, airlines choose prices (rather than quantities as in Cournot), and it is usually understood that this leads to marginal cost pricing. This, however, occurs when marginal costs are constant but here, because of congestion costs, the marginal cost each firm is increasing in its output. Bertrand competition may still give rise to marginal cost pricing (and hence be captured by $v = 0$) under increasing marginal costs, but owing to problems of existence and uniqueness of equilibria, this would require more conditions, such as certain rationing rules (see Dastidar, 1995, 1997).

in which δ may vary with Q , d_Q , N and possibly with other variables or parameters. In the conjectural-variation model, δ reduces to $Qv[(\alpha S + \beta)d_Q - \theta'(QS)S^2]/NS$; but it will take a different expression if firms' interactions arise in other forms, such as a Stackelberg leader–follower game, or a 'dominant firm' model. The crux of the matter is that, as long as δ is strictly positive, the third term in (8) is non-zero so one would not be able to solve (8) in order to write the airport demand as $Q(\rho)$.

We now turn to the second question: if the airport demand can be expressed as $Q(\rho)$, would the integration of $Q(\rho)$ correspond to airlines' profits plus passenger surplus? Specifically, we want to know how the two equivalent expressions:

$$I = \int_{\rho}^{\infty} Q(\rho)d\rho = \int_0^Q \rho(y, K)dy - \rho(Q, K)Q \quad (12)$$

relate to airlines' profits and passenger surplus.⁷ To answer this question, we first compute passenger surplus (denoted as $PaxS$). It is given by

$$PaxS = \int_0^q \theta(x)dx - \theta(q)q \quad (13)$$

where $q = QS$. But, under the assumptions needed for $Q(\rho)$ to be a sensible model, it is true from (9) that $\theta(x) = [\rho(x/S, K) + \tilde{c}]/S$. Replacing this in (13), we obtain

$$\begin{aligned} PaxS &= \frac{1}{S} \int_0^q (\rho(x/S, K) + \tilde{c})dx - \frac{\rho + \tilde{c}}{S}q = \frac{1}{S} \int_0^q \rho(x/S, K)dx + \frac{\tilde{c}q}{S} - \frac{\rho + \tilde{c}}{S}q \\ PaxS &= \frac{1}{S} \int_0^q \rho(x/S, K)dx - \rho(Q, K)Q \end{aligned} \quad (14)$$

Using $y = x/S$ to change variables in (14) one finally shows that $PaxS = I$ and, therefore, we have shown that the integration of $Q(\rho)$, given by I , is exactly equal to passenger surplus. What about airlines' profits? An airline's profit is given by Eq. (4). Using (5) and the symmetry condition, profit becomes $\pi^i = (S\theta(QS) - \rho)(Q/N) - c(Q/N)$. The aggregate (equilibrium) profit of airlines, $\Pi = \sum_i \pi^i$, is then easily obtainable as

$$\Pi = Q[S\theta(QS) - \rho] - Nc\left(\frac{Q}{N}\right) \quad (15)$$

Next, if the operational costs of airlines $c(Q_i)$ have no fixed-cost component, then the last term on the right-hand side (RHS) is equal to $\tilde{c}Q$ under either set of assumptions, as we now show. For the case of perfect competition conjectures, the assumption needed is constant marginal cost. Thus, we directly have $c(Q/N) = \tilde{c}Q/N$, which leads to $\tilde{c}Q$ in the last term on the RHS. In the case of atomistic airlines ($N \rightarrow \infty$), using the L' Hopital rule it is easy to see that $\lim_{N \rightarrow \infty} Nc(Q/N) = \tilde{c}Q$, where $\tilde{c} = \lim_{x \rightarrow 0} c'(x)$, i.e. the intercept of the marginal operational cost function; hence, (15) becomes

$$\Pi = Q[S\theta(QS) - \rho - \tilde{c}] = 0 \quad (16)$$

where the second equality arises from (9). We can thus conclude that

Proposition 2. *The integral of the derived demand for airports will correspond to airlines' profits plus passenger surplus if: (i) airlines are atomistic or (ii) they are price takers and have constant marginal operational costs.*

Certainly, all the assumptions needed are associated with competitive markets. Perfect competition in the airline market was, in fact, the maintained assumption of Oum et al. (2004). Hence, we have provided theoretical support for their claim. But we have also provided boundaries for the use of the traditional approach: it would be reasonable to use it only if market power at the airline level is absent.

⁷ This question in fact has to do with the more general subject of the relation between input and output market surplus measures (see Jacobsen, 1979; Quirmbach, 1984; Basso, 2006). The fact that full prices are being considered, however, implies that the established results in that literature are not directly applicable.

We can then move to the third and final question, i.e. what would happen to the prescribed optimal traffic and capacity levels if, despite the fact that airlines have market power, a traditional approach were used? Note that with market power, modeling the demand for the airport as $Q(\rho)$ is wrong, implying that calculating $\int_{\rho}^{\infty} Q(\rho)d\rho$ is incorrect as well. However, a modeler may still define $\rho(Q, K) = P(Q, K) + [\alpha S + \beta]d(Q, K)$ as in (5) – where $P(Q, K)$ is the inverse demand for the airport – and then maximize $I = \int_0^Q \rho dQ - \rho Q$ with respect to Q and K . $I(Q, K)$ is then the measure of ‘consumer surplus’ from the traditional approach. What we want to know first is how I compares to $PaxS + \Pi$. Focusing on the case of constant marginal cost we know, from (2) and (11), that $\theta(Q) = \rho + \tilde{c} + S\delta(Q, N, (\alpha S + \beta)d_Q)$. Replacing this in (13) and using the same change of variables as before, we obtain that the passenger surplus can be computed as

$$PaxS = \left[\int_0^Q \rho(y, K)dy - \rho(Q, K)Q \right] + \left[\int_0^Q S\delta(y, K)dy - S\delta(Q, K)Q \right]$$

where, for notational simplicity, we write δ as a function of only Q and K . On the other hand, the industry profit is given by

$$\Pi = S\delta(Q, K)Q > 0$$

Thus, the sum of passenger surplus and airlines’ profits is given by

$$PaxS + \Pi = \left[\int_0^Q \rho dQ - \rho Q \right] + \int_0^Q S\delta(y, K)dy$$

from where it follows that

$$I(Q, K) = PaxS + \Pi - \int_0^Q S\delta(y, K)dy \quad (17)$$

Since $\delta > 0$, it flows that I will fall short of giving the sum of airlines’ profits and passenger surplus. Notice further that, in line with Proposition 2, the above expression reduces to I if and only if $\delta = 0$. Hence, it is easy to see that if one uses $I(Q, K)$ to, for example, evaluate a project that changes the traffic level from Q_0 to Q_1 (at a constant capacity), ΔI would underestimate the change in surplus of passengers and airlines if $Q_0 < Q_1$, and would overestimate it if $Q_0 > Q_1$.⁸

Moreover, using I instead of the true measure of surplus would prescribe a traffic level, for given capacity, that is smaller than the social optimum. To see this, add the airport profit, $\Phi(Q, K)$, to both sides of (17), differentiate with respect to Q and then evaluate it at $Q^I(K)$, the traffic level that maximizes $I + \Phi$ for a given K . This procedure leads to

$$\frac{\partial(PaxS + \Pi + \Phi)}{\partial Q} \Big|_{Q^I(K)} = \frac{\partial(I + \Phi)}{\partial Q} \Big|_{Q^I(K)} + \frac{\partial}{\partial Q} \int_0^Q S\delta(y, K)dy \Big|_{Q^I(K)} = \delta(Q^I(K), K) > 0 \quad (18)$$

and hence, $Q^*(K) > Q^I(K)$. Note that, since there is no budget constraint for the airport, there is no guarantee that the airport would cover its costs in either the traditional or the vertical structure approach. However, our results go through if budget constraints are included. The only thing that would change in Eq. (18) is that Φ would be multiplied by $(1 + \lambda)$, where λ is the Lagrange multiplier of the airport budget constraint, which ensures cost recovery.

These discussions lead to

Proposition 3. *If airlines have market power, the surplus measure of the traditional approach will fall short of giving a true measure of total social surplus. Furthermore, its use would prescribe a traffic level that is, for given capacity, smaller than the socially optimal level.*

As for the capacity level, it is easy to prove – with a similar procedure and the proof is available from the authors upon request – that using I instead of the true measure of social surplus would prescribe a capacity

⁸ From (17) we see directly that $\Delta I = \Delta PaxS + \Delta \Pi - \int_{Q_0}^{Q_1} S\delta(y, K)dy$, and since δ is positive, if $Q_0 < Q_1$ then $\Delta I < \Delta PaxS + \Delta \Pi$ and if $Q_0 > Q_1$ then $\Delta I > \Delta PaxS + \Delta \Pi$.

Table 1
Parameter values for the numerical analysis

Demand		Airlines		Airport	
α	40	S	100	r	10,000
A	2000	\tilde{c}	36,000	C	2000
B	0.15	β	2500		

level, for given traffic volume, that is larger than the socially optimal level (for the same given traffic volume). However, while thinking of cases with fixed capacity is relatively straightforward – a matter of short versus long run – the intuition for a fixed level of traffic is harder. In reality, both prices and capacities may be decision variables especially in the long run. This would nevertheless complicate the comparisons between the approaches because it does not really make sense to compare only traffic levels, or only capacity levels. The simplest thing to do is to directly compare social surplus levels. Hence, in order to give some idea about the size of the mistake committed if the traditional approach is used when in effect airlines have market power, we further conducted some numerical examples, which are presented in the next section.

4. Numerical examples

The first thing we need for conducting numerical simulation is explicit functional forms for the demand and delay functions. We choose a simple linear inverse demand as follows:

$$\theta(q) = A - Bq \quad (19)$$

and use

$$d(Q, K) = \frac{Q}{K(K - Q)} \quad (20)$$

for the delay function, which obviously fulfills $d_Q(\equiv \partial d / \partial Q) > 0$.⁹ We also need to make explicit the airport's profit function $\Phi(Q, K)$. We consider a simple cost function, separable and linear in operating and capital costs, so that the profit is given by

$$\Phi(Q, K) = P(Q, K) \cdot Q - C \cdot Q - r \cdot K \quad (21)$$

Here, $P(Q, K)$ is the inverse demand function faced by the airport, which is derived from the equilibrium downstream and which can be obtained from Eq. (6). With these functions, we now need to find reasonable values for the parameters in the model in order to obtain good insights regarding the size of the differences between approaches. We use the parameter values in Table 1.

Most of these parameters – some of which were used by Basso (in press) in his numerical simulations – are close to what have been found in empirical studies: For α , Morrison and Winston (1989, p. 90) empirically found a value of \$45.55 an hour in 1988 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 \tilde{c} , Brander and Zhang (1990) proposed the following formula for the marginal cost per passenger in a direct connection: $cpm(dist/AFL)^{-\eta}dist$, where cpm is the cost per passenger-mile, $dist$ is the origin–destination distance, AFL is the average flight length of the airline and η is the cost sensitivity to distance. A value of $\tilde{c} = \$36,640$ results from using $\eta = -0.43$, $AFL = 800$, $cpm = \$0.20$ and $dist = 2000$.¹⁰ 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 $3\,484$ to 18^*100) in 1980 dollars.

⁹ This convex function of Q was proposed by the US Federal Aviation Administration (1969) and has been discussed and used in many articles. See details in Basso and Zhang (2007).

¹⁰ The following were the average values for American and United Airlines in the period 1981–1988 (see Oum et al., 1993): $cpm = \$0.12/pax/mile$, $AFL = 775$ miles and $\eta = -0.43$.

The two objective functions that we seek to maximize with respect to Q and K are total social surplus and the integral of the derived demand for airports. Total social surplus is obtained directly as the sum of passenger surplus, airlines profits and airport profits. Note that total social surplus is directly a function of Q and K , since passenger surplus depends on Q (see Eq. (13)), airlines profits depend on Q and $P(Q, K)$ in Eq. (4), and the same goes for airport profits in (21). On the other hand, the traditional approach maximizes the area under the airport's demand curve. Using the expression on the right hand side of (12), where ρ is defined as in (5), we also obtain an expression that depends on Q and K . We solve these two programs subject to non-negativity constraints and $Q < K$, using the software Mathematica (Wolfram Research Inc., 2007).

The numerical analysis showed that, for $N = 2$ and Cournot Competition, if the capacity is set at the socially optimal level ($K = 109$ in this case), the socially optimal traffic would be $Q = 101$ flights per unit of time, while the traditional approach would prescribe $Q = 72$. If both traffic and capacity levels are allowed to change, then the traditional approach would prescribe $Q = 67$ and $K = 75$, generating deadweight losses that correspond to 11.32% of the maximum achievable. Under Cournot competition, these deadweight losses decrease rapidly as N increases: they are 4.07% for $N = 4$ and 1.26% for $N = 8$. This is not surprising because it is well known that Cournot competition has a quite fast rate of convergence to the competitive outcome (for homogenous goods the rate is $1/N$; see e.g. Vives, 2002), and we showed that the divergence between the two airport pricing approaches is actually dependent on the degree of market power at the airline level (see Eq. (17)).

Finally, if one changes the values of the parameters for which there was less external information, such as A , B , C and r , the values of Q and K one obtains change, but deadweight losses values do not change much. For example, if for $N = 2$ we were to use $A = 5000$ and $B = 1$, as in Pels and Verhoef (2004), deadweight losses would be 11.21%, even though traffic and capacity values are now less than half of what they were. If we decrease the marginal cost of capital to half its value ($r = 5000$) deadweight losses would be 11.25%.

5. Conclusion

Our analysis has shown that the traditional approach to airport pricing is valid if air carriers have no market power, i.e. if (i) airlines are atomistic or (ii) they behave as price takers and have constant marginal operational costs. Thus, we uncovered an implicit assumption made in the traditional approach: airlines are passive players. However, when there is market power at the airline level, this approach may result in a surplus measure that falls short of giving a true measure of surplus, and would prescribe a traffic level that is, for given capacity, smaller than the socially optimal level. Its use would generate deadweight losses that may be large if the degree of competition between air carriers is low.

Although a vertical-structure approach is a more reasonable approach to airport pricing and capacity investment when carriers have market power and consequently both airports and airlines behave strategically, our analysis shows that it also requires a detailed knowledge of how competition takes place in the airline market, and of airlines' costs and demands. Such requirement may obscure the problem of optimal pricing and investment policies regarding airports. Furthermore, since our goal was to clearly delineate the boundaries of the traditional approach, we have used a simplified model of airport operations. Yet, in reality, there are a number of other issues that are of importance, such as concession revenues, competition between airports, or environmental charges. When studying these or other airport-related issues in more complicated models, it is quite clear that both approaches may still be used (see Basso and Zhang, 2007). However, we hope that it is clear now that adding any of these complexities to the model, would not make the problem depicted in this paper go away. Hence, if a particular topic has been analyzed only through the traditional approach, our suggestion would be to reassess the conclusions, using a vertical-structure approach.

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Appendix

We consider here the case in which airlines have (potentially) asymmetric costs, as in Eq. (3). With symmetry, it was natural to define ρ as $\rho = P + [\alpha S + \beta]d(Q, K)$. However, when airlines have different β_i , it is not obvious how ρ should be defined. Finding an adequate definition for ρ is then part of the answer to question 1 in this setting. The new equation that defines equilibrium in the price-taking case (perfect competition) case is

$$S\theta(QS) - P - (\alpha S + \beta_i)d(Q, K) - \frac{\partial c^i(Q_i)}{\partial Q_i} = 0 \quad (\text{A.1})$$

Eq. (A.1) holds $\forall i$. Adding from 1 to N , and dividing by N we obtain

$$S\theta(QS) - P - (\alpha S + \bar{\beta})d(Q, K) - \frac{1}{N} \sum_{i=1}^N \frac{\partial c^i(Q_i)}{\partial Q_i} = 0 \quad (\text{A.2})$$

where $\bar{\beta}$ is the average of the β_i . If we now make the assumption that airlines have constant marginal operational cost, $\partial c^i(Q_i)/\partial Q_i = c_i$, and we define

$$\rho = P + [\alpha S + \bar{\beta}]d(Q, K) \quad (\text{A.3})$$

$$\bar{c} = (1/N) \sum_{i=1}^N c_i \quad (\text{A.4})$$

Then Eq. (A.2) becomes

$$S\theta(QS) - \rho - \bar{c} = 0 \quad (\text{A.5})$$

which shows that, under perfect competition and cost asymmetry, the airport demand can still be modeled as a function of ρ , only that now ρ considers the average of the β_i , and we need to consider the average of the (constant) marginal operational costs.

For the conjectural-variation model, with asymmetry the set of first-order conditions are

$$\frac{\partial \pi^i}{\partial Q_i} = S\theta(QS) - P - (\alpha S + \beta_i)d + Q_i v \left[S^2 \theta'(QS) - (\alpha S + \beta_i) \frac{\partial d}{\partial Q} \right] - \frac{\partial c^i(Q_i)}{\partial Q_i} = 0 \quad (\text{A.6})$$

Adding from 1 to N , and dividing by N we obtain

$$S\theta(QS) - P - (\alpha S + \bar{\beta})d + \frac{QvS^2\theta'(QS)}{N} - \frac{v}{N} \sum_{i=1}^N Q_i(\alpha S + \beta_i) \frac{\partial d}{\partial Q} - \frac{1}{N} \sum_{i=1}^N \frac{\partial c^i(Q_i)}{\partial Q_i} = 0 \quad (\text{A.7})$$

Thus, again, under $v = 0$ we get back to the perfect competition case: Eq. (A.7) reduces to Eq. (A.2). For cases in which $v > 0$, the only way to obtain an expression that leads to Q as a function of ρ , where ρ is as in (A.3), is to let N approach infinity. When $N \rightarrow \infty$, each firm produces infinitesimal output, i.e. $Q_i \rightarrow 0$, while total output Q is bounded. Therefore (A.7) becomes

$$S\theta(QS) - P - (\alpha S + \bar{\beta})d - \frac{1}{N} \sum_{i=1}^N c_i = 0 \quad (\text{A.8})$$

where this time c_i is given by $c_i = \lim_{Q_i \rightarrow 0} \frac{\partial c(Q_i)}{\partial Q_i}$. Thus, re-defining $\bar{c} = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{i=1}^N c_i$, Eq. (A.8) shows that the airport's demand could be expressed as a function $Q(\rho; \bar{c})$, where ρ is still defined by (A.3). Thus, Proposition 1 may be relaxed to accommodate cost asymmetries as long as one considers an average ρ and the average of the marginal costs (or their intercepts).

Next, Proposition 2 also holds with asymmetric costs. First, notice that it is still true that PS , given by Eq. (13), is equal to I , given by Eq. (12). The only change is that in the derivation we would use \bar{c} rather than \tilde{c} . But then, it is evident that under either set of assumptions, each airline will make zero profit if it does not have a fixed-cost. For the perfect competition case, the ticket price equals the full marginal cost (per passenger) of an airline, as (A.1) shows $t = \left(P + \beta_i d(Q, K) + \frac{\partial c^i(Q_i)}{\partial Q_i} \right) / S$. Since here we need to assume that marginal costs are

flat, multiplying both sides by SQ_i leads to $SQ_{it} = c^i(Q_i) + (P + \beta_i d(Q, K))Q_i$, from where $\pi_i = 0$ and $\Pi = 0$. In the case of atomistic carriers, π_i is evidently zero because each airline produces infinitesimal output and there are no fixed-costs by assumption.

References

- Basso, L.J., 2006. On input markets surplus and its relation to the downstream market game. Working Paper. Sauder School of Business, The University of British Columbia. <<http://ssrn.com/abstract=961471>>.
- Basso, L.J., in press. Airport deregulation: effects on pricing and capacity. *International Journal of Industrial Organization*.
- Basso, L.J., Zhang, A.M., 2007. An interpretative survey of analytical models of airport pricing. In: Lee, D. (Ed.), *Advances in Airline Economics*, vol. 2. Elsevier, pp. 89–124.
- Brander, J.A., Zhang, A.M., 1990. Market conduct in the airline industry: an empirical investigation. *Rand Journal of Economics* 21 (4), 567–583.
- Brueckner, J.K., 2002. Airport congestion when carriers have market power. *American Economic Review* 92 (5), 1357–1375.
- Brueckner, J.K., 2005. Internalization of airport congestion: a network analysis. *International Journal of Industrial Organization* 23 (7–8), 599–614.
- Church, J., Ware, R., 2000. *Industrial Organization: A Strategic Approach*. McGraw-Hill, Boston.
- Dastidar, K.G., 1995. On the existence of pure strategy Bertrand equilibrium. *Economic Theory* 5, 19–32.
- Dastidar, K.G., 1997. Comparing Cournot and Bertrand in a homogenous product market. *Journal of Economic Theory* 75, 205–212.
- Jacobsen, S.E., 1979. Equivalence of input and output market Marshallian surplus measures. *American Economic Review* 69 (3), 423–428.
- Lu, C.C., Pagliari, R.I., 2004. Evaluating the potential impact of alternative airport pricing approaches on social welfare. *Transportation Research Part E (Logistics and Transportation Review)* 40 (1), 1–17.
- Morrison, S.A., 1987. The equity and efficiency of runway pricing. *Journal of Public Economics* 34 (1), 45–60.
- Morrison, S.A., Winston, C., 1989. Enhancing the performance of the deregulated air transportation system. *Brookings Papers on Economic Activity: Microeconomics* 1989, 61–112.
- Oum, T.H., Zhang, Y.M., 1990. Airport pricing – congestion tolls, lumpy investment, and cost recovery. *Journal of Public Economics* 43 (3), 353–374.
- Oum, T., Zhang, A.M., Zhang, Y.M., 1993. Inter-firm rivalry and firm specific price elasticities in deregulated airline markets. *Journal of Transport Economics and Policy* 27, 171–192.
- Oum, T.H., Yu, C., 1997. *Winning Airlines: Productivity and Cost Competitiveness of the World's Major Airlines*. Kluwer Academic Publishers.
- Oum, T.H., Zhang, A.M., Zhang, Y.M., 2004. Alternative forms of economic regulation and their efficiency implications for airports. *Journal of Transport Economics and Policy* 38 (2), 217–246.
- Pels, E., Verhoef, E.T., 2004. The economics of airport congestion pricing. *Journal of Urban Economics* 55 (2), 257–277.
- Quirnbach, H.C., 1984. Input market surplus – the case of imperfect competition. *Economics Letters* 16 (3-4), 357–362.
- Raffarin, M., 2004. Congestion in European airspace – a pricing solution? *Journal of Transport Economics and Policy* 38, 109–125.
- Swan, W.M., 2002. Airline route developments: a review of history. *Journal of Air Transport Management* 8, 349–353.
- US Federal Aviation Administration, 1969. *Airport Capacity Handbook*, second ed. US Government Printing Office, Washington, DC.
- Vives, X., 2002. Private information, strategic behavior, and efficiency in Cournot markets. *Rand Journal of Economics* 33, 361–376.
- Wolfram Research Inc., 2007. *Wolfram Mathematica version 6.0.1.0*.
- Zhang, A.M., Zhang, Y.M., 1997. Concession revenue and optimal airport pricing. *Transportation Research Part E (Logistics and Transportation Review)* 33 (4), 287–296.
- Zhang, A.M., Zhang, Y.M., 2006. Airport capacity and congestion when carriers have market power. *Journal of Urban Economics* 60, 229–247.