The Economics of Airport Congestion

by J.K. Brueckner

Flight delays are a problem world-wide.

Summer-2007 delays in the US were the worst in 12 years.

European delays are also severe.

Solutions?

Build more runways? Cost is in the $ billions.

Use price mechanism by levying airport congestion tolls?

Cost is zero since weight-based landing-fee system is already in place at most airports. Must only change billing software.

Fees must vary over the day to reflect the airport's current congestion level.

Daniel (1995) shows that congestion relief from toll system at Minneapolis airport matches that from 30% increase in capacity!

Road pricing is gaining new acceptance (London, Stockholm)

The same thing could happen with price-based approaches to airport congestion, despite current airline opposition.

FAA recently gave airports permission to set time-varying landing fees, but no adoption yet.

FAA also proposed to randomly reclaim a small number of slots from the airlines each year and auction them, but airlines blocked proposal in court.

If airport congestion pricing were adopted, does road pricing model need adjustment when applied to airports?

Recent work argues yes, because of internalization of congestion:

- Airlines take account of congestion imposed on themselves
- Need to be charged only for congestion imposed on other carriers
- Implies lower tolls than required by road pricing formula

Possible internalization of congestion first recognized by Daniel (1995).

Idea explored further by Brueckner (2000, 2005) and then by other authors. Presentation here draws on simplified models in Brueckner and Van Dender (2008) and Brueckner (2009).

Lecture explains internalization idea, then considers theoretical challenges, and also considers empirical evidence.

Use of slot system in place of tolls is then considered.

Basic Model

2 airlines, 1 congested airport, peak and off-peak collapsed into single period, which is always congested.

Perfectly elastic demand for air travel, ruling out exercise of market power (relaxed later).

Implies fixed "full price" p, which includes fare plus passenger time costs from congestion.

f_1 and f_2 are flight volumes for the two airlines.

Time cost per passenger is $t(f_1 + f_2)$, with $t', t'' > 0$ over positive range.

So fare is $p - t(f_1 + f_2)$.

Falls with an increase in total flights because of higher time costs (consistent with empirical evidence in Forbes (2008)).

Letting s denote seats per flight, revenue for carrier i is

$$[p - t(f_1 + f_2)]sf_i, \quad i = 1, 2.$$

Airline cost per flight is $[\tau s + g(f_1 + f_2)]$, with $g', g'' > 0$ over positive range.

So airline profits are written

$$\pi_i \;=\; [p - t(f_1 + f_2)]sf_i \;-\; [\tau s + g(f_1 + f_2)]f_i, \quad i = 1, 2,$$

and normalizing s to equal 1, profits are rewritten as

$$\pi_1 = (p-\tau)f_1 - c(f_1+f_2)f_1$$

$$\pi_2 = (p-\tau)f_2 - c(f_1+f_2)f_2,$$

where

$$c(f_1+f_2) \equiv st(f_1+f_2) + g(f_1+f_2)$$

gives passenger plus airline congestion cost per flight $(c', c'' > 0)$.

Social optimum

Since consumer surplus is zero, social optimum maximizes combined profits of the carriers. Condition for f_i is

$$p \;-\; \tau \;-\; [(f_1 + f_2)c\,' + c] \;\;=\;\; 0,$$

and solution is symmetric.

Flight volume is optimal when the full price p equals the social marginal cost of a flight.

Cournot behavior

With Cournot behavior, each airline maximizes profit viewing the other's flight volume as fixed. Condition for airline 1 is

$$p \;-\; \tau \;-\; [f_1 c' + c] \;\;=\;\; 0.$$

Congestion impact on own flights ($f_1 c'$) is taken into account (internalized).

But congestion imposed on airline 2 ($f_2 c'$) is ignored. Requires charging airline 1 a toll of $f_2 c'$ per flight.

Given symmetry, toll is $T = f^* c'(2f^*)$, where f^* is the common optimal flight volume. Can be written as

$$T = f^* c'(2f^*) = \frac{1}{2}[2f^* c'(2f^*)] = \frac{1}{2}\text{MCD}^*,$$

where MCD^* is the marginal congestion damage per flight.

So each carrier is charged a toll equal to MCD^* times its airport flight share of $1/2$.

Atomistic congestion toll from road pricing equals 100 percent of MCD^* and is too large.

Asymmetric carriers

To generate asymmetry, consider two asymmetric carriers, serving separate markets with different full prices, $p_1 > p_2$.

For model to work right, need decreasing returns, with cost per flight τ increasing in the number of flights ($\tau(f)$, with $\tau' > 0$).

For carrier 1, social optimum characterized by

$$p_1 - \tau(f_1) - f_1\tau'(f_1) - c(f_1 + f_2) - (f_1 + f_2)c'(f_1 + f_2) = 0$$

As before, $f_2 c'(f_1 + f_2)$ is missing from profit-max. condition.

At both optimum and equilibrium, $f_1 > f_2$ holds. Since carrier 1 then internalizes more congestion, tolls must be

$$T_1 \quad = \quad (1-\phi)\mathrm{MCD}^* \quad < \quad T_2 \quad = \quad \phi\,\mathrm{MCD}^*,$$

where ϕ is carrier 1's flight share at optimum.

Bigger carrier internalizes more congestion, gets a lower toll (controversial).

Imperfectly elastic demand

Means full price is $p = d(f_1 + f_2)$, with $d' < 0$.

Flight reduction raises fare, offsetting tendency to excessive flights from uninternalized congestion. Optimum-equilibrium comparison now ambiguous.

If toll is only instrument, could be positive or negative (Pels and Verhoef (2004)).

Better idea is to pay subsidy at market level to deal with market power, charge toll at airport level (two instruments).

Empirical tests

Compare two airports with same level of total operations per year.

One is concentrated, with a dominant carrier, while the other is less concentrated, having many smaller carriers.

Since the big carrier will internalize most of the congestion it creates, flight operations at the first airport will be arranged to limit congestion.

Not so at less concentrated airport.

Implication is that, holding total operations constant, delays should fall as airport concentration rises.

Leads to following regression equation:

$$\begin{aligned} Delays = \alpha \ &+ \ \beta * Concentration \ + \ \gamma * Hub \\ &+ \ \delta * Operations \ + \ \theta * Other \ + \ error \end{aligned}$$

Brueckner (2002) estimated using aggregate data for small sample, Mayer and Sinai (2003) using individual flight data.

Found negative concentration effect and positive hub effect.

Confirms internalization, but Daniel (1995) and Daniel and Harback (2008) use a different approach to reach different conclusion.

They look at hourly data on flight patterns at individual hub airports, and compare to predictions of a simulation model.

If the hub carrier internalizes congestion, then the model predicts relatively flat traffic "banks," without much peaking.

Data show banks that are too peaked to be consistent with internalization.

Authors conclude that internalization doesn't occur, with hub carrier behaving "atomistically."

Result, they argue, is due to behavior of "competitive fringe" airlines, who view congestion as uninfluenced by own flight choices.

Can show result in a modified model where Stackelberg leader anticipates response of fringe carriers, who act competitively.

Turns out that tolls for both leader and fringe must then equal atomistic value, MCD* (charge 100 percent of congestion damage).

Which approach is right is still hotly debated.

Slot sales

What if slot-based system is used to manage congestion rather than congestion tolls?

Consider slot-sale regime, where carriers can buy as many slots as they want from airport authority at a common price z.

Fails to duplicate impact of asymmetric tolls.

Overpenalizes large carrier and underpenalizes small carrier for congestion.

Tends to make f_1 too small and f_2 too large.

High-priced markets underserved and low-priced markets over-served under slot sales.

Works fine when carriers are symmetric or don't internalize congestion.

Above ideas developed in Brueckner (2009) and Verhoef (2010).

Slot trading

Under a different regime, airport authority distributes slots free of charge to the carriers, who then trade at a price w to adjust flight volumes (setup follows Verhoef (2010)).

Slots allocated to the two carriers are n_1 and n_2, and carrier 1's profit is

$$\pi_1 \quad = \quad [p - \tau(f_1)]f_1 \;-\; c(n)f_1 \;-\; w(f_1 - n_1).$$

Key element: carrier understands that total flight volume remains constant when it trades a slot with the other carrier.

The equilibrium condition for carrier 1 is

$$p_1 \;-\; \tau(f_1) \;-\; f_1\tau'(f_1) \;-\; c(n) \;\;=\;\; w$$

and similarly for 2 ($f_1 + f_2 = n_1 + n_2 = n$ also holds).

Expression up to $c(n)$ is set equal to a common value.

Since above property holds at optimum, slot trading is efficient.
At optimum, $w = \mathrm{MCD}^*$.

Not true under slot sales, where carrier's slot purchase is expected to affect total flight volume.

Same analysis shows that a slot auction is also efficient.

Problem: number of slots to distribute or auction (n) still must be chosen efficiently.

Conclusions

A key conclusion is that slot-trading or slot-auctions are equivalent to a first-best regime of carrier-specific congestion tolls.

Since tolls must be inversely related to carrier size (a political non-starter), these other regimes are better.

Also, since carriers strongly resist any cost-increasing policy changes, a slot-trading regime where they get slots for free, looks best.

Caveat: Daniel claims that slot system is too crude to optimize airport use, which requires minute-by-minute adjustment in cost of access.

Remaining issue under slot-trading regime: how to choose the number of slots to distribute?

Excessive conservatism should be avoided (overbooking of airport needed).

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