Determining the Number of Slots to Submit to a Market Mechanism at a Single Airport

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Research Question

Given various economic concerns, and airport-specific conditions, how many arrival slots should be made available in a given time period?

Outline:

1. Background
2. Models
3. Calibration
4. Slot value determination
5. Sensitivity analysis
6. Conclusions

Background Information

- U.S. slot control
  - High Density Rule (HDR) enacted 1969 for ORD, DCA, EWR, JFK, and LGA
  - FAA NPRM released in 2006 concerning redistribution of slots at LGA
  - New York Aviation Rulemaking Committee 2007
  - FAA SNPRM April 2008, Final Rule October 2008
- Motivation
  - Cannot simply use VMC or IMC capacity
  - Higher value times-of-day
  - Cascading queuing delays
- LGA used as case study
  - Because of its significance as a slot-controlled airport
  - *Methodology is not limited to application at LGA*

Literature

- Primarily focused on **how** to allocate slots
  - Grether, et al. (1979,1989)
  - Rassenti , et al. (1982)
  - NEXTOR
    - Le et al. (2004)
    - Ball et al. (2006)
  - Daniel (1995)
  - Brueckner (2002)

Auctions: Grether, et al. (1979,1989); Rassenti , et al. (1982); NEXTOR (Le et al. (2004); Ball et al. (2006))

Congestion pricing: Daniel (1995); Brueckner (2002)

- International interest
  - DotEcon (2001)

Modeling Framework

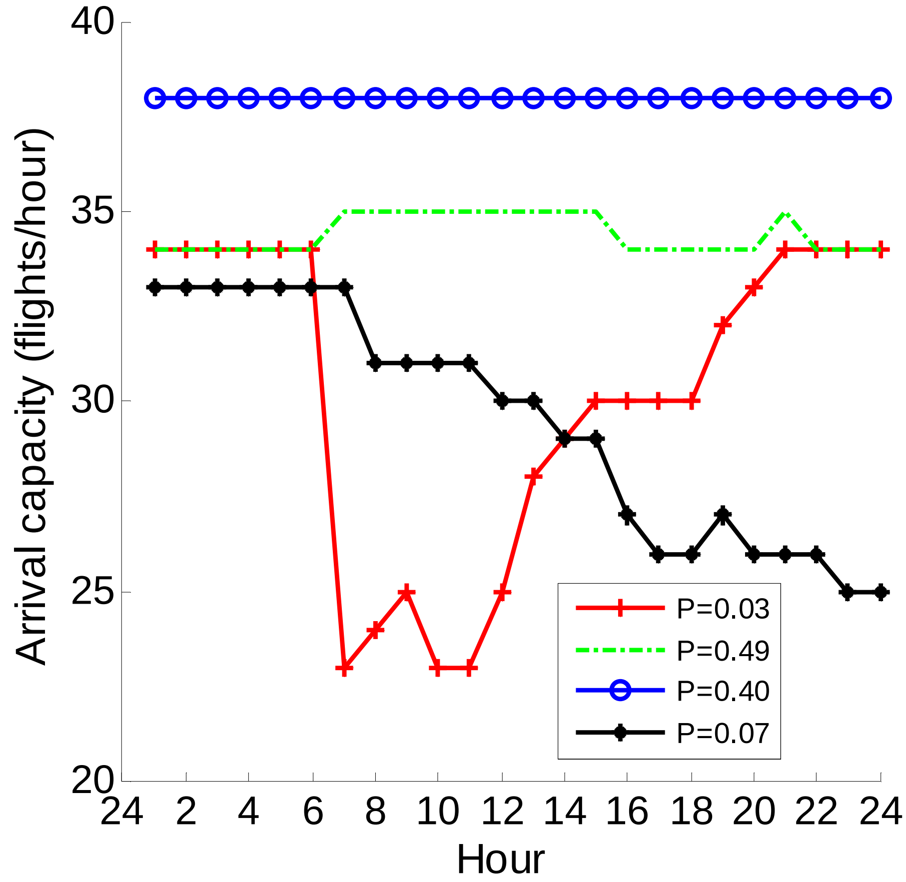
- Two formulations
- Common elements
  - Integer-valued linear optimization problems
  - Posed as network flow problems
    - Objects in network are flights
    - Exits from network are landings and cancellations
  - Model cancellation behavior
- Different elements
  - Objective functions
  - Policy trade-offs

Assumptions

- Day broken into discrete periods (e.g. hour, quarter hour)
- Number of slots to offer in each hour has upper and lower bounds, D_{min} and D_{max}
  - Driven by operational limits and policy constraints
- Costs normalized to one unit delay cost
- Cancellations
  - Modeled as exits from network
  - Several capacitated arcs, each with increasing cost
- Delays
  - Modeled as horizontal arcs in flow diagrams
  - Flights can be delayed up to U time periods

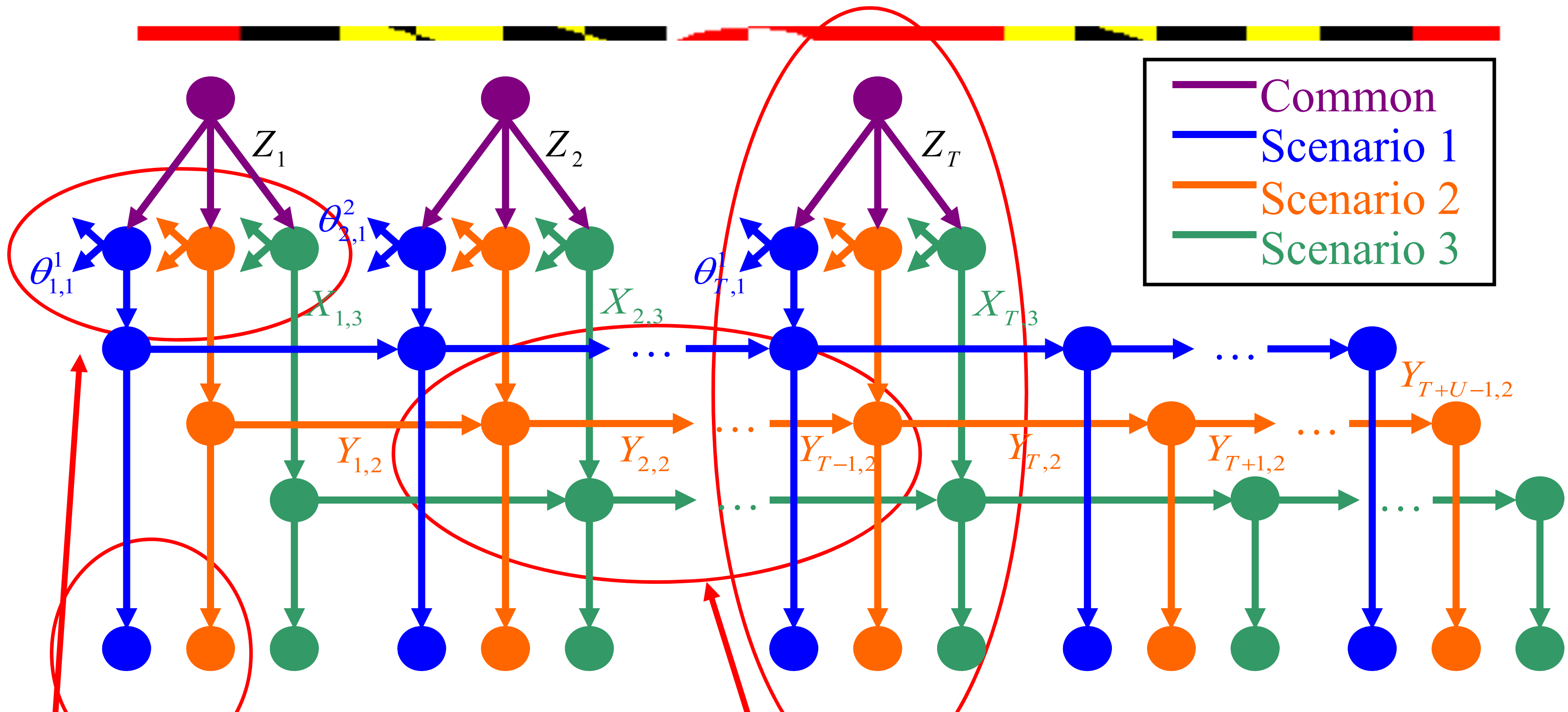
Capacity scenarios

- Work undertaken by Liu, et al. (2005) to cluster arrival capacity (AAR) profiles



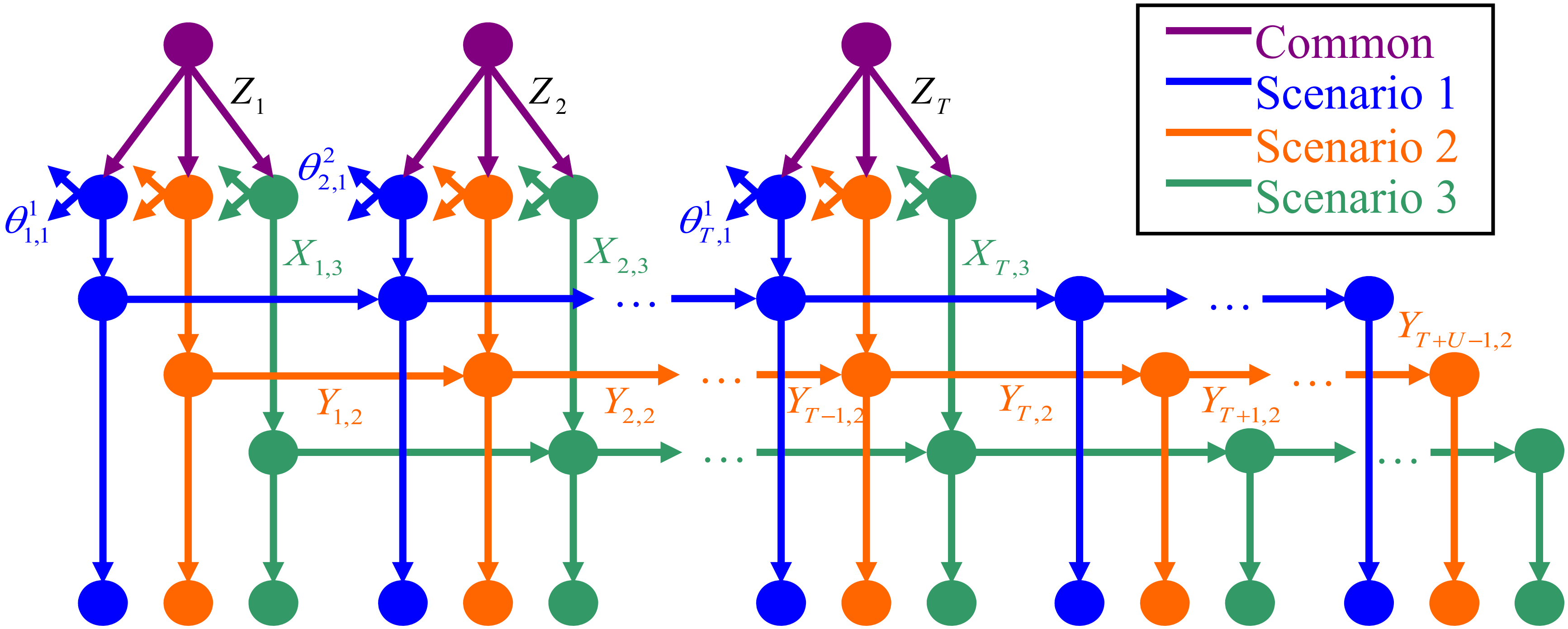
Results shown for LGA, 2003

Base Formulation



- Constraints: Flow balance
- Objective function: Maximize total net benefit, as difference between total value of slots offered and cost of delays and cancellations

Parametric Formulation



- Same network structure as base model
- Constraints: Flow balance, **cap on average delay per flight and overall cancellation percentage**
- Objective function: Maximize total value of slots offered; no longer requires pecuniary equivocation between delays and cancellations

Mathematical Properties

- Base constraint matrix is TU under limited conditions
  - Very small problem sizes (not useful)
  - Even-valued ***b*** vector
- Parametric constraint matrix is not TU under any conditions
- However, …
  - The base formulation solves with LP relaxation
  - The parametric formulation solves quickly

Parameter Calibration

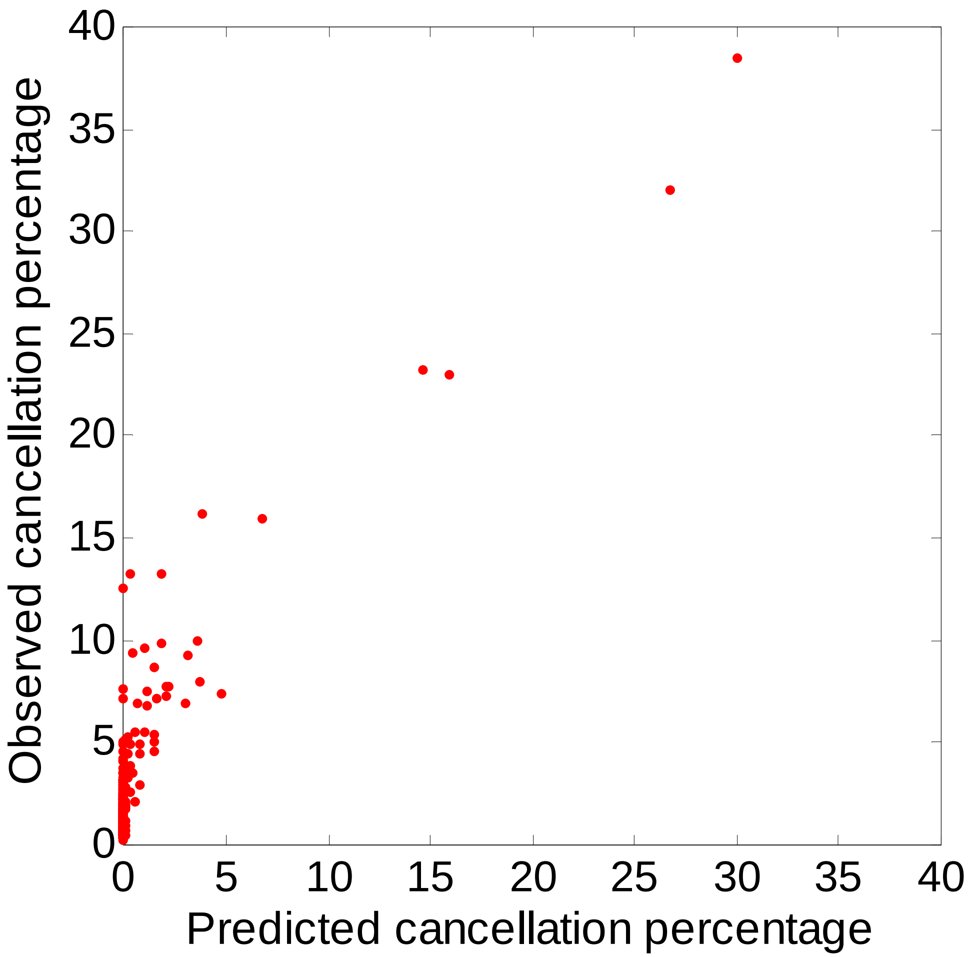
- Need method to estimate several parameters from historical data
  - U - maximum delay length
  - N - number of cancellation arcs
  - P - cancellation arc capacity
  - $\{\lambda_i\}$ - cancellation cost vector = $\alpha[1, 2, 4, 7, 11, \ldots]$

Parameter	**Lower Bound**	**Upper Bound**	**Additional Constraints**
U	4	20	Multiple of 4
N	1	5	
P	2	6	
α	1	10	

Parameter Calibration Procedure

- Define search space by bounding parameters
- For each unique combination of parameters
  - Apply same network as Base model with one capacity scenario (historical realization) and historical demand
  - Objective: minimize total cost, as weighted sum of cancellations and delays
  - Conduct analysis for many days (1 year)
  - Quantify relationship between observed and predicted data for all days using several metrics
- Choose “best” set of parameters based on metric criteria

Sample Calibration Results



ORD, 2005

U = 1 hour

λ = [4 8]

P = 6 flights/arc

R^2 = 0.774

Slope = 1.320

Intercept = 1.9%

Determining Slot Valuation

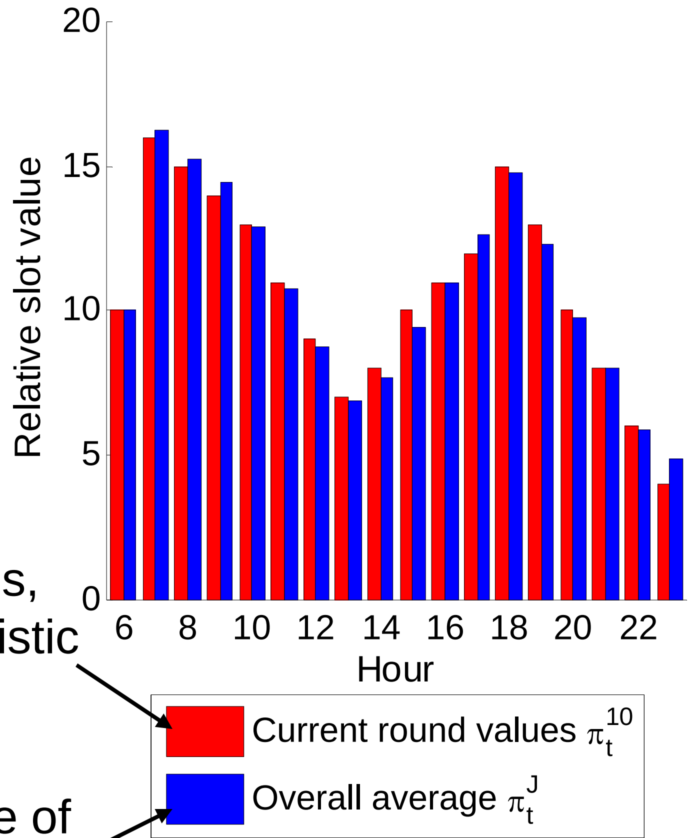
- Acquire proprietary data
  - Best to have data from many carriers
  - Carriers obviously reluctant to release such data
- Inference from ticket pricing data
  - High cost of data access
  - Confounding issues in ticket pricing
- Infer from auction results
  - True values revealed
  - Phased in over several years

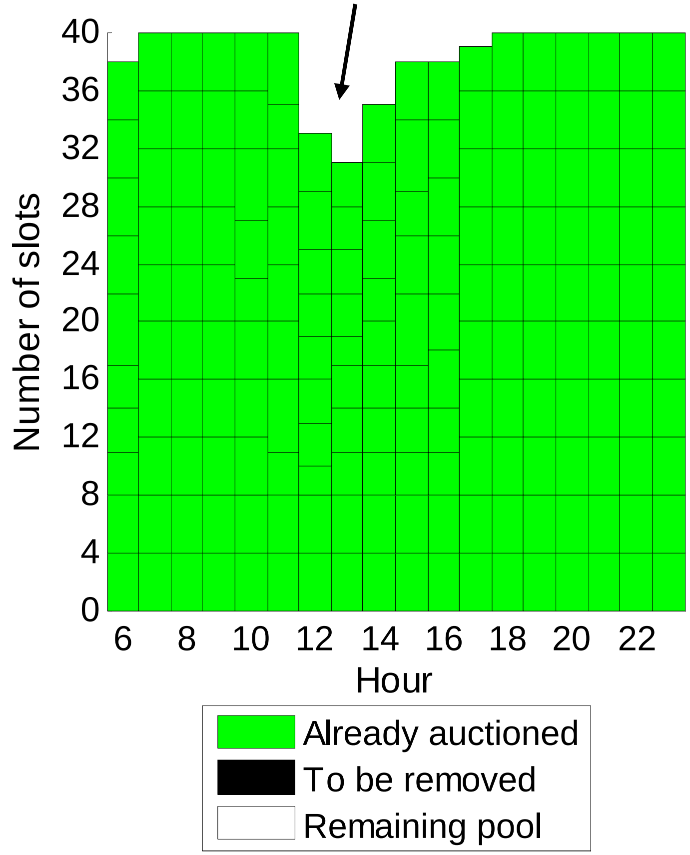
Value Inference from Auctions

- Goals
  - Determine true slot valuations
  - Spread slot removal over several years
  - *Combines value inference, slot removal, and distribution*
- General process
  - Wait several years for prices to stabilize
  - Use model to determine number of slots to offer in each time period
  - Remove slots from circulation over several years
  - Update values and slots to be removed each year until process stabilizes

Value Inference Example

Real results, generated by Parametric model





Fictitious, but realistic

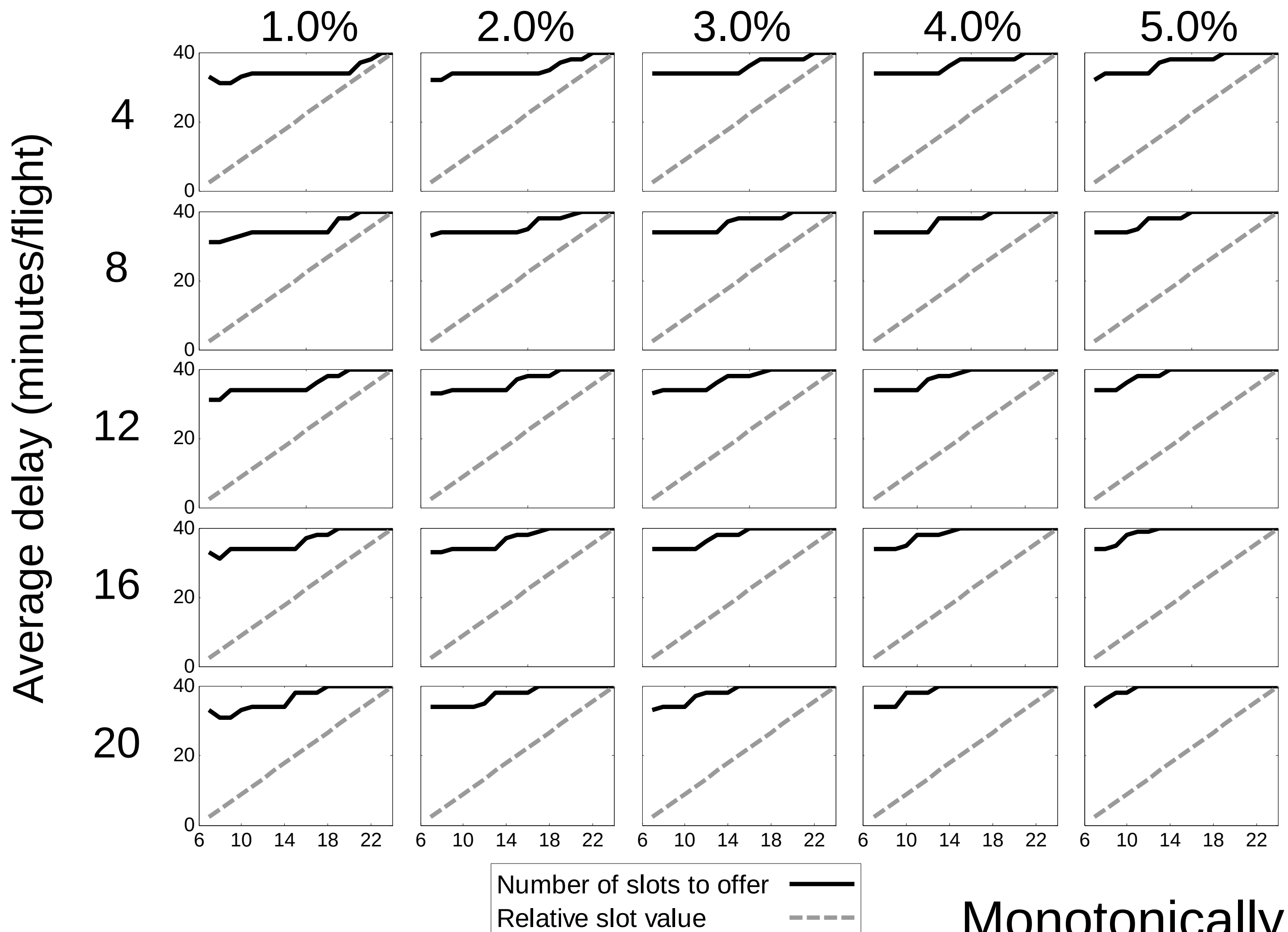
Average of red values

Parameters: Delay: 15 minute/flight, 3.0% cancellations

Sensitivity Analysis

- Tested effects of variations in slot values V_t
- Used Parametric formulation
  - Data from LGA, 2003
  - Slot valuations from Year 10 of auction example
  - Cancellations: maximum of 9 per hour permitted
  - Delay: 15 minutes/flight
  - Cancellations: 3.0%

Model Sensitivity to Slot Valuation



Monotonically increasing slot values

Summary of Results

- Presented two possible formulations to determine number of arrival slots to offer
- Addressed model calibration
- Discussed various methods to estimate slot valuation
  - Proposed procedure that integrates valuation, removal, and allocation
- Examined model sensitivity to slot values