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Airport Demand Management under Airline Frequency Competition

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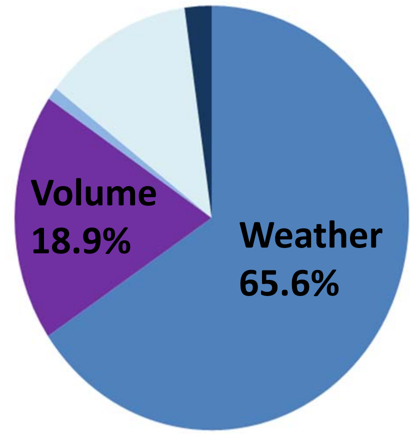
Aviation Delays: Costs and Causes

- **$31.2** billion cost to US economy in 2007[1]
  - Just **$5.0** billion total profits of US airlines[2]
- Causes of delay[3]: 84.5% delays due to demand exceeding realized capacity (airport congestion)



All values normalized to 100 for 2007 (www.bts.gov, 2011)

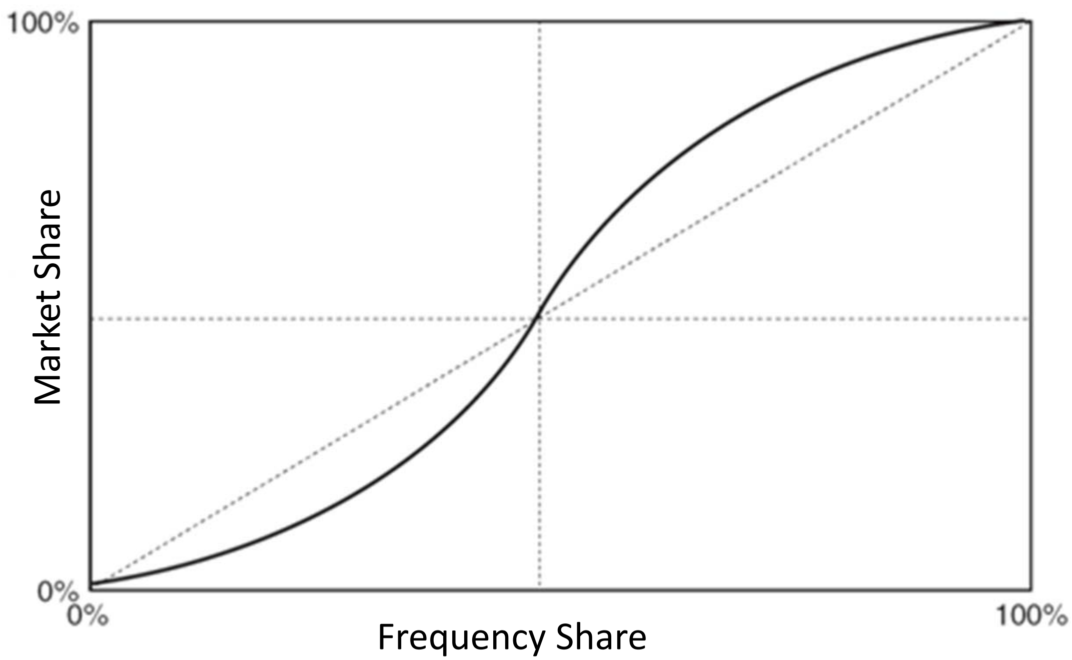
Year	Number of Passengers	Number of Flights	Total Arrival Delays to Flights (Minutes)
2000	100	100	100
2001	93.34	96.47	78.15
2002	92.06	102.32	59.75
2003	97.29	119.65	75.18
2004	105.04	126.09	103.58
2005	109.62	126.98	107.80
2006	109.81	122.86	120.99
2007	113.28	124.46	138.58

- Increase in number of flights much greater than that in passengers
  - #passengers: **13.3%⇑**
  - #flights: **24.5%⇑**
  - #passengers per flight: **9.0%⇓**

[1]NEXTOR TDI Study (2010), [2]Air Transport Association (2008), [3]Bureau of Transportation Statistics (2008)

Frequency Competition

- More frequent flights attract more passengers
- Higher frequency shares associated with disproportionately higher market shares
  - Sigmoidal (or S-shaped) relationship[10][11][12][13]



$$MS_i = \frac{FS_i^{\alpha}}{\sum_{j=1}^{n} FS_j^{\alpha}}.$$

MS_i: Market share of airline i

FS_i: Frequency share of airline i

n: Number of competing airlines

α: Model parameter

Hence a tendency towards flying **more frequent** flights with **smaller** aircraft

Prior Research

a. In the presence of competition,
   - level of congestion directly proportional to the intensity of competition

     (Vaze and Barnhart, 2010)

b. In the absence of competition,
   - existing capacity more than enough to satisfy all passenger demand, with a similar level-of-service
   - over 80% reduction in congestion related delays

     (Vaze and Barnhart, 2011)

- How to mitigate congestion imposed by competition?
  - Quantity-based control (administrative)
  - Price-based control (congestion pricing)

Game Theoretic Model of Decision Making under Competition

maximize: Revenue – Operating Cost – Delay Cost

– Congestion Toll

subject to:

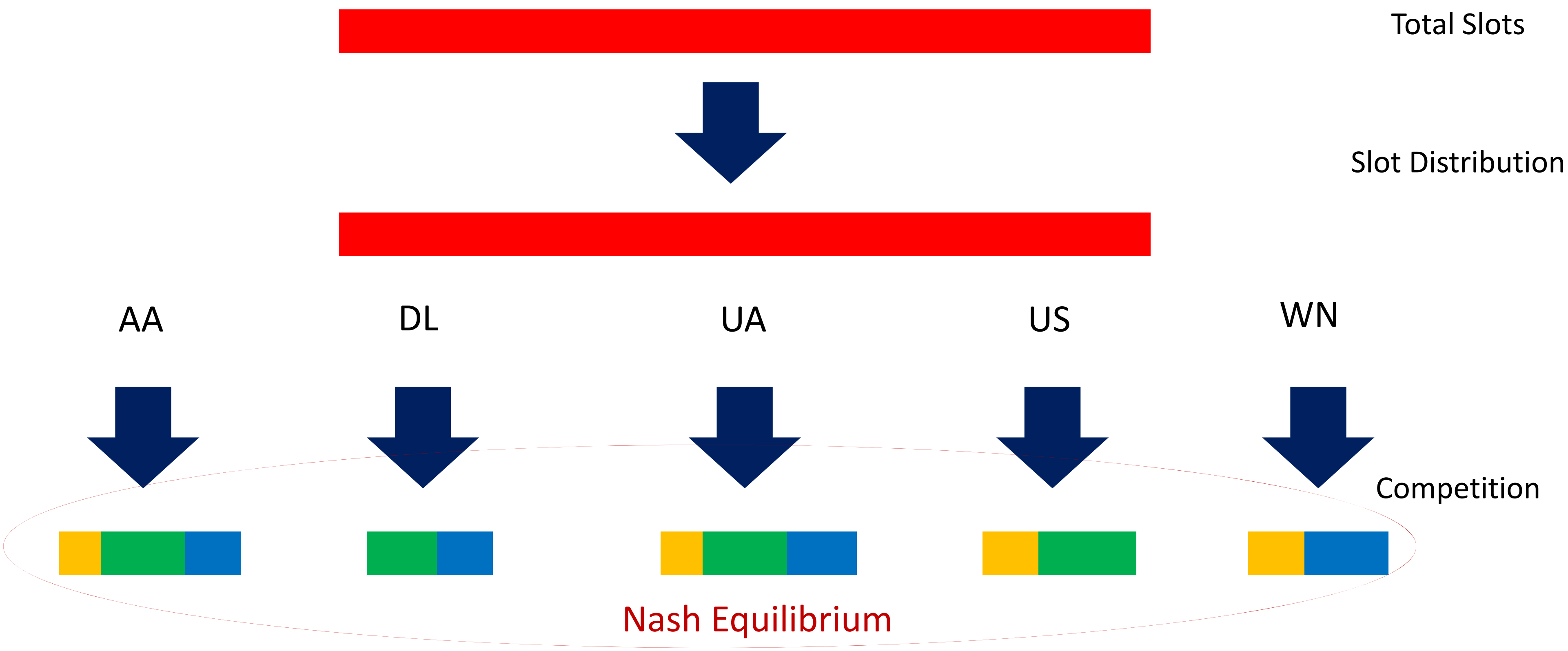
Passengers carried depends on my frequency and competitors' frequencies	Frequency competition
Passengers carried cannot exceed available seats	Seating capacity constraint
My total number of flights cannot exceed the maximum slots available to me	Upper bound on total slots
My total number of flights cannot be lower than those dictated by use-it-or-lose-it rules	Lower bound on total slots

$f_{as} \in \mathbb{Z}^{+} \ \forall s \in \mathbb{S}_a$

- Extremely large number of possible solutions > 10^{50}
- Solved using **successive optimizations heuristic**
  - Each optimization performed using **dynamic programming**

Quantity-based Controls

- Slot controls: very common in practice
  - Five congested US airports
  - Many major airports in Europe and Asia



Experimental Setup

- All flights into LGA airport
- Passenger demands, operating costs, fares, and seating capacities obtained from BTS website

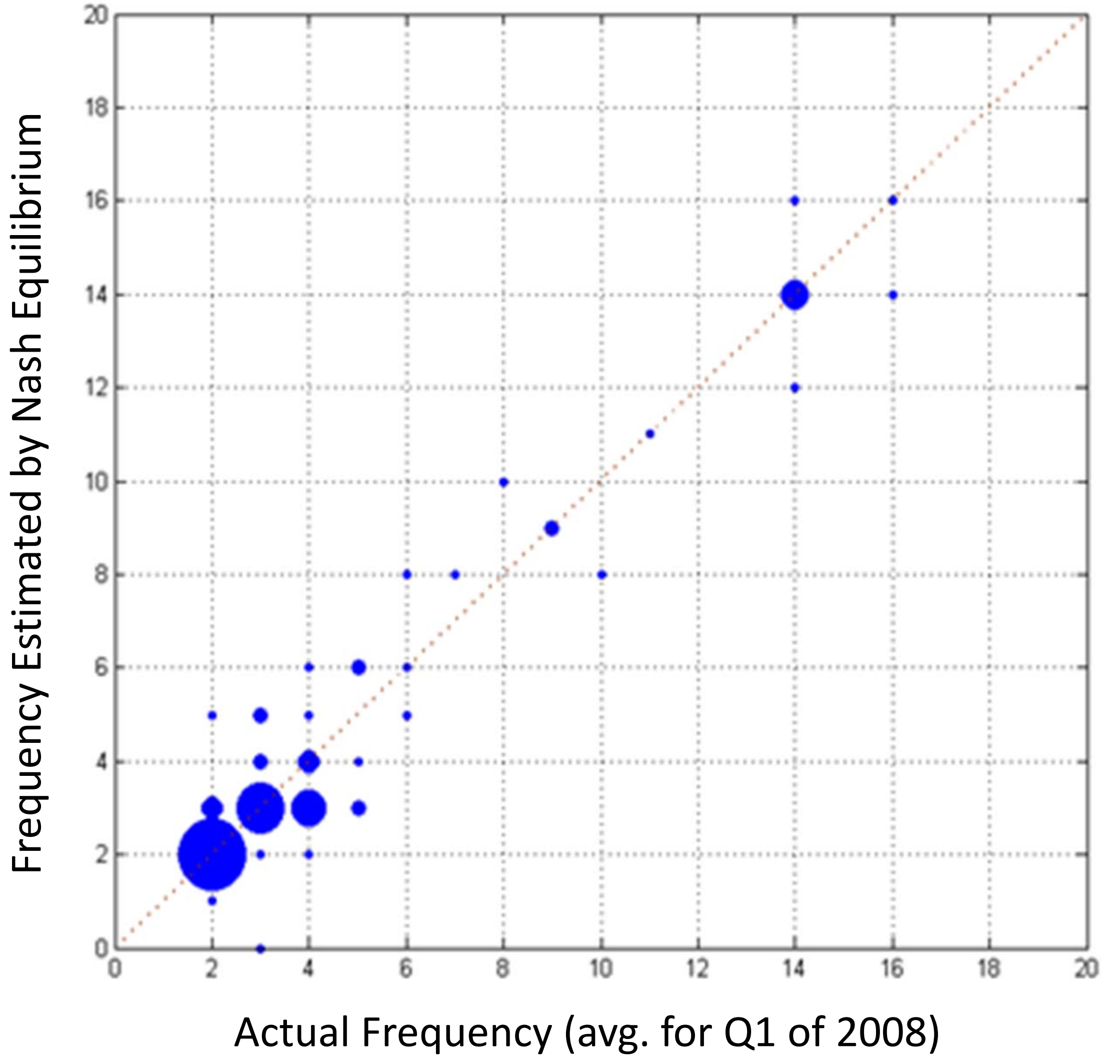
Obtain Nash equilibrium solution for:

1. Existing slot controls (validation)
2. 12.3% slot reduction (policy analysis)

   (~reduce the planned #operations from VMC level to IMC level)

   a. *Proportionate allocation*: slots distributed in same ratio as current slots
   b. *Reward-based allocation*: slots distributed in same ratio as current passengers

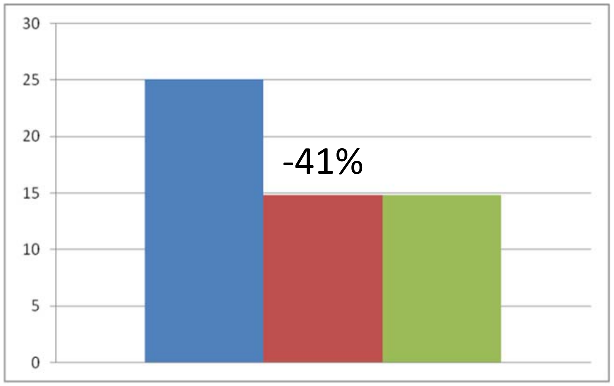
Empirical Validation



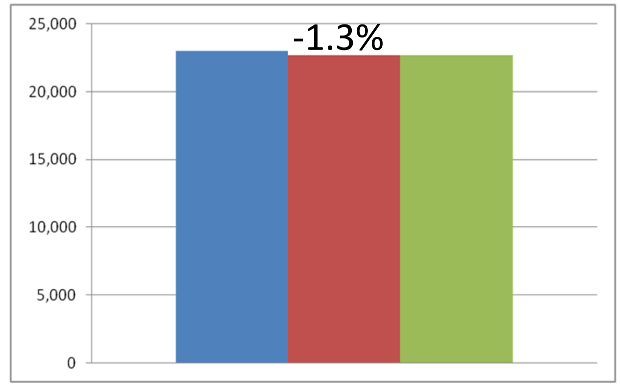
Radius of each circle = #observations corresponding to that point

Impact of Administrative Slot Reduction

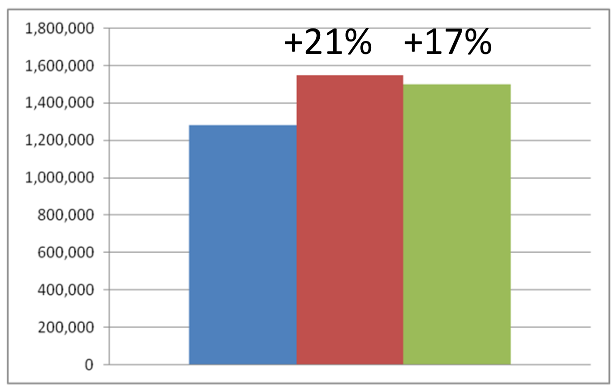
No Reduction Proportionate Reward-based



Avg. Flight Delays (min.)



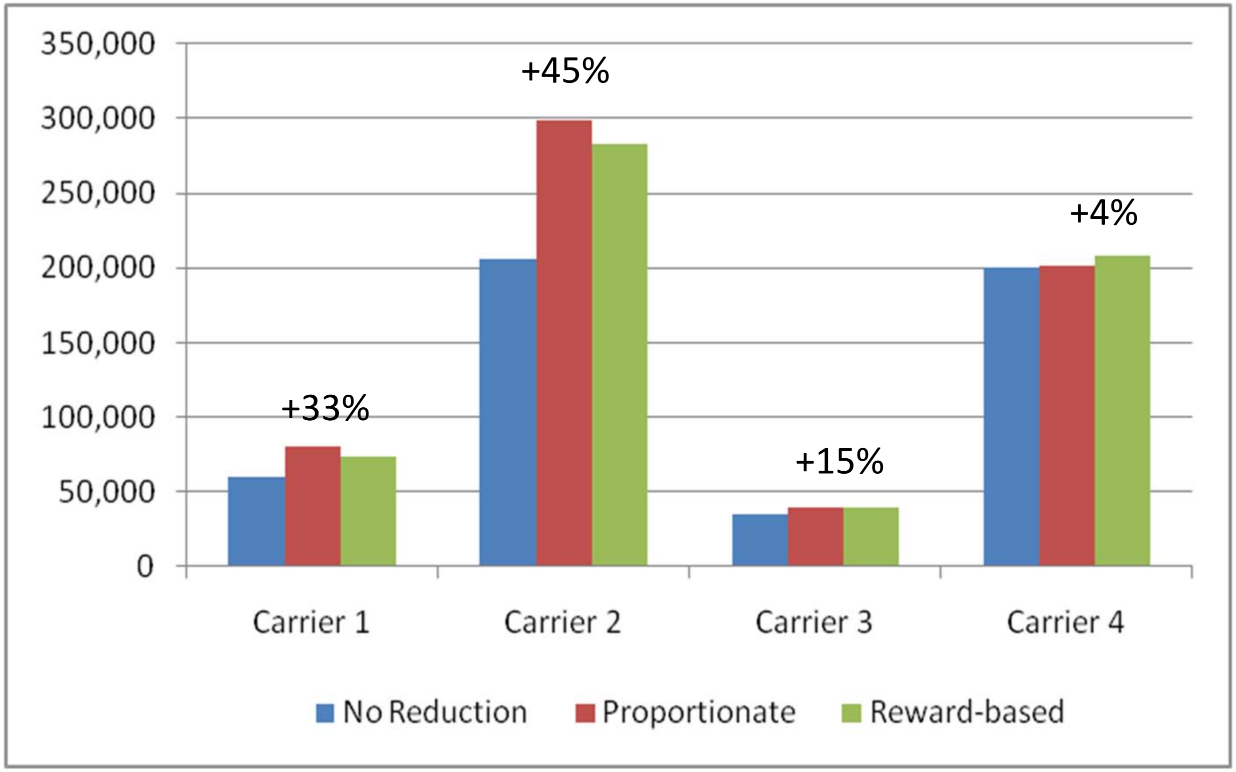
Passengers Carried



Operating Profit ($)

Profit Impact on Individual Airlines

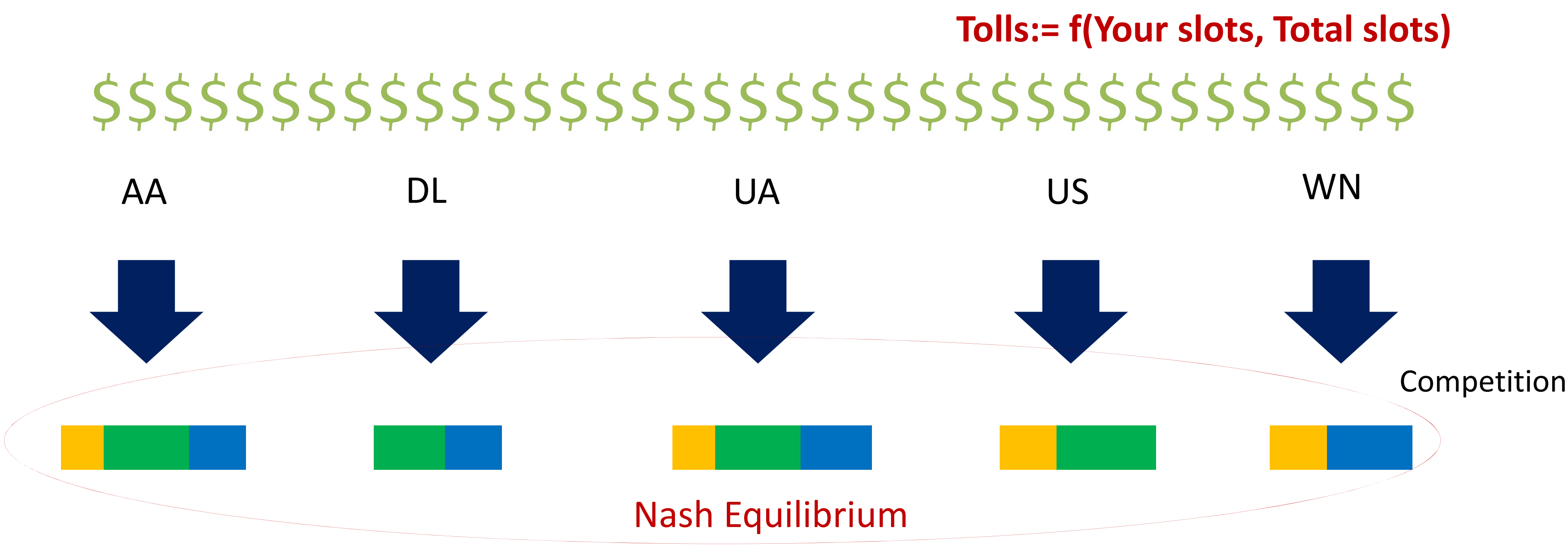
- Each airline's profit increases under both strategies



Slot reduction reduces delays to flights and passengers, and also improves profits of all airlines considerably

Price-based Controls

- Congestion pricing: not common in practice
  - Expected passenger benefits due to delay reduction
  - Expected airline benefits through operating cost reduction (due to fewer flights) and delay reduction



Price-based Controls

Summary of results:

- Effectiveness of congestion pricing can change dramatically with the characteristics (intensity) of competition
  - Congestion pricing can increase airline profits!!! (despite toll payments)
  - A major part of the benefits due to more passengers per flight, as slots get expensive
  - Marginal cost pricing more promising than flat pricing
- Airline-industry specific factors need to be modeled
  - Factors not captured by general micro-economic models
  - **Can make-or-break the case for congestion pricing**

References

- V. Vaze and C. Barnhart, “An assessment of the impact of demand management strategies for efficient allocation of airport capacity”, *International Journal of Revenue Management*, Upcoming, 2011.
- V. Vaze and C. Barnhart, “Price of airline frequency competition”, Working Paper ESD-WP-2010-10, Engineering Systems Division, Massachusetts Institute of Technology, 2010.

QUESTIONS?