Market structure and internalization of congestion in air transportation

Kurt Van Dender[1]

Department of Economics
University of California, Irvine
Irvine, CA 92697-5100

kvandend@uci.edu

April 2007

Abstract

We use a simple analytical framework to derive pricing rules for oligpolistic airlines at airports that are served by competitive airlines as well. The pricing rules show how the degree of internalization of marginal congestion costs depends on market structure. The analysis illustrates the importance of selecting an accurate representation of market structure, when making recommendations about the desirability of congestion pricing mechanisms.

[1] I am grateful to Jan Brueckner for comments on an earlier version of this note.

1. Introduction

Congestion in air travel occurs when many flights use scarce airport capacity in a short time span, so that an additional flight increases the time it takes to process another. Airlines may like to concentrate flights in short time intervals for two reasons. First, passenger demand for air travel is higher in peak periods than during the off-peak. Second, many large airports are hubs in one or several airlines' hub-and-spoke network. In order to be attractive to passengers, layovers at hubs should be relatively short, and this induces airlines to organize "flight banks", with congestion as a byproduct. And since flights carry both connecting and local passengers, flight banks at least partly coincide with peak hours.

Congestion results in delays and in reduced reliability of flight schedules, leading to high time costs for passengers and high operating costs for airlines, and perhaps to increased accident risks. Since there are benefits associated with concentrating flights instead of spreading them over the day, and since airport capacity is costly, it is clear that some positive level congestion is desirable. But is congestion inefficiently high, at current capacity levels? The answer depends on whether marginal congestion costs are mostly internal or external. Otherwise said, we need to know if airport operations are more similar to a fully centralized operation (where the network operator makes cost-minimizing decisions on network use, as would be expected in a monopoly) or to a completely decentralized operation (where network users make uncoordinated decisions on network use, like in a road network). To the extent that marginal congestion costs are external, policies to reduce congestion, like tolls, are justified. Tolls reduce demand, so that calls for airport capacity expansion become less pressing.[2] However, if most congestion costs are internal, then capacity expansions are more likely to pass a cost-benefit test, as demand is not far from its optimal level.

This note introduces a simple analytical framework that tells us how much internalization of marginal congestion costs should be expected at a typical large airport in the U.S. The analytical framework is a stylized description of current practice at many large airports, where one or two legacy airlines use the airport to serve local passengers, but also as a hub; the airport is also served by one or more low-cost carriers, like

[2] Of course, capacity expansion may still be desirable if tolls are introduced.

Southwest airlines, which do not offer connecting services, so they serve local passengers only. The airport is congestion-prone,[3] but no efficient scheme of airport charges is in place.[4] Absence of efficient airport charges does not necessarily mean that marginal congestion costs are external, however, as airline fares may reflect marginal congestion costs. The extent to which fares internalize marginal congestion costs depends on the market structure in which the airlines operate. We make the following assumptions on market structure: the airport is served by two airlines that are Cournot competitors (the legacy carriers), and by one or more airlines that price at marginal operating cost (the low cost carriers). The duopolists take account of the competitive airlines' behavior, so they are Stackelberg leaders. Only the duopolist airlines use the airport as a hub.

Our assumptions on market structure are slightly different from those of Brueckner (2002), who considers a Cournot duopoly of airlines, but ignores the presence of competitive airlines. As a consequence, in his Cournot equilibrium, the duopolists restrict runway use through prices that equal marginal social cost plus a markup; no third party can move in and use valuable runway capacity. In our model, the competitive airlines would use that runway space, because it allows them to offer highly valued peak period flights.[5] However, the duopolists are Stackelberg leaders, so they anticipate on the competitor's reaction, and charge lower prices and offer more flights than they would if there were no competitive airlines. In this sense, our model is similar in spirit to that of Harback and Daniel (2005); in their microscopic model, a similar type of Stackelberg interaction is assumed, and the consequence is that marginal congestion costs are not internalized. Our result is less extreme (less internalization than in the Brueckner model, but still some internalization), because we consider elastic demand for flights instead of fixed demand.

We consider two extensions of the basic model. First, in the basic model all congestion occurs on a facility that is shared by all airlines and where space is allocated on a first-come first-serve basis (runways); the extended version allows for carrier-

[3] We ignore congestion caused by the limited capacity of the air traffic control system, as well as spillovers of delays among airports

[4] This is in line with current practice, as airport charges are often weight-based, and are designed to meet break-even constraints rather than reflect marginal costs.

[5] Since peak period slots are relatively valuable, the competitive carriers have an incentive to use them, even though they do not generate hub benefits.

specific congestible facilities (gates, terminals). Since we assume that carriers act as monopolists over this type of facility, congestion costs will be internalized. Considering this feature is relevant, as it allows us to consider the effects of differences among carriers in gate access. High costs for gate access may result from real capacity shortage, but airlines may also experience difficulties acquiring valuable gate slots when a competing airline dominates the airport (FAA/OST, 1999). Second, since many metropolitan areas are served by more than one large airport, we consider the consequences of competition among airports on pricing and internalization of marginal congestion costs. The findings are similar to those of the basic model in the sense that airport competition reduces the extent of internalization of marginal congestion costs, but different in the sense that to the extent that runway space is not shared, this reduces the level of internalization, *ceteris paribus*.

Section two introduces the analytical model, and section three concludes.

2. Airline pricing at congested airports

We first develop the basic model, where duopoly airlines and competitive airlines demand access to a congested runway, in two steps. In section 2.1., we consider the case where the airport is not a hub, and in section 2.2 we introduce the hub function. Next, in section 2.3, we consider extensions where airlines also use specific capacity and where airports compete with other airports. Lastly, section 2.4 summarizes the results of the various model versions (see especially Table 1).

2.1 Joint use of a congestible runway and its impact on fares

When runways are congestible and airports do not charge congestion fees, and when flights request access to airports in an uncoordinated fashion, then marginal congestion costs are external. If there is complete coordination, as would be expected in a monopoly, then there is no externality. With an oligopoly of airlines, each airline internalizes congestion costs imposed on its other flights, but not those imposed on other airlines' flights (Brueckner, 2002). Here, we show that in an oligopoly where oligopolists anticipate on supply decisions by competitive airlines, internalization declines below the level obtained in a pure oligopoly.

We first consider the case where an airport is not a hub, so serves only as the origin or destination of a trip. Assuming symmetry between the origin and destination function allows us to restrict attention to the airport as a trip destination. The airport is served by two identical Cournot duopolists, airlines *A* and *B*, and by one or several airlines that set prices equal to marginal operating costs (airline *C*). When demand functions from all origins are the same, we can normalize the number of origins to one. The inverse demand function for trips with airlines *A* and *B* is $G\left[q_A+q_B\right]$. The inverse demand function for trips with competitive airlines is $H\left[q_C\right]$.[6] Passengers' generalized costs are the sum of fares and time costs, where the latter depend on passenger trip volumes (or flight volumes, given our assumption of fixed occupancy rates).[7] Now consider the profit maximization problem for airport *A*. Since airline *B* is a Cournot competitor, airline *A* takes the trip volumes of airline *B* as given. This means the airline takes account of consumer equilibrium in the duopolistic market. Airline *A* takes the quantity of *B* as given, but takes into consideration that prices adapt to ensure consumer equilibrium. Airline *A* also is a Stackelberg leader with respect to airline *C*; this means it is aware that equilibrium will be obtained in the market for competitive trips, and that airline C prices at marginal cost. Marginal resource costs are fixed for all airlines.[8] Assuming an interior solution, the Lagrangean function for the profit maximization problem for airline *A* becomes:

$$
\begin{aligned}
\Im_A = &\left(p_A - c\right) q_A \\
&+\lambda_1\left(G\left[q_A+q_B\right]-p_A-a\left[q_A+q_B+q_C\right]\right) \\
&+\lambda_2\left(G\left[q_A+q_B\right]-p_B-a\left[q_A+q_B+q_C\right]\right) \\
&+\lambda_3\left(H\left[q_C\right]-p_C-a\left[q_A+q_B+q_C\right]\right)
\end{aligned}
$$

[6] These inverse demand functions imply independence of the demand for duopoly trips and competitive trips. This is clearly unrealistic, as trips with United Airlines and with Southwest Airlines are in fact substitutes. Introducing such substitutability into the model is straightforward, but adds little insight – except that allowing substitution tends to weaken the effect of market power, so weakens the effects that depend on it.

[7] Our congestion model also implies that all passengers have the same value of time. Extending the model to allow for differences in value of time between the duopoly airlines (higher values of time because of a higher share of business travelers) and competitive airlines (lower values of time because of a higher share of leisure travelers) is straightforward and has no effect on fundamental results; the extension is not made here in order to keep results as transparent as possible.

[8] They can be made dependent on volumes with no change to the nature of results.

To capture Cournot competition, we derive first-order conditions with respect to p_A, q_A and p_B. The Stackelberg interaction requires a first-order condition with respect to q_C (not with respect to the competitive price, as that is equal to the fixed marginal resource cost). So we get:

$$\frac{\partial \Im}{\partial p_A} = q_A - \lambda_1 = 0$$

$$\frac{\partial \Im}{\partial q_A} = p_A - c + (\lambda_1 + \lambda_2)(G' - a') + \lambda_3 a' = 0$$

$$\frac{\partial \Im}{\partial p_B} = \lambda_2 = 0$$

$$\frac{\partial \Im}{\partial q_C} = (\lambda_1 + \lambda_2) a' + \lambda_3 (H' - a') = 0$$

These conditions can be combined to find:

$$p_A - c = -q_A G' + a' q_A - \frac{a'}{a' - H'} a' q_A$$

This price rule consists of three components. First, prices depend on the slope of the inverse demand curve, as in the familiar inverse elasticity rule for a supplier with market power. Second, the marginal congestion costs imposed on all demand served by airline *A* is charged. This is the partial internalization result: congestion imposed on other airlines' flights is ignored. Third, however, there is a markdown that is equal to a portion of the marginal congestion costs incurred by airline *A*. This markdown is larger as the runway is more susceptible to congestion (higher *a'*) and as demand for competitive travel is more price elastic (higher absolute value of *H'*). Partial internalization (second component) occurs because internalization helps the duopolist keep prices high, as internalization leads to lower time costs, and this is valued by travelers. The third component can be interpreted as follows: the presence of competitive airlines forces the duopolists to internalize a smaller portion of congestion costs, because such internalization does not fully translate into reduced time costs for their customers, as it is partly undone by increased demand in the competitive market. This third component is larger as the congestion function is steeper, because then increased time costs strongly discourage travel, and there is less of a need to increase fares. It also is larger as demand in the competitive market is more elastic, because then the impact of not internalizing on competitive demand is comparatively large.

2.2 Joint use of a congestible runway in a hub airport

We extend the previous model with a highly stylized model of an airport's hub function. Specifically, we allow the duopolists to use the airport as a hub, but not the competitive airlines. The demand function facing a duopolist used in section 2.1 represents demand for non-hub travel, i.e. it is demand for which the airport is the destination. This demand originates from any number of origins, but demand functions are identical at each origin, and we normalize the number of origins to one, and denote the demand function G_o. In order to capture the fundamental benefits from hub operations, we make the demand for hub traffic per airline (from the single origin, or alternatively from all identical origins) dependent on the number of destinations served by that airline at the airport ($N_i, i = A, B$). Demand for all final destinations is taken to be identical, so total hub demand per airline is the product of demand in N_i+1 markets[9]; demand in each market is denoted G_h. Runway congestion now depends on airline demand, but also on the number of destinations served, so as to capture the cost of flight banking in terms of congestion. In addition, we introduce a cost component that depends on the number of flights ($c[N_i]$, $i=A,B$), reflecting the fact that the costs are defined on the network level; we also retain a constant marginal cost per passenger (m_i, $i=A,B$).

The Lagrangian for this problem is slightly more complicated, as each duopolist now serves non-hub and hub markets. It takes the following form:

$$\begin{aligned}
\Im_A = {} & \left(p_{o,A} - m_A\right) q_{o,A} + \left(N_A + 1\right)\left(p_{h,A} - m_A\right) q_{h,A} - c\left[N_A\right] \\
& + \lambda_1 \left(G_o\left[q_{o,A} + q_{o,B}\right] - p_{o,A} - a_o\left[N_A + N_B, q_{o,A} + q_{o,B} + q_{h,A} + q_{h,B} + q_C\right]\right) \\
& + \lambda_2 \left(G_o\left[q_{o,A} + q_{o,B}\right] - p_{o,B} - a_o\left[.\right]\right) \\
& + \lambda_3 \left(N_A + 1\right)\left(G_h\left[q_{h,A} + q_{h,B}\right] - p_{h,A} - a_h\left[.\right]\right) \\
& + \lambda_4 \left(N_A + 1\right)\left(G_h\left[q_{h,A} + q_{h,B}\right] - p_{h,B} - a_h\left[.\right]\right) \\
& + \lambda_5 \left(H\left[q_C\right] - p_C - a_0\left[.\right]\right)
\end{aligned}$$

[9] N_i is an integer, but in what follows we will treat it as a continuous variable.

Similar to the previous problem, we consider first-order conditions with respect to $p_{o,A}, q_{o,A}, p_{o,B}, p_{h,A}, q_{h,A}, p_{h,B}, q_C$. In addition, the number of destination is endogenous, requiring a first-order condition with respect to N_A, while N_B is taken as given.[10] Denoting the derivative of time costs with respect to passenger volumes as a_{oq}' and a_{hq}', and those with respect to the number of destinations as a_{oN}' and a_{hN}', the first order conditions read as follows:

$$\frac{\partial \Im}{\partial p_{o,A}} = q_{o,A} - \lambda_1 = 0 \Rightarrow q_{o,A} = \lambda_1$$

$$\frac{\partial \Im}{\partial p_{o,B}} = \lambda_2 = 0$$

$$\frac{\partial \Im}{\partial p_{h,A}} = (N_A + 1) q_{h,A} - (N_A + 1)\lambda_3 = 0 \Rightarrow q_{h,A} = \lambda_3$$

$$\frac{\partial \Im}{\partial p_{h,B}} = \lambda_4 = 0$$

Using these results to simplify the remaining first-order conditions leads to:

$$\frac{\partial \Im}{\partial q_{o,A}} = p_{o,A} - m_A + q_{o,A}\left(G_o' - a_{oq}'\right) + q_{h,A}(N_A + 1)a_{hq}' + \lambda_5 a_{oq}' = 0$$

$$\frac{\partial \Im}{\partial q_{h,A}} = (N_A + 1)\left(p_{h,A} - m_A\right) + a_{oq}' q_{o,A} + \left(G_h' - a_{hq}'\right) q_{h,A}(N_A + 1) - \lambda_5 a_{oq}' = 0$$

$$\frac{\partial \Im}{\partial q_C} = a_{oq}' q_{o,A} + a_{oq}' q_{h,A} + \lambda_5\left(a_{oq}' - H'\right) = 0$$

$$\frac{\partial \Im}{\partial N_A} = \left(p_{h,A} - m_A\right) q_{h,A} - c' - a_{oN}' q_{o,A} - (N_A + 1) a_{hN}' q_{h,A} + \lambda_5 a_{oN}'$$
$$+\lambda_3\left(G_h\left[q_{h,A} + q_{h,B}\right] - p_{h,A} - a_h[.]\right) = 0$$

The pricing rules in the non-hub and hub markets are straightforward extensions of those obtained in the no-hub model. The only difference is that prices reflect

[10] The model focuses on the trade off between adding more destinations and creating more congestion. We ignore increased hub benefits due to shorter layovers following from higher flight frequencies.

congestion costs in both hub and non-hub markets, and that account is taken of the number of non-hub markets where necessary.

$$p_{o,A} - c = -q_{o,A}G_o' + a_{oq}' q_{o,A} + \left(N_A + 1\right) a_{hq}' q_{h,A} - \frac{a_{oq}'}{a_{oq}' - H'} a_{oq}' \left(q_{o,A} + q_{h,A}\right)$$

$$p_{h,A} - c = -q_{h,A}G_h' + a_{hq}' q_{h,A} + a_{oq}' \frac{q_{o,A}}{N_A + 1} - \frac{a_{oq}'}{a_{oq}' - H'} a_{oq}' \frac{\left(q_{o,A} + q_{h,A}\right)}{N_A + 1}$$

Using the expression for λ_5 implied by the first-order condition with respect to q_c, and observing that the last expression on the right-hand side of the condition with respect to N_A is equal to zero, the following expression for the optimal choice of the number of hub destinations results:

$$N_A = \frac{p_{h,A} - m_A}{a_{hN}'} - \frac{c_N' + a_{oN}' q_{o,A} + a_{hN}' q_{h,A}}{a_{hN}' q_{h,A}} + \frac{a_{oq}'\left(q_{o,A} + q_{h,A}\right)}{a_{hN}' q_{h,A}} \frac{a_{oN}'}{a_{oq}' - H'}$$

The first two terms on the right-hand side would also appear in a pure duopoly, i.e. if there were no competitive airlines. The first term says that large markups in the hub market lead to more hub destinations being offered. However, when time costs for hub travel increase strongly with the number of destinations, this reduces the number of destinations. The numerator of the second term equals the marginal social cost of adding a destination; when that cost is large, fewer destinations are offered. The denominator is the marginal congestion cost incurred by hub travelers when a destination is added. When that cost is large, the ratio is small, meaning that more destinations will be offered. The intuition is that the congestion costs themselves will restrict demand, an effect that can be offset partially by adding more destinations (where the upper portion of the demand curve can be served, so the impact of high congestion costs is limited). The third term on the right-hand side would not appear in a pure duopoly model, so it captures the impact of the competitive airlines' presence on the duopolists choice of the number of destinations. The term is positive and it is larger (a) when marginal congestion costs caused by higher passenger volumes are larger, for a given number of destinations, and (b) when the marginal congestion costs caused by additional destinations and incurred by hub traffic are smaller. Furthermore, when congestion incurred by non-hub travelers is very sensitive to the number of destinations, this increases the number of destinations, because a larger downward effect on non-hub travel demand needs to be compensated. But when congestion incurred by non-hub travelers is very sensitive to passenger volumes, this reduces the number of destinations. Similarly, a larger absolute value for *H'*, meaning more elastic demand from the competitive airlines, reduces the number of destinations.

2.3 Extensions

2.3.1 Airline-specific congestible infrastructure

In the basic model, the congestible infrastructure is jointly used by all airlines, as is the case for runways. Airlines also use gates to access terminals, however, and most such infrastructure is often directly controlled by each airline separately. Like runways, gates are subject to congestion. Adding this type of infrastructure to the basic model is straightforward: an extra term is added to passengers' generalized price, to capture the time cost of using gates[11]; this extra time cost depends on airlines' own travel volume. So the generalized price of a trip with airline *A* now reads:

$$g_A \equiv p_A + a\left[q_A + q_B + q_C\right] + t_A\left[q_A\right].$$

Since the marginal costs of gate use are internal to each airline, they will be internalized through fares, resulting in the addition of a term like $t_A' q_A$ to the pricing rules. While this extension is of no particular analytical interest, it points to a potentially important feature of an empirical analysis. While airlines may have equal access to runways in most airports, there can be large asymmetries in gate access. It is well-known that dominant airlines can influence airport decisions on gate allocation (e.g. through contracts on exclusive or restricted gate use). Dresner et al. (2002) show that gate constraints affect yields, in the sense that gate constraints are barriers to entry and so increase yields for incumbents (while not leading to more entry). From our point of view,

[11] A similar extension could be made for airlines' operating costs.

restricted gate access translates into limited capacity and high congestion costs for airlines facing the restrictions. If this interpretation is reasonable, our model applies and one would expect higher fares and more congestion at the same airport for airlines affected by the gate access restrictions.

2.3.2 Multi-airport regions: the impact of airport competition

Two airports, one duopoly airline per airport

Many airports are located in metropolitan areas served by several substitutable airports.[12] Assuming for simplicity that the airports are perfect substitutes, we can easily modify the basic model to take account of airport competition. For simplicity, we first abstract from duopolistic interaction within each airport and from hub functions, obtaining a model where airline *A* serves airport *A* and airline *B* serves airport *B*, and both airports are served by one or more competitive airlines (see below for pricing rules that take account of duopoly structures within each airport). The only difference between this model and the basic model is that the duopolists now use separate congestible infrastructures (runways), rather than sharing the same one. The model is formally identical to the one described in Van Dender (2005), p. 352-353.[13] The following pricing rule is obtained (this is a slightly rearranged version of equation (24) in Van Dender (2005):

$$p_A - c = -G' q_A + a_A' q_A \left(1 + \frac{H' - a_B'}{a_A' a_B' - H'\left(a_A' + a_B'\right)} a_A' \right)$$

Like in the basic model, the presence of competitive airlines reduces the extent of internalization, since the second term of the bracketed expression is between -1 and 0. Comparing the basic and multi-airport rule is easier when it is assumed that $a_A' = a_A' = a'$ (at least in equilibrium), in which case the multi-airport rule reduces to:

$$p_A - c = -G' a' + a' q_A \left(1 - \frac{a' - H'}{a' - 2H'} \right) = -G' a' + a' q_A \frac{H'}{2H - a'}$$

[12] Roughly 40% of the largest US airports compete with a nearby large airport (Van Dender, 2006).
[13] In this paper, we assume Cournot competition. Van Dender (2005) shows that under Bertrand competition, the presence of competitive traffic prevents all internalization of marginal congestion costs.

Rewriting the rule for the basic (single airport) model in the same form gives:

$$p_A - c = -q_A G' + a' q_A - \frac{a'}{a' - H'} a' q_A = -q_A G' + a' q_A \frac{H'}{H' - a'}$$

Comparison of the factors by which the marginal congestion costs are multiplied shows that internalization is more limited in the multi-airport case (since the denominator for that case in bigger in absolute terms). The difference becomes smaller, and the portion of external costs that is internalized becomes larger, as *H'* decreases (i.e. *H'* becomes a larger negative number, so its absolute value increases, meaning that demand in competitive markets becomes less elastic with respect to the generalized price, i.e. the inverse demand function is steeper).

Two airports, two duopoly airlines per airport

We extend the model with two airports by considering the case where each airport is served by two oligopolists, and different oligopolists serve the different airports. Each airport is served by competitive airlines as well. So there are two airports (*A* and *B*), four oligopoly airlines (*A1*, *A2*, *B1*, and *B2*), and a competitive airline *C*. We abstract from hub traffic. The first-order conditions for profit maximization result in the following price rule for airline *A1*:

$$p_{A1} - c = -G' q_{A1} + a_A' q_{A1} \left(1 + \frac{H' - a_B'}{a_A' a_B' - H' \left(a_A' + a_B' \right)} a_A' \right)$$

This rule is the same as the one for the one airline per airport case, except that the airline only internalizes congestion costs imposed on its own flights.

Two airports, two duopoly airlines serve both airports

We modify the model with two airports by considering the case where each airport is served by two oligopolists, but now there are two oligopolists each of which serve both airports. Each airport is served by competitive airlines as well. So there are two airports (*A* and *B*), two oligopoly airlines (*1* and *2*), and a competitive airline *C*. We abstract from hub traffic. The first-order conditions for profit maximization result in the following price rule at airport *A* for airline *1*:

$$p_{A1} - c = -G'\left(q_{A1} + q_{B1}\right) + a_A' q_{A1} \left(1 + \frac{H' - a_B' - \dfrac{a_B' q_{B1}}{a_A' q_{A1}}}{a_A' a_B' - H'\left(a_A' + a_B'\right)} a_A' \right)$$

$$= -G'\left(q_{A1} + q_{B1}\right) + a_A' q_{A1} \left(1 + \frac{H' - a_B'}{a_A' a_B' - H'\left(a_A' + a_B'\right)} a_A' \right)$$

$$+ \left(\frac{a_B' q_{B1}}{a_A' a_B' - H'\left(a_A' + a_B'\right)} (-H') a_A' \right)$$

The only change with respect to the four airline case is that the extent of internalization by airline 1 at airport *A* now depends on the marginal congestion costs incurred by airline 1 and airport *B*: the last term on the right-hand side is positive, so that more congestion at airport *B* leads to more internalization at airport *A*.

2.4 Summary

Table 1 summarizes the main model features and the pricing rules for the various versions developed in the previous sections.

Table 1 Pricing rules for various model versions

Model version	**Airport labels**	**Airline labels**	**Congestion function**	Pricing rule
Single airport, 2 duopoly airlines, competitive airline	-	A, B, C	$a\left(q_A+q_B+q_C\right)$	$p_A-c=-q_A G'+a'q_A-\frac{a'}{a'-H'}a'q_A$
Two airports, single duopoly airline per airport, competitive airline	A, B	A, B, C	$a_A\left(q_A+q_{AC}\right)$ $a_B\left(q_B+q_{BC}\right)$	$p_A-c=-G'q_A+a_A'q_A\left(1+\frac{H'-a_B'}{a_A'a_B'-H'\left(a_A'+a_B'\right)}a_A'\right)$
Two airports, duopoly per airport, four oligopoly airlines, competitive airline	A, B	A1, A2, B1, B2, C	$a_A\left(q_{A1}+q_{A2}+q_{AC}\right)$ $a_B\left(q_{B1}+q_{B2}+q_{BC}\right)$	$p_{A1}-c=-G'q_{A1}+a_A'q_{A1}\left(1+\frac{H'-a_B'}{a_A'a_B'-H'\left(a_A'+a_B'\right)}a_A'\right)$
Two airports, duopoly per airport, four oligopoly airlines, competitive airline	A, B	1, 2, C	$a_A\left(q_{A1}+q_{A2}+q_{AC}\right)$ $a_B\left(q_{B1}+q_{B2}+q_{BC}\right)$	$p_{A1}-c=-G'\left(q_{A1}+q_{B1}\right)+a_A'q_{A1}\left(1+\frac{H'-a_B'}{a_A'a_B'-H'\left(a_A'+a_B'\right)}a_A'\right)+\left(\frac{a_B'q_{B1}}{a_A'a_B'-H'\left(a_A'+a_B'\right)}(-H')a_A'\right)$

3. Concluding remarks

The various model versions of the previous section all suggest that duopolists partly internalize congestion costs through fares. At the level of an airline – airport combination, the basic rule is that a duopoly airline *at most* internalizes congestion costs imposed on its own flights, but that the degree of internalization declines when competitive airlines are present. This "markdown" depends on how congestible the infrastructure is (a higher slope of the congestion function leads to more internalization) and on the elasticity of demand for competitive travel (when that demand becomes less elastic, the duopolists are less concerned about competitive airlines undoing their congestion management). The same mechanisms are at work in single and multi-airport settings, but the markdown is larger in the multi-airport case.

The fundamental assumptions guiding the analytical model are (a) that airports charge no congestion-related fees, but that (b) duopoly airlines take account of congestion when deciding on fares and they act as Cournot competitors, and (c) competitive airlines do not charge congestion-dependent fares. The first of these assumptions is reasonable, as airport charges are in fact independent from congestion levels. The second assumption is defensible because many large airlines have market power and use it to extract consumer surplus. The only reason why the duopoly airlines in our model are interested in internalizing congestion costs, is because it allows them to charge higher prices and increase profits. The Cournot assumption is harder to justify and it is restrictive, since with Bertrand interaction there is no internalization of congestion costs incurred by passengers, when there are competitive airlines (Van Dender, 2005). We note that the Cournot assumption is routinely made in related literature (e.g. Brueckner, 2002; Pels and Verhoef, 2004). The third assumption is restrictive as well. Our term "competitive airlines" refers to low cost carriers that seem to follow pricing rules which differ from those of legacy carriers, and which seem more cost-based that market-power oriented. Our assumption of marginal cost pricing could be replaced with one of a markup that does not depend on congestion, so the restrictive assumption is that the competitive airlines do not internalize passenger-related congestion (they do take account of the effects of congestion on operating costs, but we have not made that explicit in our model). Fundamentally, this means that we assume that the low-cost airlines do not engage in yield management that relies on passengers' value of time.

References

Brueckner J.K., 2002, Airport congestion when carriers have market power, *American Economic Review*, 92, 1357-1375

Dresner M., R. Windle and Y. Yao, 2002, Airport Barriers to Entry in the US, *Journal of Transport Economics and Policy*, 36, 2, 389-405

FAA/OST, 1999, *Airport business practices and their impact on airline competition*, FAA/OST Task Force Study

Harback and J. Daniel, 2005, (When) do hub airlines internalize their self-imposed congestion delays?, Working paper, University of Delaware

Pels E. and E.T. Verhoef, 2004, The economics of airport congestion pricing, *Journal of Urban Economics*, 55, 257-277

Van Dender K., 2005, Duopoly prices under congested access, *Journal of Regional Science*, 45, 2, 343-362

Van Dender K., 2006, Determinants of fares and operating revenues at U.S. airports, forthcoming in the *Journal of Urban Economics*