Airport Capacity and Congestion When Carriers Have Market Power

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Abstract: It is well accepted that optimal pricing at congested airports includes a congestion toll. However, Brueckner (2002) pointed out that congestion pricing has no (or only partial) place at an airport when carriers have market power, since carriers themselves will internalize full or partial congestion costs. This would effectively deprive the airport an important source of financing and would have serious implications for capacity investment by the airport. This paper extends the literature by studying the implications of congestion pricing for the capacity investment and airport congestion when carriers have market power. Three airport types are examined: a welfare-maximizing public airport, a profit-maximizing private airport, and a budget-constrained public airport. We find that airline market structure will have an important impact on airport capacity and congestion and that, unless a welfare-maximizing public airport gets a financial subsidy, its capacity level will be socially inefficient. Furthermore, whilst market structure would affect capacity investment and congestion at a profit-maximizing airport, it would have no impact on capacity and congestion at a welfare-maximizing public airport.

1. Introduction

The world has experienced a long period of rapid growth in air transportation. From 1971 to 2001, air passengers grew by six-fold worldwide, which translates to an average growth of 7% per annum. While many new airports have been built and entered service, existing airports may still face capacity shortage at peak travel periods, and airlines and passengers have been suffering from congestion at most of the major airports in the world. Economic literature has advocated the use of congestion pricing, under which landing fees are based on a flight's contribution to congestion. Such pricing principle will make the use of scarce resources at the congested airport socially efficient in the sense that the user will pay the full cost of his consumption of the services provided by the airport. The resulting congestion toll would thus curtail demand and help relieve congestion.

Brueckner (2002) is the first author to point out that this principle of congestion pricing only applies to an airport servicing competitive (atomistic) carriers. If the airport is used by only one carrier or a few oligopolistic carriers, although the additional delay costs imposed by one flight are external to that flight, these costs would become internal if other flights also belong to the same carrier. Naturally, the carrier will internalize these costs by raising ticket prices. Therefore, there is no room left for the airport to levy congestion tolls if all the flights belong to a single carrier (the monopolist), or only partial room if some flights belong to the same carrier (the oligoplists). This implies that carriers themselves will be effective in curtailing demand by making their passengers pay the social cost (fully so for monopolist and partially so for oligopolists) of using the scarce resources at a congested airport (or during congested periods). Hence, the resulting passenger demand and thereby the output decision by the carriers will be socially efficient.

Assuming duopoly airlines, Pels and Verhoef (2004) analyzed a model with a simple two-node network and two airport regulators that maximize social welfare. They found that congestion tolls under second-best circumstances are typically lower than what would be suggested by congestion costs alone and may even be negative. They suggested setting the lower bound of tolls to zero. Furthermore, under the two-node network setting, they concluded that cooperation between the regulators need not be stable and that non-cooperation may lead to welfare losses when compared to a no-congestion-toll situation.

These studies on airport pricing and congestion with non-atomistic carriers have also raised a new issue regarding capacity financing at airports. As is known, apart from demand management, congestion tolls also serve a second purpose, namely providing funds to finance capacity expansion by the airports. Literature on congestion pricing and airport capacity financing is abound; see, among others, Levine (1969), Carlin and Park (1970), Walters (1973), Morrison (1983, 1987), Gillen *et al.* (1987, 1989), Oum and Zhang (1990), Oum *et al.* (1996), and Zhang and Zhang (1997, 2001, 2003). However, almost all of the existing papers assumed, explicitly or implicitly, that the airport is serviced by competitive (atomistic) carriers. When carriers have market power at a congested airport and therefore are able to internalize congestion costs, they would effectively deprive the airport the source of capacity financing and would leave the airport with either a financial deficit or socially suboptimal investment in capacity.

Thus, a public airport whose mandate is to maximize social welfare faces a dilemma: either making suboptimal capacity investment, or becoming a financial burden to the public. In this paper, we attempt to study such a dilemma faced by the airport with non-atomistic carriers. We will examine three alternative airport objectives: namely, a public airport that maximizes social welfare, a private airport that maximizes profit, and a public airport that is subject to a budget constraint. We study the impact of airline market structure (concentration, or degree of competition, at an airport) on airport pricing, investment and financing. Our results show that market structure will have an important impact on airport capacity and congestion and that, unless a welfare-maximizing public airport gets a financial subsidy, its capacity level will be socially inefficient. These results have practical implications for both the airport operation and structure of the airline industry.

Our analysis will also shed some light on the significance of market structure in explaining airport congestion. As discussed above, Brueckner (2002) predicted that carriers' internalization of congestion rises as airport concentration rises. He further tested this hypothesis using cross-section data from the 25 most delayed U.S. airports in 1999. Although he found a negative association between the congestion level and carriers' market concentration, the association was rather weak. On the other hand, Morrison and Winston (2003) did not find that air carriers internalize congestion as airport concentration rises, when they analyzed a larger sample of 78 U.S. airports accounting for 67% of all domestic airline operations in 2000. Daniel (1995), in his study of the Minneapolis-St. Paul airport dominated by the hub airline Northwest, also rejected internalization in favor of atomistic behavior. We attempt to provide an explanation for this "inconsistency" of the analytical and empirical results based on different objectives airports may have. We find that whilst market structure would affect capacity investment and congestion at a profit-maximizing airport, it would have no impact on capacity and congestion at a welfare-maximizing public airport.

The paper is organized as follows. Section 2 sets up the model. Section 3 analyzes equilibria for three airport types, and derives optimality conditions for airport pricing and investment. Section 4 focuses on the interactions between the airline market structure and the capacity and congestion at the airport. Section 5 concludes.

2. The Model

Consider an airport with an aggregate demand by the passengers $Q(\rho)$, where ρ represents the 'full price' faced by passengers:

$$\rho = P + D(Q,K) \tag{1}$$

In words, the full price is the sum of ticket price, P, and cost of delay, D, that depends on total traffic Q and capacity K at the airport. For simplicity, Q is measured by the number of flights. This measurement is equivalent to the number of passengers if each flight has equal number of passengers, which will be true if carriers use the same size of aircraft and have the same load factor. For the delay cost function, we make the standard assumption that D(Q,K) is differentiable in Q and K and

$$\frac{\partial D}{\partial Q} > 0, \quad \frac{\partial D}{\partial K} < 0, \quad \frac{\partial^2 D}{\partial Q^2} > 0, \quad \frac{\partial^2 D}{\partial Q \partial K} < 0 \qquad (2)$$

These assumptions are quite general, requiring that increasing traffic volume will increase congestion while adding capacity will reduce congestion and that the effects are more pronounced when there is more congestion.

There are N air carriers servicing the airport. We assume the following structure of a three-stage game:

Stage 1: The airport decides on the airport charge μ and capacity K, where K is continuously adjustable.

Stage 2: Each carrier chooses its output in terms of the number of flights, q_i, in the Cournot fashion. The carriers produce homogeneous outputs.

Stage 3: The 'full' price is determined by the inverse demand function ρ(Q), where Q is the aggregate output, and then the equilibrium ticket price P is set according to equation (1).

We first analyze carriers' decisions. For simplicity, we assume that each carrier has a linear cost function with per-flight cost c_i for carrier i. This assumption simplifies analysis but is not crucial to our results. By (1), the ticket price is the difference between the full price and cost of delay, so the profit function for carrier i can be rewritten as follows:

$$\pi_i = q_i \times (\rho - D) - c_i q_i - \mu q_i$$

where $\rho = \rho(\sum q_i)$. According to Cournot behavior,[1] the first-order conditions for profit maximization gives

$$\frac{\partial \pi_i}{\partial q_i} = \rho - D + q_i(\rho' - \frac{\partial D}{\partial Q}) - c_i - \mu = 0, \quad \forall i \qquad (3)$$

Let

$$\varepsilon \equiv -\frac{dQ}{d\rho}\frac{\rho}{Q} = -\frac{\rho}{\rho' Q}$$

[1] Brander and Zhang (1990) and Oum *et al.* (1993), for example, find some empirical evidence that rivalry between airlines is consistent with Cournot behavior.

represent the demand elasticity with respect to full price and note that ρ – D = P, (3) can be rewritten as:

$$P = \mu + c_i + s_i (Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}) \qquad (4)$$

where $s_i = q_i/Q$ is the market share of carrier i.

It is clear that the ticket price is the carrier's operating costs including airport charge plus some extra charges. The extra charges have two components. The first is the marginal delay costs to all flights due to one flight, and the second is a pure markup term inversely related to demand elasticity that shows the carrier's market power. Just as Brueckner (2002, 2005) first pointed out that carriers having market power would internalize some of the congestion delay cost according to their market share, (4) confirms that congestion delay cost as well as the markup reflecting market power is incorporated in the ticket price by the factor of the carriers' market share. In particular, for monopoly carrier, $s_i = 1$, congestion delay will be fully reflected in the ticket price while for competitive (atomistic) carriers, congestion delay will not enter the ticket price.

It is worth noting that the terms inside the parenthesis in (4) represent the aggregate effect of congestion delay and market power, which is invariant across individual carriers. Since Cournot model assumes one equilibrium 'full' price, it follows that ticket price is also constant across carriers. Thus, equation (4) shows that outputs of individual carriers are negatively related to their operating efficiency by the factor of aggregate congestion delay plus market markup.

As air carriers make output decisions in the second stage, the airport charge μ and airport capacity K are given and are considered exogenous to the carriers. Now we derive the comparative static results concerning carriers' output with respect to μ and K. Differentiating (3) with respect to μ gives:

$$\frac{\partial^2 \pi_i}{\partial q_i} \frac{\partial q_i}{\partial \mu} + \sum_{j \neq i} \frac{\partial^2 \pi_i}{\partial q_i \partial q_j} \frac{\partial q_j}{\partial \mu} + \frac{\partial^2 \pi_i}{\partial q_i \partial \mu} = 0, \quad \forall i$$

where

$$\frac{\partial^2 \pi_i}{\partial q_i^2} = 2(\rho' - \frac{\partial D}{\partial Q}) + q_i(\rho'' - \frac{\partial^2 D}{\partial Q^2})$$

$$\frac{\partial^2 \pi_i}{\partial q_i \partial q_j} = \rho' - \frac{\partial D}{\partial Q} + q_i(\rho'' - \frac{\partial^2 D}{\partial Q^2})$$

and

$$\frac{\partial^2 \pi_i}{\partial q_i \partial \mu} = -1$$

Solving the equations yields

$$(\rho' - \frac{\partial D}{\partial Q})\frac{\partial q_i}{\partial \mu} = 1 - [\rho' - \frac{\partial D}{\partial Q} + q_i(\rho'' - \frac{\partial^2 D}{\partial Q^2})]\sum_j \frac{\partial q_j}{\partial \mu}, \quad \forall i \tag{5}$$

Sum over i and solve,

$$\frac{\partial Q}{\partial \mu} = \frac{N}{(N+1)(\rho' - \frac{\partial D}{\partial Q}) + Q(\rho'' - \frac{\partial^2 D}{\partial Q^2})} \tag{6}$$

Differentiating (3) with respect to K and solving the resulting equations, we can similarly obtain the following results:

$$(\rho' - \frac{\partial D}{\partial Q})\frac{\partial q_i}{\partial K} = \frac{\partial D}{\partial K} + q_i \frac{\partial^2 D}{\partial Q \partial K} - [\rho' - \frac{\partial D}{\partial Q} + q_i(\rho'' - \frac{\partial^2 D}{\partial Q^2})]\sum_j \frac{\partial q_j}{\partial K}, \quad \forall i \tag{7}$$

and

$$\frac{\partial Q}{\partial K} = \frac{N\frac{\partial D}{\partial K} + Q\frac{\partial^2 D}{\partial Q \partial K}}{(N+1)(\rho' - \frac{\partial D}{\partial Q}) + Q(\rho'' - \frac{\partial^2 D}{\partial Q^2})} \tag{8}$$

3. Analysis of Equilibria

The above analysis shows airport decisions – namely, airport charge μ and airport capacity K – influence subsequent output competition. We now examine the subgame perfect equilibrium of our three-stage airport-carrier game. Taking the second-stage equilibrium output into account, the airport chooses μ and K to maximize its objective. We will consider three alternative airport objectives: namely, a public airport that maximizes social welfare, a private airport that is a profit-maximizer, and a public airport that must achieve financial breakeven.

3.1 Welfare-Maximizing Airport

First assume a public airport whose mandate is to maximize social welfare. Given our setting, the objective of such an airport can be formulated as follows:

$\max_{\mu,K} SW$

where

$$
\begin{aligned}
SW &= \int_0^Q \rho(\xi)d\xi - \rho Q + \sum_i (Pq_i - c_i q_i) - c_0 Q - rK \\
&= \int_0^Q \rho(\xi)d\xi - DQ - \sum_i c_i q_i - c_0 Q - rK
\end{aligned}
\tag{9}
$$

In (9), c_0 is the airport's unit operating cost and r is its cost of capital. Here again, we assumed linear operating cost for the airport for easier exposition. The first-order conditions for this problem are derived below.

$$
\frac{\partial SW}{\partial \mu} = (\rho - D - Q\frac{\partial D}{\partial Q} - c_0)\frac{\partial Q}{\partial \mu} - \sum_i c_i \frac{\partial q_i}{\partial \mu} = 0 \tag{10}
$$

$$
\frac{\partial SW}{\partial K} = (\rho - D - Q\frac{\partial D}{\partial Q} - c_0)\frac{\partial Q}{\partial K} - Q\frac{\partial D}{\partial K} - \sum_i c_i \frac{\partial q_i}{\partial K} - r = 0 \tag{11}
$$

Let

$$
\bar{c} = \sum_i c_i \frac{\partial q_i}{\partial \mu} \Big/ \frac{\partial Q}{\partial \mu} \tag{12}
$$

Note that $\bar{c}$, while maybe interpreted as a weighted average cost of all carriers, is a function of the outputs, rather than a constant. Now, condition (10) leads to

$$
\rho - D - Q\frac{\partial D}{\partial Q} - c_0 - \bar{c} = 0 \tag{13}
$$

which gives

$$
P = c_0 + \bar{c} + Q\frac{\partial D}{\partial Q} \tag{14}
$$

This simply states that the socially optimal ticket price should be the social marginal costs, which includes airport operating cost, carrier operating cost, and congestion delay cost.

In our model, the ticket price is set by the carriers to clear the market after output decisions are made (the last stage of the game). However, exogenous to the carriers, the airport charge μ can be set in the first stage so as to induce the optimal outcome in later stages. Specifically, equation (4) reveals the link between airport charge and ticket price. Substituting (4) into (14) and simplifying, we get

$$\mu = c_0 + \bar{c} - c_i + (1 - s_i)Q\frac{\partial D}{\partial Q} - s_i\frac{\rho}{\varepsilon} \tag{15}$$

This indicates that the socially optimal airport charge includes airport operating cost, a residual share of congestion cost which is not internalized by the carriers, and a negative term related to the carriers market power (Brueckner, 2002, and Pels and Verhoef, 2004, reached the same conclusion with different model settings). In particular, if there is only one monopoly carrier serving the airport, all congestion cost will be internalized, and as Brueckner pointed out that there would be no room for congestion toll to be levied by the airport. On the other hand, for competitive (atomistic) carriers, the airport charge will be the full social marginal cost (except carrier operating cost).

For the general oligopoly carriers, (15) implies that there will be partial congestion tolls in the optimal airport charges. From (15), it appears that the extent of the 'partial' congestion toll depends on the market share of individual carriers and so the airport charge would be carrier specific. However, a close examination reveals that market share of individual carriers in a Cournot game is inversely related to their operating cost in such a way that renders (15) invariant across all carriers.

Next, we examine the capacity decision of the airport. Simplifying (11) using (13) gives

$$\bar{c}\frac{\partial Q}{\partial K} - \sum_i c_i \frac{\partial q_i}{\partial K} - Q\frac{\partial D}{\partial K} = r$$

or

$$(\bar{c} - \tilde{c})\frac{\partial Q}{\partial K} - Q\frac{\partial D}{\partial K} = r \tag{16}$$

where

$$\tilde{c} = \sum_i c_i \frac{\partial q_i}{\partial K} \Big/ \frac{\partial Q}{\partial K} \tag{17}$$

In the two extreme cases, namely, the monopoly case and the competitive case, $\bar{c}$ and $\tilde{c}$ are identical, which yields

$$-Q\frac{\partial D}{\partial K} = r \tag{18}$$

This equation states that the marginal effect of capacity on congestion cost (the social value of capacity) is equal to the cost of capacity, and thus implying socially efficient investment in capacity.

For the general oligopoly, the capacity investment by the airport will be inefficient in the sense that the social value and cost of capacity are unequal as shown in (16). Nevertheless, this inefficiency is unlikely to be significant. To the extent that the two weighted average costs, $\bar{c}$ and $\tilde{c}$ are close, and indeed if carriers are symmetric, the capacity decision of the airport is basically efficient. We summarize these results in the following proposition.

Proposition 1. For a welfare-maximizing public airport, its capacity investment will be efficient if the airport is serviced by either

i) a monopoly carrier
ii) competitive (atomistic) carriers, or
iii) symmetric Cournot oligopolistic carriers.

For the airport charge, however, social optimum may have undesirable consequences. Rewriting (15), we have

$$\mu - c_0 = \bar{c} + Q\frac{\partial D}{\partial Q} - (c_i + s_i Q\frac{\partial D}{\partial Q} + s_i\frac{\rho}{\varepsilon})$$

The first two terms in the right-hand side represents the social marginal cost incurred by the carriers and passengers and the rest of the terms in the parenthesis reflect the portion of ticket price that is payable to the airline. In fact, using (14) and (2) we can write

$$\mu - c_0 = (SMC - c_0) - (P - \mu) \equiv SMC_c - P_c \qquad (19)$$

where SMC_c is the social marginal cost excluding airport operating cost and P_c stands for carrier revenue from ticket price. This leads to the following proposition.

Proposition 2. For a welfare-maximizing public airport, the optimal airport charged is set at the level such that the ticket price paid by the passengers is equal to social marginal costs.

Airport charges based on (19) is efficient if carriers are competitive. In this case, P_c equates carriers' marginal costs, and so the difference between SMC_c and P_c represents marginal congestion costs which is fully captured by the airport in terms of congestion toll. Congestion toll collected by the airport serves two purposes: to curtail congestion by making passengers pay marginal congestion costs and to raise funds for capacity expansion. Under certain conditions, congestion toll would exactly cover capacity cost at the optimal level of capacity (See Mohring, 1970, 1976; Morrison, 1983; and Oum and Zhang, 1990).

When carriers have market power, however, (19) will be undesirable. Whether for monopoly or for oligopoly carriers, P_c will be higher than carriers' marginal costs, both because internalization of congestion costs (by the carriers) and the price markup due to carriers' market power. Such pricing by the carriers deprives airport of full congestion toll and thus makes airport in shortage of funds if investment in capacity is to be optimal. Furthermore, in the case of monopoly or oligopoly with

$$(1-s_i)Q\frac{\partial D}{\partial Q} < s_i\frac{\rho}{\varepsilon}$$

$\mu - c_0$ will be negative, indicating that airport charge is insufficient even to cover operating cost of the airport.

In essence, the objective of the airport charge, as formulated in (19), is to make passengers eventually pay a ticket price equating social marginal cost, as stated in Proposition 2. Therefore, when carriers overcharge passengers by setting a price markup over cost, the airport essentially provides a rebate to passengers which matches the difference between social marginal cost and what the carriers charge. While this achieves the optimality of the ticket price, the airport itself will suffer from financial deficit. As a public airport, such pricing policy inevitably would require subsidy from the government. On the other hand, airport charges in practice are paid by the carriers in terms of landing/take-off fees (apart from airport fees/taxes directed collected by airports from passengers). Although it is expected that the benefits of a lower airport charge would be passed over to passengers, it is hard to argue that a below-cost airport charge levied to a carrier is not a subsidy to the carrier. Consequently, the idea of a public airport *giving subsidy to a profitable monopoly* (or oligopoly) carrier while itself asking for financial help might be politically implacable.

Several options may be considered to prevent the airport from becoming a public burden. For instance, the airport may be privatized/incorporatized or be subject to regulations of self-financing. For the airports that have both aeronautical and commercial operations, the profits made from commercial/concession activities may be used to cross-subsidize aeronautical operations and eliminates the need for government aid. However, different forms of regulation concerning commercial operations exist. Single till regulation, for instance, requires airport achieve overall break-even (with allowances for cost of capital as in ROR regulation and for productivity progress as in price-cap regulation). Dual till regulation, on the other hand, requires airport to achieve financial break-even in aeronautical operation, effectively eliminating cross-subsidy, while commercial operations may or may not be subject to regulation. (For recent studies on airport privatization and regulation/deregulation, see, for example, Forsyth, 1997, 2002a, 2002b; Beesley, 1999; Starkie and Yarrow, 2000; Kunz and Niemeier, 2000; Starkie, 2001; Gillen and Morrison, 2001; Tretheway, 2001; Graham, 2002; Hooper, 2002; Niemeier, 2002; Zhang and Zhang, 2003; Oum, Zhang and Zhang, 2004.)

In this paper, we examine two alternatives: a privatized airport and a public airport subject to cost-recovery in aeronautical operations.

3.2 Profit-Maximizing Airport

First consider a private airport pursuing profit-maximization. For such an airport, the objective is

$$\max_{\mu,K} \; \mu Q - c_0 Q - rK$$

and the first-order conditions for optimality are

$$(\mu - c_0)\frac{\partial Q}{\partial \mu} + Q = 0 \tag{20}$$

$$(\mu - c_0)\frac{\partial Q}{\partial K} - r = 0 \tag{21}$$

Substituting (6) into (20) and simplifying, we obtain

$$\mu = c_0 + (1 + \frac{1}{N})(Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}) + \frac{Q^2}{N}(\frac{\partial^2 D}{\partial Q^2} - \rho'') \tag{22}$$

By assumption (2), all terms in the right-hand side, perhaps except the one involving ρ", are positive. If ρ" is not too large, airport charge will be greater than social marginal costs. In particular, when the carriers are atomistic, i.e., $N \to \infty$,

$$\mu \to c_0 + Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}$$

i.e., apart from the full congestion toll, the airport will also capture all the price markup due to market power.

Interestingly, with decreasing number of carriers, the congestion toll and price markup will increase in proportion. Indeed, in the case of a monopoly carrier, the airport charge will be

$$\mu = c_0 + 2(Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}) + Q^2(\frac{\partial^2 D}{\partial Q^2} - \rho'')$$

This result may be explained by the fact that the airport has a first-mover advantage. By setting μ to maximize airport profits, while fully anticipating carriers' subsequent output behavior (reaction), the airport is effectively in a leader's position and can play the game similar to Stackelberg fashion. In fact, a close examination of (20) and (6) reveals the following relationship:

$$(1 + \frac{1}{N})(Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}) + \frac{Q^2}{N}(\frac{\partial^2 D}{\partial Q^2} - \rho'') = -\frac{Q}{\partial Q / \partial \mu} = \frac{\mu}{\varepsilon_0}$$

and so (22) is equivalent to

$$\mu = c_0 + \frac{\mu}{\varepsilon_0} \tag{23}$$

where

$$\varepsilon_0 \equiv -\frac{\partial Q}{\partial \mu}\frac{\mu}{Q}$$

may be interpreted as the elasticity of carriers' aggregate output with respect to airport charge.

Substituting (22) into (4) gives us the resulting ticket price that passengers will pay

$$P = c_0 + c_i + (1 + \frac{1}{N} + s_i)(Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}) + \frac{Q^2}{N}(\frac{\partial^2 D}{\partial Q^2} - \rho'') \tag{24}$$

which is invariant across all carriers. In particular, when there is only a monopoly carrier, the ticket price consists of marginal operating costs of the carrier and the airport, plus three times the congestion costs and the conventional markup term (ignoring the last parenthesis). Of the congestion costs and markup term, the carrier retains one portion and the airport captures two.

Of course, by our assumption of linear cost functions, the carrier will enjoy pure profits from congestion charge and price markup, while the airport has to cover its capacity cost. To determine the optimal capacity for the airport, substitute (8) into (21) and simplify. Then we obtain the following condition

$$-Q\frac{\partial D}{\partial K} - \frac{Q^2}{N}\frac{\partial^2 D}{\partial Q \partial K} = r \tag{25}$$

By assumption (2), the second term on the left-hand side is positive, indicating that

$$-Q\frac{\partial D}{\partial K} \le r \tag{26}$$

where equality holds only for the case of atomistic carriers. Comparing (26) with the socially optimal condition (18), we see that the capacity decision of a profit-maximizing airport is inefficient in the sense that the social value of capacity is smaller than the cost of capacity, unless the carriers are atomistic. Thus, we have the following proposition.

Proposition 3. For profit-maximizing airport, its capacity investment is socially inefficient when carriers have market power. Specifically, the airport will over-invest in capacity. As a result, the social value of capacity, defined as the marginal effect of congestion reduction, will be smaller than the cost of capacity.

Intuitions and implications of this result will be discussed in Section 3.

3.3 Budget-Constrained Public Airport

Now we consider another alternative, namely, a public airport subject to cost-recovery in aeronautical operations. For this airport, the objective is

$$\begin{aligned} &\max_{\mu,K} \int_0^Q \rho(\xi)d\xi - DQ - \sum_i c_i q_i - c_0 Q - rK \\ &s.t. \quad \mu Q - c_0 Q - rK = 0 \end{aligned} \tag{27}$$

The first-order conditions for this problem can be derived as follows:

$$(\rho - D - Q\frac{\partial D}{\partial Q} - c_0 - \bar{c})\frac{\partial Q}{\partial \mu} + \lambda[Q + (\mu - c_0)\frac{\partial Q}{\partial \mu}] = 0 \tag{28}$$

$$(\rho - D - Q\frac{\partial D}{\partial Q} - c_0 - \tilde{c})\frac{\partial Q}{\partial K} - Q\frac{\partial D}{\partial K} - r + \lambda[(\mu - c_0)\frac{\partial Q}{\partial K} - r] = 0 \tag{29}$$

$$(\mu - c_0)Q - rK = 0 \tag{30}$$

where λ is the Lagrangean multiplier.

Using (1) and (4), (28) can be transformed to yield

$$\mu = c_0 + \frac{1}{1+\lambda}[\bar{c} + Q\frac{\partial D}{\partial Q} - (c_i + s_i Q\frac{\partial D}{\partial Q} + s_i\frac{\rho}{\varepsilon})] - \frac{\lambda}{1+\lambda}\frac{Q}{\partial Q/\partial \mu}$$

Comparing the above with (15) and using the notations in (19) and (23), we have the following simple form of pricing policy for the budget-constrained airport:

$$\mu - c_0 = \frac{1}{1+\lambda}(SMC_c - P_c) + \frac{\lambda}{1+\lambda}\frac{\mu}{\varepsilon_0} \tag{31}$$

This shows that the optimal airport charge subject to cost-recovery is effectively a weighted average between the unconstrained social optimal charge (19) and the unregulated profit-maximizing charge (23).

The weight parameter λ is determined by the budget constraint such that

$$(\mu - c_0)Q - rK = 0$$

which leads to

$$\frac{rK}{Q} = \frac{1}{1+\lambda}(SMC_c - P_c) + \frac{\lambda}{1+\lambda}\frac{\mu}{\varepsilon_0} \tag{32}$$

When carriers have little market power, a carrier's revenue from ticket price P_c will be little more than just to cover its costs and so the airport will capture most of the congestion toll, which can be then used to finance airport capacity. In this case, the first term involving $SMC_c - P_c$ on the right-hand side of (32) makes the most contribution to airport revenues (under certain conditions, cost recovery can be achieved from that source of revenues alone) and the value of λ will be close to zero.

When carriers have market power, however, the first term becomes smaller and can even be negative. Then, according to pricing policy (32), the airport will play a leader-follower game and raise airport charge based on the anticipated responses of the carriers, just as a profit-maximizing private airport would do. As a result, the second term on the right-hand side of (32) will make a larger contribution to airport revenues and the value of λ will increase.

Next, subtracting (28) from (29) and rearranging to derive the conditions determining capacity decision of the budget-constrained airport:

$$(\bar{c} - \tilde{c})\frac{\partial Q}{\partial K} = (1+\lambda)(r + Q\frac{\partial D}{\partial K}) + \lambda Q\frac{\partial Q / \partial K}{\partial Q / \partial \mu}$$

Using (6) and (8) and simplifying, we get

$$-Q\frac{\partial D}{\partial K} + \frac{1}{1+\lambda}(\bar{c} - \tilde{c})\frac{\partial Q}{\partial K} - \frac{\lambda}{1+\lambda}\frac{Q^2}{N}\frac{\partial^2 D}{\partial Q \partial K} = r \tag{33}$$

Again, the left-hand side of (33) may be viewed as a weighted average of conditions (16) and (25), which are under unconstrained welfare-maximization and unregulated profit-maximization, respectively. To the extent that $\bar{c}$ and $\tilde{c}$ are close (they are identical for monopoly carrier, for atomistic carriers, or for symmetric oligopoly carriers), we may ignore the middle term in left-hand side. The first term and the last term remaining are both non-negative, implying

$$-Q\frac{\partial D}{\partial K} \le r$$

where the equality holds only for atomistic carriers as $\bar{c} = \tilde{c}$ and $N \to \infty$.

When carriers have market power, the first term, which reflects the social value of capacity, will be smaller than *r*, the cost of capacity. This implies that the capacity decision of the airport is inefficient. Specifically, the airport tends to over-invest in capacity under budget constraint, despite that even efficient level of capacity would cause deficit to the airport without constraint. Furthermore, (33) shows that the degree of inefficiency increases in the value of λ. When carriers' market power increases, P_c will increase relative to SMC_c in terms of (31). Hence, value of λ will increase and the efficiency of airport capacity will deteriorate. Nevertheless, due to the factor of $\lambda/(1+\lambda)$, the relative importance of the last term on left-hand side of (33) is generally smaller than that of the second term in (25), indicating that a constrained public airport is generally more efficient than an unregulated private airport in capacity investment. These results are summarized below.

Proposition 4. A welfare-maximizing public airport under the constraint of cost-recovery will over-invest in capacity when carriers have market power. The extent of over-investment for such an airport will be less severe than for a profit-maximizing airport.

4. Congestion, Capacity and Market Structure: Symmetric Carriers

The preceding section discussed pricing and capacity decisions of airport when carriers have market power. Now, we examine further the implication of market structure on airport capacity and congestion. For simpler exposition, we will in this section assume "symmetric carriers:" i.e. the carriers have the same costs.

Proposition 1 states that a welfare maximizing public airport will have an efficient investment in capacity, while in comparison proposition 3 shows that a profit-maximizing airport will over-invest in capacity. Now we take a closer look at the over-investment problem. As stated in condition (25), a profit-maximizing airport will invest in capacity until

$$-Q\frac{\partial D}{\partial K}-\frac{Q^2}{N}\frac{\partial^2 D}{\partial Q\partial K}=r$$

The intuition for this condition can be explained as follows. According to the passenger's (inverse) demand

$$\rho = P + D(Q,K)$$

any reduction in congestion cost D will raise passengers' willingness to pay, giving total demand unchanged. On the other hand, as indicated in the carriers' pricing formula (4),

$$P=\mu+P_c$$

The carriers will *fully* pass the airport charge μ onto the passengers. Therefore, while expanding capacity to reduce congestion, the airport can raise airport charge by the amount

$$d\mu=\frac{\partial D}{\partial K}dK \tag{34}$$

so that passengers' perceived full price remained the same and so the total demand will be unchanged. (34) suggests that benefits of a reduction in congestion can be fully captured by the airport in terms of increased airport revenues. When this increase in revenues equals the cost of additional capacity,

$$Qd\mu = Q\frac{\partial D}{\partial K}dK = rdK$$

or,

$$Q\frac{\partial D}{\partial K} = r$$

the level of capacity will also be socially efficient. Such would be the case if carriers are competitive.

When carriers have market power, however, an interesting twist arises. After the airport expanded capacity and simultaneously raised airport charge according to (34), it would leave the same room for carrier revenue P_c without perturbing the total demand. Yet, the carrier now would find that although demand had not changed, the congestion actually declined due to the capacity expansion by the airport. Thus, as shown in the pricing formula of the carrier (4), the portion of congestion costs, which is internalized by the carrier

$$q_i\frac{\partial D}{\partial Q}$$

would also decline by the amount

$$q_i\frac{\partial^2 D}{\partial Q \partial K}dK$$

In other words, *there would also be a room for* P_c *to go down* given carriers' optimal pricing formula.

As the airport is in the leader's position, such room for P_c to go down would translate to the same room for μ to go up. Therefore, taking into account the carriers' market power, the airport can further raise its charge by an additional amount such that

$$d\mu = \frac{\partial D}{\partial K}dK + \frac{Q}{N}\frac{\partial^2 D}{\partial Q \partial K}dK \tag{35}$$

without perturbing the demand. Indeed, since

$$dQ = \frac{\partial Q}{\partial \mu}d\mu + \frac{\partial Q}{\partial K}dK$$

where $\partial Q / \partial \mu$ and $\partial Q / \partial K$ have been derived in (6) and (8), respectively, dQ would be zero if $d\mu$ and dK satisfy (35).

In sum, the benefits of capacity expansion to the airport have two components when carriers have market power. The first term in (35) shows the direct effect by a reduction of congestion cost, which is also the net gain by the society and so we call it the social value of capacity. The second term reflects a transfer of some market power, so to speak, from the carriers to the airport. Consequently, the airport has a stronger incentive to expand capacity when carriers have market power than when the carriers are competitive. As the second term merely represents a profit transfer from the carriers to the airport with no effect on social welfare, it follows that the profit-maximizing airport, which *internalizes such profit transfer* will over-invest in capacity from a social point of view.

Note that the term indicating the profit transfer in (35) is inversely related to *N*, which leads to the following result.

Proposition 5. For a given level of demand, Q, the over-investment problem of a profit-maximizing airport will be more pronounced when carriers have stronger market power. In other words, the volume/capacity ratio Q/K and consequently the level of congestion will be less severe for a monopoly carrier than for the oligopoly carriers, which in turn will be less severe for the competitive carriers.

While congestion at the profit-maximizing airport is less severe when carriers have market power, it should be pointed out that *this lower level of congestion is socially sub-optimal because it arises from over-investment by the airport*.

Now we turn to the welfare-maximizing airport.

Proposition 6. For a given level of demand, the capacity investment by a welfare-maximizing public airport does not depend on the degree of carriers' market power. In other words, market structure of the carriers has no impact on the volume/capacity ratio, and consequently the level of congestion, at such an airport.

Proof: The optimal airport charge and capacity investment for the welfare-maximizing airport are determined by conditions (10) and (11). Assuming symmetric carriers, differentiating these two equations with respect to N, we obtain (after some substitution and simplification):

$$\frac{d}{dN}\left(\frac{\partial SW}{\partial \mu}\right) = (\rho' - 2\frac{\partial D}{\partial Q} - Q\frac{\partial^2 D}{\partial Q^2})\frac{dQ}{dN} - (\frac{\partial D}{\partial K} + Q\frac{\partial^2 D}{\partial Q \partial K})\frac{dK}{dN} = 0 \qquad (36)$$

and

$$\frac{d}{dN}\left(\frac{\partial SW}{\partial K}\right) = (\frac{\partial D}{\partial K} + Q\frac{\partial^2 D}{\partial Q \partial K})\frac{dQ}{dN} + \frac{\partial^2 D}{\partial K^2}\frac{dK}{dN} = 0 \qquad (37)$$

where

$$\frac{dQ}{dN} = \frac{\partial Q}{\partial \mu}\frac{d\mu}{dN} + \frac{\partial Q}{\partial K}\frac{dK}{dN} + \frac{\partial Q}{\partial N} \tag{38}$$

Using the similar method in the derivation of $\partial Q/\partial \mu$ and $\partial Q/\partial K$, which are shown in (6) and (8), we can derive $\partial Q/\partial N$ in (38). The result is as follows:

$$\frac{\partial Q}{\partial N} = \frac{\frac{Q}{N}(\rho' - \frac{\partial D}{\partial Q})}{(N+1)(\rho' - \frac{\partial D}{\partial Q}) + Q(\rho'' - \frac{\partial^2 D}{\partial Q^2})} \tag{39}$$

Substituting (6), (8) and (39) into (38), and solving the resulting system of equations (36), (37) and (38), we finally have:

$$\frac{d\mu}{dN} = \frac{1}{N^2}(Q\frac{\partial D}{\partial Q} + \frac{\rho}{\varepsilon}), \quad \frac{dK}{dN} = 0, \quad \frac{dQ}{dN} = 0$$

This shows that aggregate demand and capacity at the airport does not depend on N. *Q.E.D.*

Intuitively, as N increases, carriers' market power declines, leading to a lower ticket revenue P_c to the carriers. Since the airport charge is formulated such that passengers' ticket price is equal to social marginal cost, a decrease in P_c will result in an increase in μ by the same amount as indicated in (19). However, the social-marginal cost only depends on aggregate demand Q, regardless of N. Therefore, as N changes, P, Q, and thereby congestion D and full price ρ, will all remain the same. Consequently, optimal level of capacity K, which is determined by congestion and capacity cost, will not change either.

There is a stark contrast between Propositions 5 and 6. As being shown, market structure of the carriers would affect capacity investment and congestion at a profit-maximizing private airport but would be irrelevant at a welfare-maximizing public airport. As indicated in the introduction, Brueckner (2002) provided some empirical results that relate airport congestion levels to carriers' market concentration in a sample of U.S. airports. Although he found a negative association between congestion and concentration, the association was rather weak. Here we speculate that one reason that Brueckner's results were weak is that his sample of airports might include some non-profit-maximizing public airports. As our results suggest, concentration would have no impact on capacity and congestion at welfare-maximizing public airports. More generally, our results may provide an explanation for the inconsistency between Brueckner's analytical prediction – that carriers' internalization of congestion rises as airport concentration rises – and empirical results by Morrison and Winston (2003) and Daniel (1995), which did not find market structure as a significant factor in explaining observed variations of delays at major U.S. airports. We note that major U.S. airports are still public owned, either by local governments or by the public authorities such as the Port Authorities of New York and New Jersey.

Finally, we consider the public airport which is under the cost-recovery constraint. As we showed earlier that the conditions governing pricing policy and investment decision by such an airport is somehow in between those for profit-maximizing and for welfare-maximizing airports. Therefore, the impact of market structure on congestion would also fall somewhere in between. In fact, from the budget constraint $\mu Q - c_0 Q - rK = 0$, it follows that

$$\frac{\mu - c_0}{r} = 1 \bigg/ \frac{Q}{K}$$

That is, the volume/capacity ratio is inversely related to airport charge. Consequently, congestion will be affected by concentration to the extent that airport charge depends on carriers' market power.

5. Concluding Remarks

As Brueckner (2002) first pointed out, when carriers have market power, there would be no place (or only partially) for congestion pricing on the airport side. This, however, has raised a new question on airport investment and financing. It is well known in the literature that congestion tolls serve two purposes: first as a means for demand management and second as a source for investment financing. When carriers have market power, they will be able to internalize congestion costs – fully by a monopolist and partially by Cournot oligopolists – by setting a higher ticket price so that passengers will eventually bear the costs that they impose on each other. Such practice by the carriers can well serve the purpose of demand management, as a higher ticket price will curtail demand and reduce congestion. On the other hand, however, the internalization of congestion costs by the carriers would effectively deprive the airport of an important source of funds for its capacity investment.

Indeed, when some technical conditions hold, congestion tolls imposed by the airport would exactly cover the optimal amount of capacity. It follows that optimal timing of capacity expansion could be signaled by the funds available for such expansion, provided that the funds are collected by the nature of congestion tolls. Now, when the carriers have market power and will include congestion charges into their ticket price, the airport will be unable to raise funds needed for capacity investment. This inevitably leaves the airport to a position of financial deficit, if the investment in capacity is to be carried out at the socially optimal scale.

Such is the dilemma faced by a public airport whose mandate is to maximize social welfare: either make suboptimal capacity investment or become a financial burden to the public. In this paper we have examined two alternatives: to privatize the airport, or to impose a budget-constraint to the airport. Our analysis suggested, somewhat surprisingly, that both alternatives would in fact lead to over-investment in capacity, in the sense that the marginal effect of congestion reduction would be smaller than the marginal cost of capacity. This over-investment problem will be present as long as carriers have market power, and the problem will be more pronounced as the market becomes more concentrated. This result has practical implications on such issues as airline mergers/alliances since market structure on the airline side could have direct consequences on airport financing and efficiency.

The present analysis is a first attempt to study the implication of carriers' market power on airport investment and financing. Here, we have not considered the role of commercial/concession operations in the airport pricing and financing. In practice, many airports make ends meet by cross-subsidy between aeronautical operations and concession operations. Incorporating concession operations into the analysis would greatly increase the analytical complexity and would be left for future research. We believe, however, the basic mechanism of the interaction between the airline market structure and the investment/financing of the airport will play the same important role as revealed in the present paper.

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