The economics of airport congestion pricing

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Outline

- Background
- Literature review
- Model
- Numerical experiment
- Conclusion

Background

- Airport congestion/scarce capacity
- How to allocate slots?

- Pricing.
- Weight based fees plus surcharges (noise, night, distance).
- Congestion pricing.

Literature

- Road pricing:
  - Atomistic users
  - Regulator (government, road owner) sets toll
- Airport pricing:
  - atomistic users (passengers)
  - non-atomistic users (airlines)
  - airport prices capacity/service
  - regulator (e.g. slot coordination)

Literature

- Brueckner (2001, 2003)
  carriers internalize their “own” congestion;
  toll=(1-flight share)*(congestion damage extra flight)
- Daniel (1995)
  Vickrey style bottleneck model, stochastic queuing, traffic patterns at Minneapolis/St. Paul consistent with atomistic behavior
- Oum and Zhang (1990)
  Cost recovery, capacity expansion

Objective

- Evaluate welfare economic effects of welfare maximizing tolls
  congestion
  market power
- Evaluate welfare economic effects of pure congestion tolls
  congestion; toll=(1-flight share)(damage)

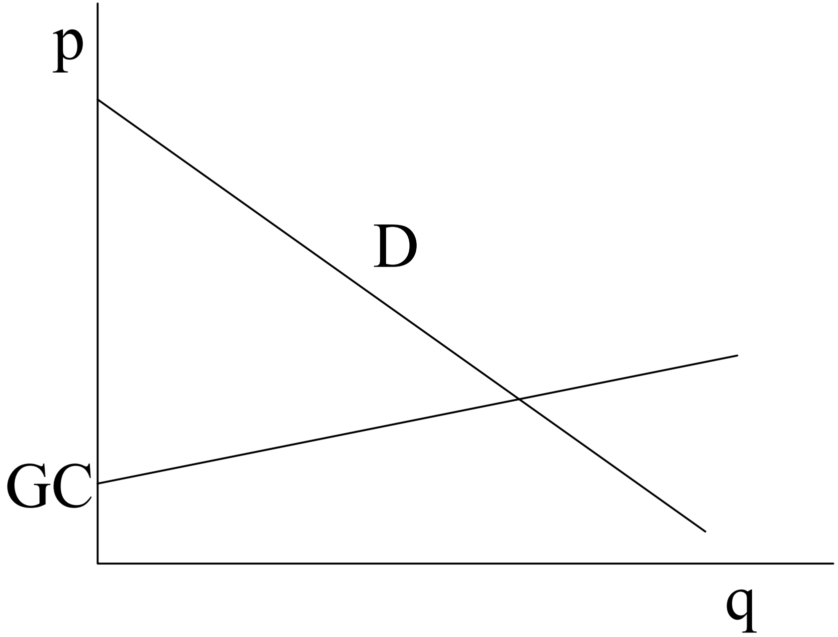
Model

- Linear inverse demand: $D=\alpha-\beta(Q_1+Q_2)$
- Linear generalized cost: includes fare and congestion $gc=p+vot_p\phi_p$
- Constant load factor λ
- Constant cost per flight and passenger:

$$q_i\left[\frac{c^f+2t+2vot_l\phi_l}{\lambda}+c^q\right]-F$$

Model

- Passenger equilibrium follows from Wardrop's equilibrium conditions (inverse demand equals generalized cost in equilibrium); yields optimal fare.



Model

- Network configuration (symmetry):

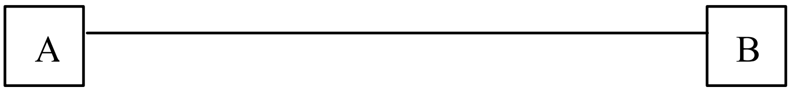


Figure 1 *Network configuration*

Model

- Airlines maximize profits with respect to the number of passengers (Cournot oligopoly):

$$\max_{q_i} \pi_i = \left[\alpha - \beta(q_1 + q_2) - 2vot_p\Phi_p\right]q_i - q_i\left[\frac{c^f + 2t + 2vot_l\Phi_l}{\lambda} + c^q\right] - F$$

Model

- Regulator maximizes welfare:

$$\max_{q_i} \varpi_G = \int_0^{q_1+q_2} (\alpha - \beta x)dx - 2(q_1 + q_2)\Phi_p - (q_1 + q_2)\left[\frac{1}{\lambda_i}\left(c^f + vot_l\Phi_l\right) + c^q\right]$$

Model: first-order conditions

- $$\frac{\partial \varpi_G}{\partial q_i} - \frac{\partial \pi_G}{\partial q_i} = -q_{-i}\frac{2\eta_h}{\lambda}\left(vot_p + \frac{vot_l}{\lambda}\right) + q_i\beta + \frac{2t}{\lambda}$$

  » uninternalized congestion — market power — toll

- Welfare optimal toll:

$$t^w = \frac{\lambda}{2}\left[q_{-i}\frac{2\eta_h}{\lambda}\left(vot_p + \frac{vot_k}{\lambda}\right) - q_i\beta\right]$$

Model: first-order conditions

- Welfare maximizing toll negative when

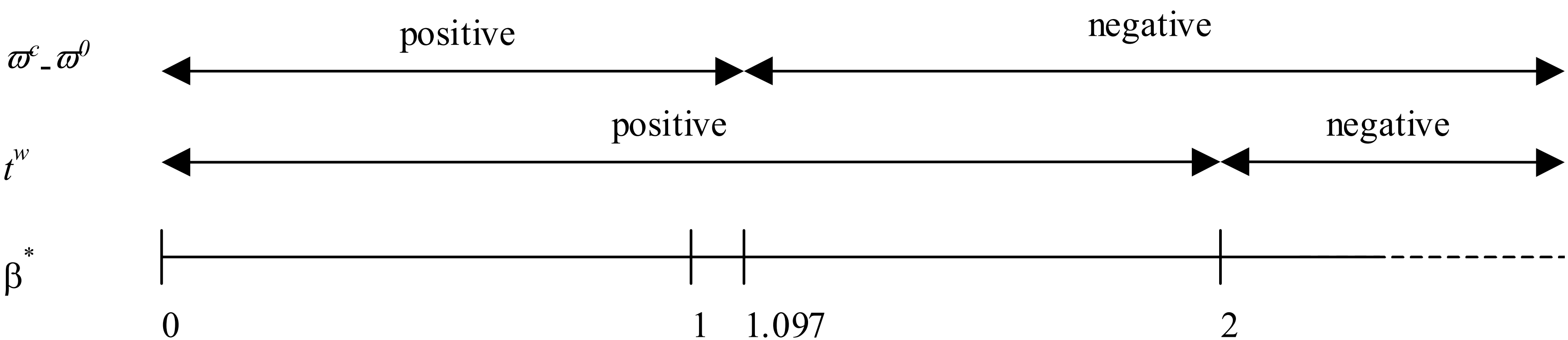
$$\beta^* \left(= \beta / \eta_h \left(vot_p \lambda + vot_k\right) / \lambda^2\right) > 2$$

- Optimal congestion toll

$$t^c = q_{-i}\eta_h\left(vot_p + \frac{vot_k}{\lambda}\right)$$

Model: comparison of tolls

- How do welfare economic performances of the two tolls compare?



Model: symmetry, simulations

- Inputs:

Demand characteristics				*Airline characteristics*				*Node characteristics*	
α	5000	vot_p	50	c^f	100000	λ	200	η	0.5
β	1			c^q	100	vot_l	500		

Table 2. Parameter values for the symmetric numerical model

	q	generalized costs		ε	welfare effects		
		fare	congestion		consumer surplus	profits	welfare
airline 1	1162	2096	581	1.15	$1.35 \cdot 10^6$	$0.70 \cdot 10^6$	$2.05 \cdot 10^6$
airline 2	1162	2096	581	1.15	$1.35 \cdot 10^6$	$0.70 \cdot 10^6$	$2.05 \cdot 10^6$
total	2324				$2.70 \cdot 10^6$	$1.40 \cdot 10^6$	$4.10 \cdot 10^6$

Table 3. Equilibrium outputs and welfare: no toll

	q	generalized costs		ε	toll	welfare effects		
		fare	congestion			consumer surplus	profits	welfare
airline 1	1443	1393	721	0.73	$-0.11 \cdot 10^6$	$2.08 \cdot 10^6$	$1.63 \cdot 10^6$	$2.17 \cdot 10^6$
airline 2	1443	1393	721	0.73	$-0.11 \cdot 10^6$	$2.08 \cdot 10^6$	$1.63 \cdot 10^6$	$2.17 \cdot 10^6$
total	2886	2786				$4.16 \cdot 10^6$	$3.26 \cdot 10^6$	$4.34 \cdot 10^6$

Table 4. Equilibrium outputs and welfare: first-best welfare maximizing toll

	q	generalized costs		ε	toll	welfare effects		
		fare	congestion			consumer surplus	profits	welfare
airline 1	1086	2284	543	1.30	28519	$1.18 \cdot 10^6$	$0.49 \cdot 10^6$	$1.98 \cdot 10^6$
airline 2	1086	2284	543	1.30	28519	$1.18 \cdot 10^6$	$0.49 \cdot 10^6$	$1.98 \cdot 10^6$
total	2172					$2.36 \cdot 10^6$	$0.98 \cdot 10^6$	$3.96 \cdot 10^6$

Table 5. Equilibrium outputs and welfare: pure congestion toll

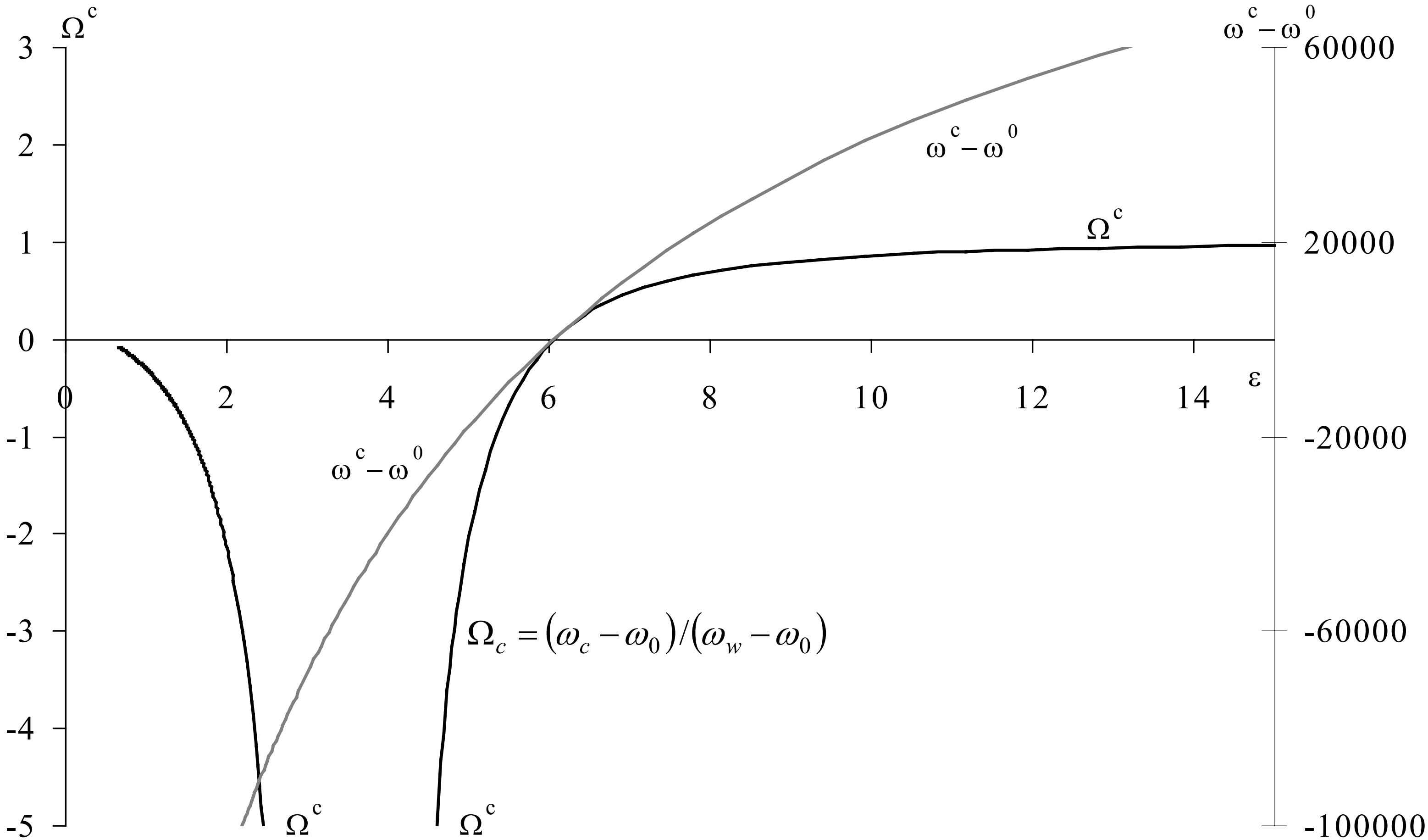


Figure 2. Welfare effects of pure congestion tolling t^c

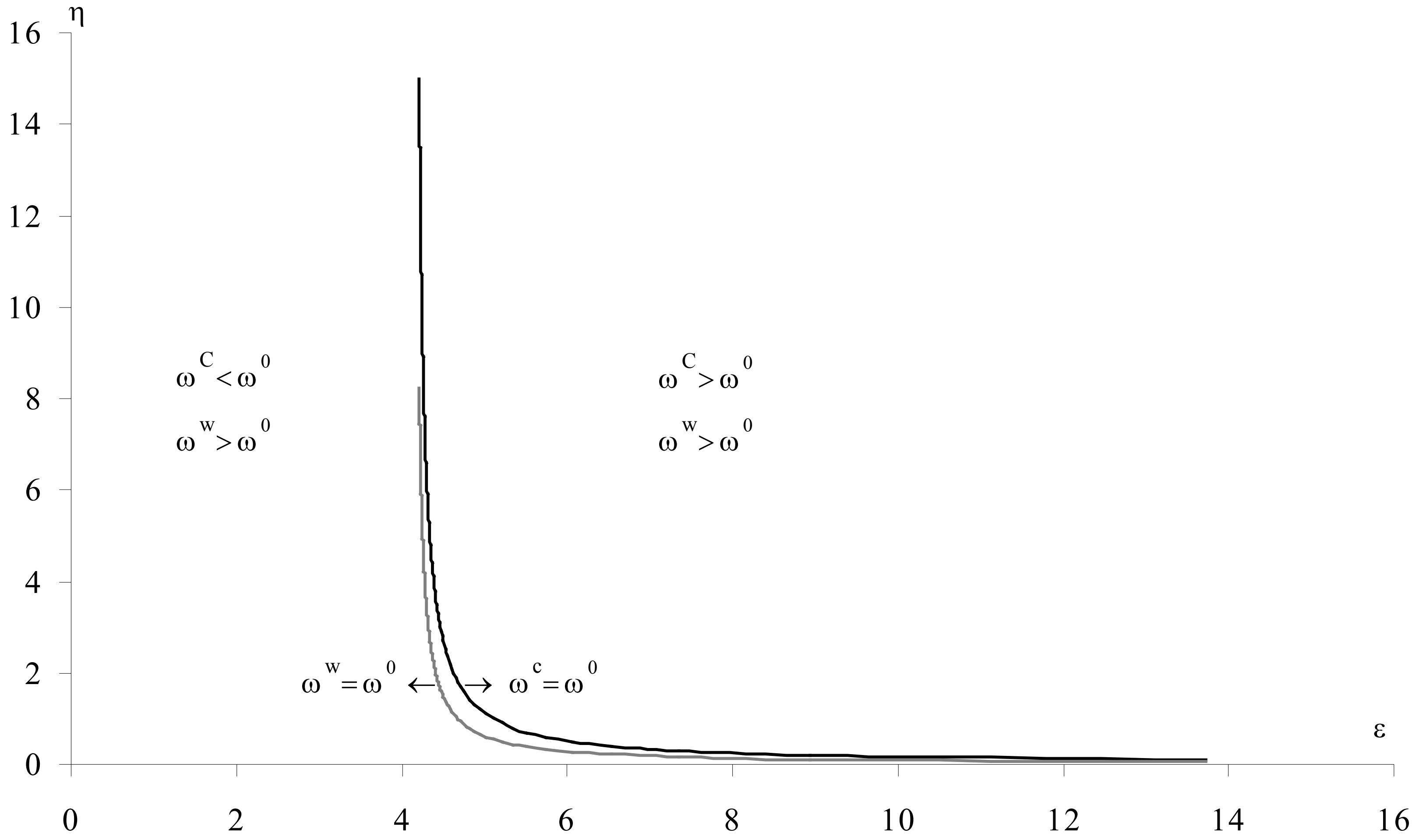


Figure 3. Optimality of pure congestion tolling t^c

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Model: asymmetry

- When airlines are asymmetric, graphs are similar.
- One airline (with highest cost per passenger) pushed out of market.

Conclusions so far

- Pure congestion toll unlikely to be optimal.
- Welfare maximizing toll can be negative.
- When negative toll (subsidy) not possible, then non-negativity constraint leads to zero-toll (no tolling).
- Pure congestion toll out-performs congestion toll at unlikely values for demand elasticity.

Competition between regulators

- Local regulator maximizes local welfare: half of consumer surplus, profits of "home" airline, and toll revenues.

$$\varpi_{\mathrm{h}}^{\mathrm{L}} = \frac{1}{2}\left[\int_{0}^{q_1+q_2}(\alpha-\beta x)dx - (\mathrm{q}_1+\mathrm{q}_2)[\alpha-\beta(\mathrm{q}_1+\mathrm{q}_2)]\right] + \pi_{\mathrm{h}} + \sum_{\mathrm{i}=1}^{2}\mathrm{q}_{\mathrm{i}}\frac{\mathrm{t}_{\mathrm{h,i}}}{\lambda_{\mathrm{i}}}$$

Competition between regulators

	global welfare maximization	zero toll	local welfare maximization, differentiated tolls	local welfare maximization, undifferentiated tolls
t_i	$-0.11 \cdot 10^6$	0	$0.033 \cdot 10^6$	$0.196 \cdot 10^6$
t_{-i}	$-0.11 \cdot 10^6$	0	$0.36 \cdot 10^6$	$0.196 \cdot 10^6$
ω	$2.17 \cdot 10^6$	$2.05 \cdot 10^6$	$1.20 \cdot 10^6$	$1.20 \cdot 10^6$
Ω	1	0	-7.09	-7.09

Table 10. Local welfare levels, symmetric equilibrium

	regulator 2 sets zero toll	regulator 2 maximizes local welfare
regulator 1 set zero toll	$2.05 \cdot 10^6$	$0.18 \cdot 10^6$
regulator 1 maximizes local welfare	$3.78 \cdot 10^6$	$1.20 \cdot 10^6$

Table 11. Local welfare levels at airport 1.

Conclusion

- Pure congestion toll likely leads to welfare loss.
- When welfare maximizing toll (subsidy) not possible, then congestion pricing is likely to be suboptimal.
- Local regulators (also) maximize toll revenues; leads to welfare loss.
- Prisoner's dilemma: regulator end up in "worst" equilibrium.

Extensions

- More extensive networks.
- More carriers.
- Peak vs. off peak.
- Product differentiation.
- Airport strategies.

- Thank you.