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Analysis of Passenger Delays and the Tarmac Delay Rule

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Outline

- Passenger Delay Estimation
  - Multinomial logit model to estimate itinerary flows
  - Regression model bypassing itinerary flow estimation
- Passenger Delays
  - In the national aviation system
  - Impacts of flight schedule design
  - Impacts of airport passenger connections
  - Impacts of DOT Tarmac Delay Rule

Airline and Passenger Delays

- Delay costs to airlines ~ 7% of total operating costs in 2007
  - Total aircraft delay in 2007: 134M minutes [1] (cost = $8.1B[1])
- Passenger delay estimates vary widely from study to study
  - $12 Billion (US Congress Joint Economic Committee report, 2008)
  - $5 Billion (Air Transport Association, 2008)
    - Both studies ignore passenger delays due to cancellations and missed connections
  - $18 Billion (U.S. Airline Passenger Trip Delay Report to FAA from NEXTOR, 2010)

[[1]Source: Air Transport Association, 2008; [2]Source: U.S. Airline Passenger Trip Delay Report, 2008]

Our Research: Passenger-Centric Delay Analysis

- **Goal:** Measure system performance through passenger delays (instead of flight delays)
- **Challenge:** Flight delays are poor surrogates of passenger delays
  - Longer flight delays lead to flight cancellations and missed connections (Bratu and Barnhart, 2005)
  - Primary obstacle is the unavailability of disaggregate passenger itinerary data
    - Publicly available data is aggregated monthly or quarterly
      - T100 Segment data: aggregated monthly by carrier-segment
      - DB1B Route data: aggregated quarterly by carrier-route
- **Approach:** Estimate historical passenger itinerary flows to calculate passenger delays

Data for Passenger Delay Estimation

- Planned flight schedules
  - On-time performance data [ASQP]
- Flight seating capacities
  - Airline inventories, aircraft codes, monthly seat counts [ASQP, FAA Aircraft Registry, T100]
- Aggregate passenger demand data
  - Monthly segment demands [T100], quarterly 10% coupon samples (one-way itineraries) [DB1B]
- Proprietary booking data
  - One quarter of data for a major U.S. carrier

Multinomial Logit Model

- Passenger allocations based on multinomial logit model of itinerary shares
  - Multinomial logit utility function includes time-of-day, day-of-week, connection time, cancellations, and aircraft size

$$u(x_i) = \sum_{d=1}^{7}\sum_{n=1}^{6} \beta_{dn}^{\text{day-time}} \mathrm{I}\,(x_i^{\text{day}} = d)\mathrm{I}\,(x_i^{\text{time}} \in \mathrm{T}_n) + \sum_{m=1}^{3} \beta_m^{\text{connect}} \left(\min\{x_i^{\text{connect}}, c_m\} - c_{m-1}\right)^+ + \beta^{\text{cancel}} x_i^{\text{cancel}} + \beta^{\text{seats}} x_i^{\text{seats}}$$

- Train model using proprietary data
- Overall model statistically highly significant
  - All but one parameter estimate found to be significant at 99% confidence level

Passenger Allocation and Delay Calculation

- From the estimated choice probabilities, $P(i) = \frac{e^{\beta X_i}}{\sum_j e^{\beta X_j}}$, passengers are allocated to itineraries through a single sampling (subject to flight seating capacity constraints)

- Passenger delays calculated using an extended multi-carrier version of the passenger delay calculator (Bratu and Barnhart, 2005)

Passenger Delay Analysis

- Total Passenger Delay Minutes in 2007 = 14.4 Billion (240 Million hours)
- Out of all passenger delays:
  - 52% due to flight delays
  - 29% due to cancellations
  - 19% due to missed connections
- Average delay of 30 minutes / passenger
  - 7.5 hours / disrupted passenger
- Total cost of passenger delays is $9 Billion
  - Assuming $37.6/hr value of passenger time (JEC report)

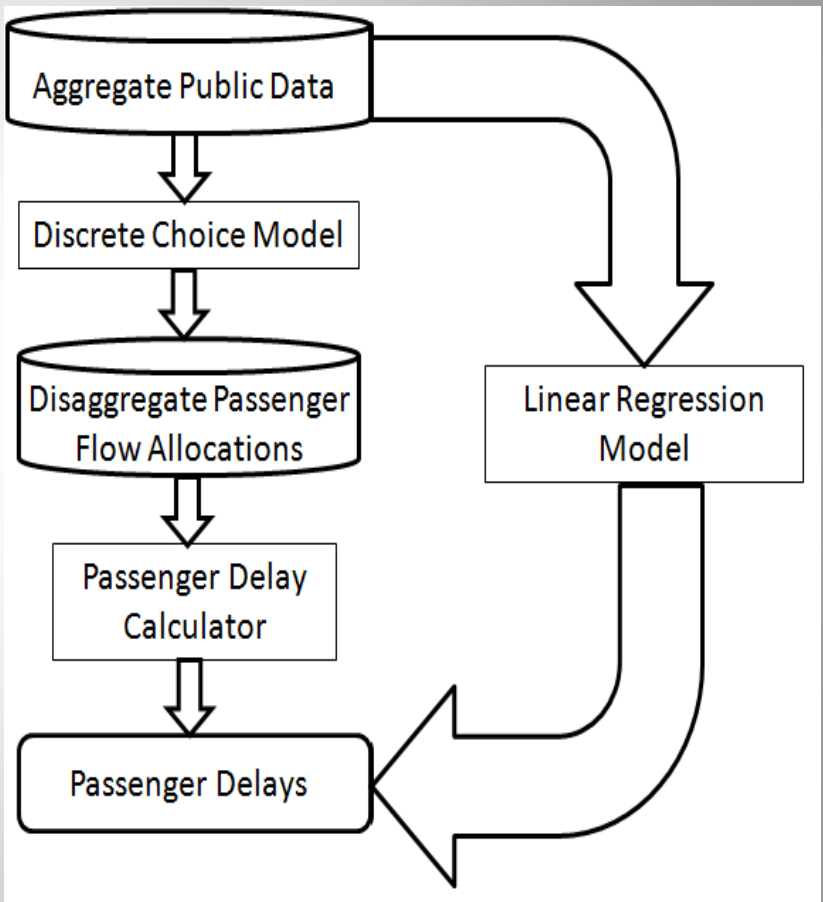
Impact of Network Structures and Schedules

- *The ratio of average passenger delay in 2007 to average flight delay is maximum for regional carriers, and minimum for low-cost carriers, due primarily to their cancellation rates and connecting passenger percentages*
  - Overall ratio = 1.97
  - Overall Cancellation rate = 2.4%
  - Overall Connecting passengers= 27.2%

	Regional	Legacy	Low-cost
Avg Pax Delay to Avg Flight Delay Ratio	2.61 (Range: 2.27 to 2.99)	2.03 (Range: 1.65 to 2.23)	1.61 (Range: 1.49 to 1.89)
Cancellation Rate	3.4%	2.2%	1.2%
% Connecting Passengers	39.6%	31.0%	17.0%

Regression Model to Bypass Passenger Allocation Procedure

- Simplified one-step approach to passenger delay estimation using public data directly
- Dependent variable = Average passenger delay
- Independent variables = Aggregate attributes of airline schedules, passenger itineraries etc.
- Regression model estimated using the allocation-based delay estimates



Factors Affecting Passenger Delays

- Flight Delays ↑
- Cancellation Rates ↑
- Connecting Passenger Percentages ↑
- Load Factors ↑
- Fraction of Flights with Long Delays (e.g., > 60 min) ↑

Parameter Estimates

- 20 airlines x 365 days in the year = 7300 observations (2007)

Parameter Description	Estimate	Std Error	p-value
Intercept	-0.73	0.21	0.00
Average flight delay	1.01	0.01	0.00
Fraction of cancelled flights	420.49	2.49	0.00
Fraction of cancelled flights * High load factor dummy	90.05	3.94	0.00
Fraction of connecting passengers	6.16	0.42	0.00
Fraction of connecting passengers * Fraction of flights with at least 60 minutes of delay	127.92	3.86	0.00

- All parameter estimates are statistically significant with at least 99.99% confidence level, Model R^2 value of 95.06%
- Regression-based estimation has slightly larger error than the complicated process

Error Comparison at Different Aggregation Levels

- Regression-based estimation has slightly larger error than the complicated process

Aggregation Level	Passenger Allocation and Delay Calculation	Regression-based Delay Estimation
By Carrier-Day	11.1%	15.1%
Daily	10.3%	12.4%
Monthly	3.3%	8.0%
Quarterly	2.7%	8.0%

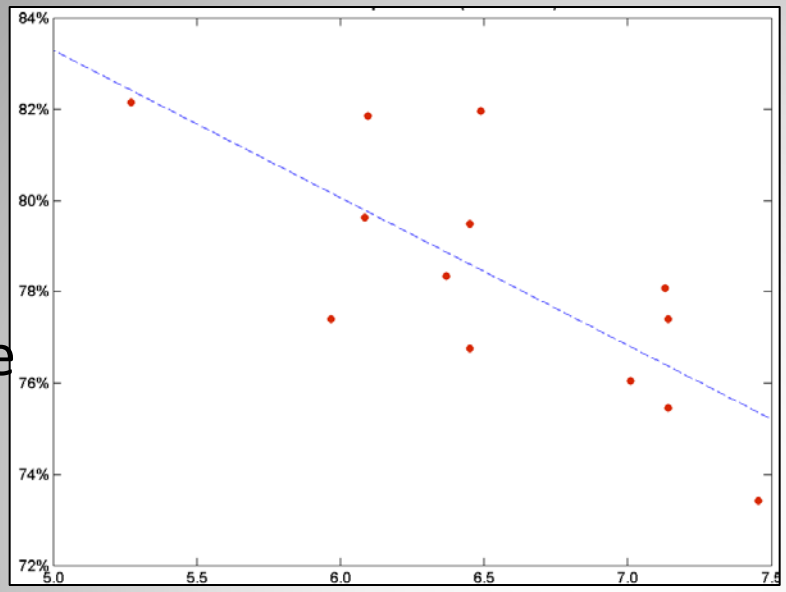
- Passenger delay estimation for 2008 (a sample application of the direct approach)
  - Model inputs: Flight schedules and aggregate passenger flows
  - 6% fewer passengers and 6.7% lower avg. passenger delays compared to 2007 resulting in 12.2% lower total passenger delays

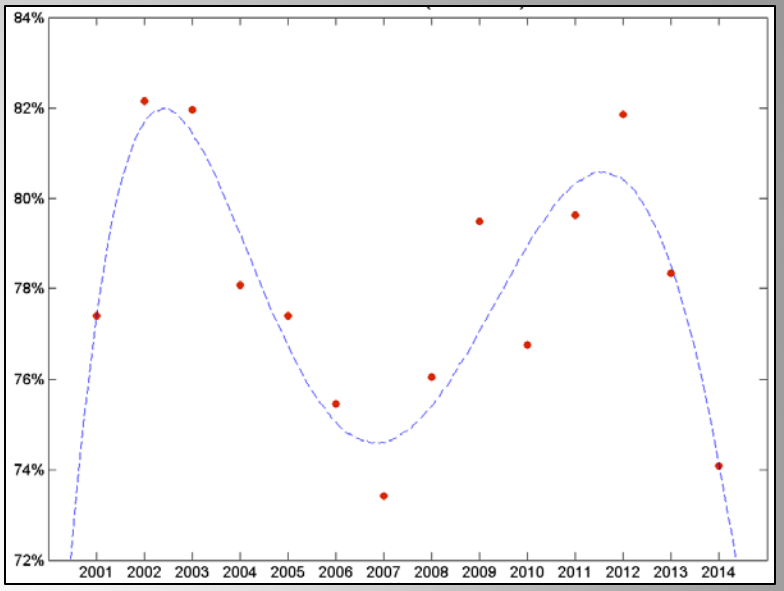
Delays, OTP, Longitudinal Analysis

#Operations (Millions)

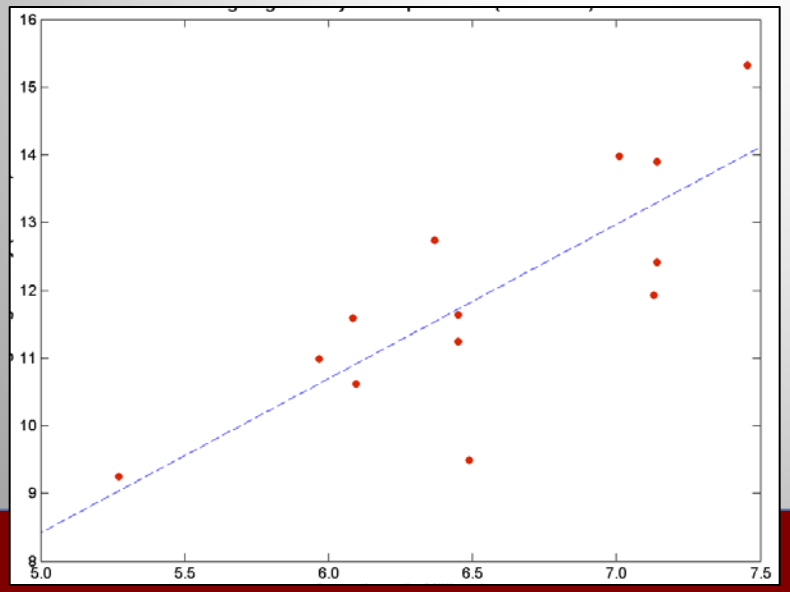
Year

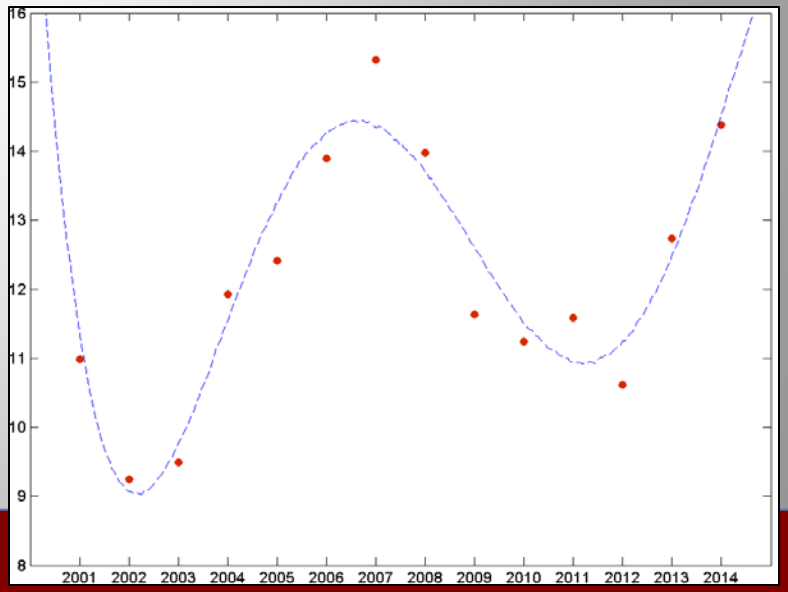
15 Minute On-Time Performance





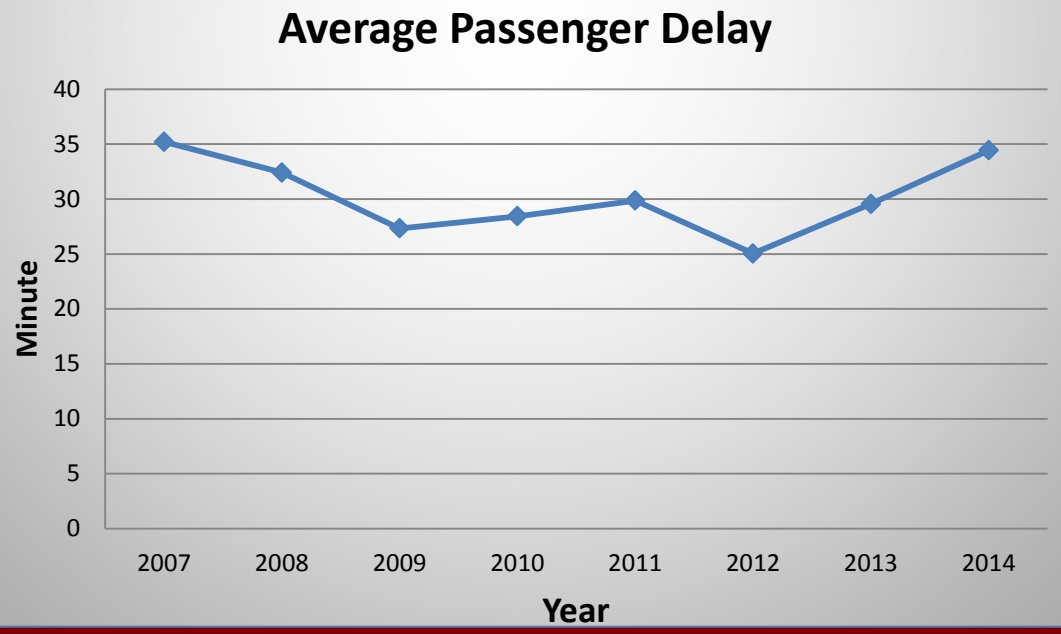
Average Delays/ Flight (Minutes)





Longitudinal Analysis Based on the Regression Model

Year	2007	2008	2009	2010	2011	2012	2013	2014
Load Factors (%)	79.87	79.74	81.06	82.18	82.87	83.36	83.47	84.47
Cancellation Rate (%)	2.16	1.96	1.39	1.76	1.91	1.29	1.51	2.18
Average Flight Delay (Minute)	15.29	14.08	11.7	11.2	11.52	10.58	12.63	13.59
Fraction of Connecting Passengers (%)	35.76	36.15	37.32	37.89	37.9	37.55	36.72	36.4
Fraction of Long Delayed (>60 min) Flights (%)	7.2	6.6	5.35	5.11	5.37	4.84	5.91	6.3



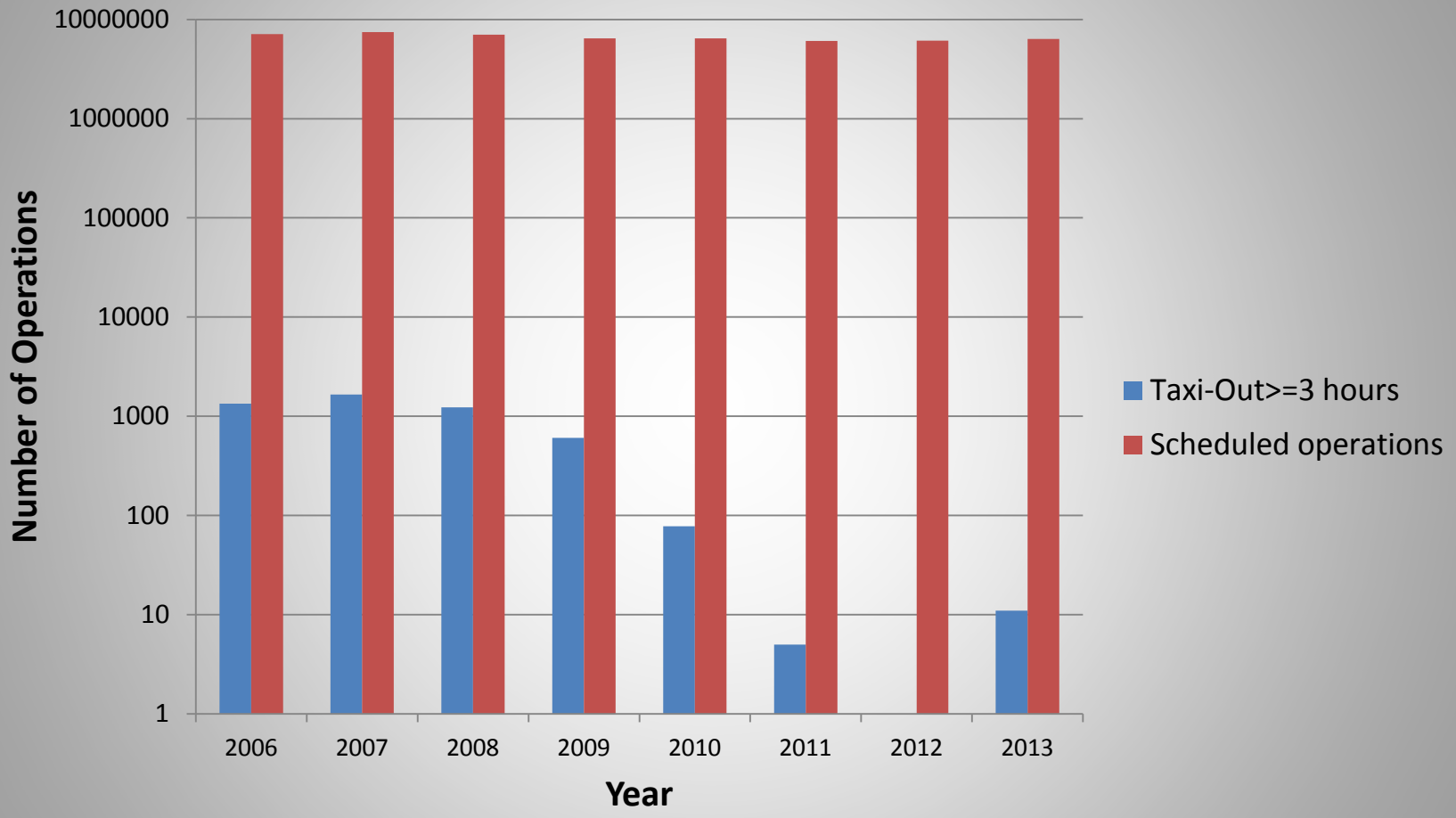
The Impact on Passenger Delays of the DOT Tarmac Delay Rule

Background of Rule

Airlines shall not keep passengers on an aircraft on the tarmac, upon taxi-out or taxi-in, longer than 3 hours *without the opportunity to deplane, or they will risk* ***fines up to $27,500 per passenger****.*

- Announced December 21st, 2009, in effect April 29th, 2010
- Currently applies to
  - U.S. flag carriers operating domestic flights
  - International flights, operated by U.S. or international carriers, originating or landing at U.S. airports (limit 4 hours)
- Aircraft under 30 seats exempt

Rule is a Deterrent to Long Tarmac Delays!



But… the rule can lead to increased passenger delay

- GAO Report (Sept, 2011) findings:
  - Airlines changed decision making in response to the rule
  - Likelihood of cancellation increased after its implementation (due to desire to avoid fines)
  - ➢ Increased passenger delays

- **What is the impact of the rule on passenger delays?**
- **Does the rule strike the right balance between "increased passenger delays" and "decreased tarmac delays" ?**

Data and Methodologies

- We cannot directly compare the passenger delays in years before and after the year the rule was implemented
  - Year-to-year variations in airline schedule: congestion levels, demand fluctuations, capacity changes, and weather differences
- We use schedule data from year 2007 to calculate delay to passengers under two hypothetical scenarios:
  - ***As-flown schedule (pre-rule baseline)***: aircraft sit on tarmac longer than 3 hours and eventually depart
  - ***Flights delayed more than three hours on taxi-out are cancelled (post-rule baseline)***, and passengers rebooked
    - Passenger delay calculator used to estimate passenger delays

System-wide Passenger Delays

- Allow other flights in the departure queue to take off in the “slots” occupied by the tarmac delayed flights.

Metric	Pre-Rule Baseline	Post-Rule Baseline	Change	% Change
Avg Delay to A-Passengers (min)	282.943	616.552	333.609	117.9%
Avg Delay to All Passengers (min)	31.045	31.162	0.117	0.4%

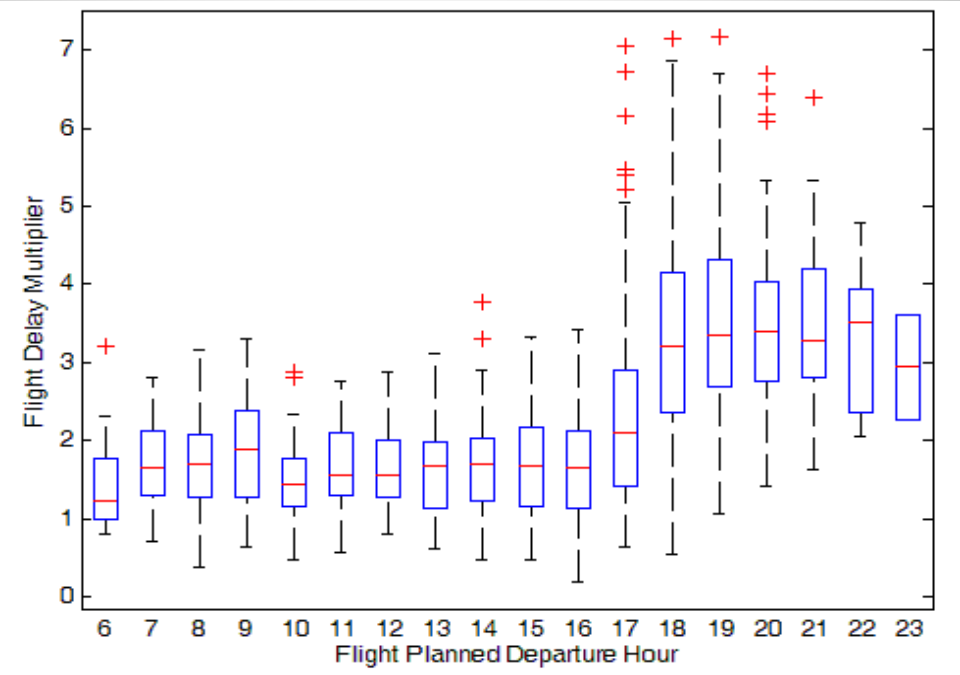
- **Total passenger delay increase:** 57,275,117 (passenger*minute)
- **Total tarmac time reduction:** 19,263,340 (passenger*minute)
- Total passenger delay increase / Total tarmac time reduction = **2.973**
- Result: Overall passenger delay increases, especially for passengers . **One minute** of tarmac time saving is at the cost of **three minute** passenger delay increment.

Sensitivity of the Rule to Tarmac-Time Limit

Metric	Tarmac Time Threshold (hours)				
	2	2.5	3	3.5	4
Increase in Average Delay to A-Passengers (%)	114.4%	118.7%	117.9%	110.7%	106.2%
Increase in Average Delay to All Passengers (%)	1.93%	0.87%	0.38%	0.11%	0.04%
Increase in Average Delay to All Passengers (passenger*min)	291,328,204	131,478,135	57,269,910	16,318,893	5,966,404
Reduction in Tarmac Time (passenger*min)	77,070,927	38,231,502	19,263,340	6,409,620	2,317,050
Total Delay Increase / Tarmac Time Saving	3.780	3.439	2.973	2.546	2.575

The Rule and the Impact of Flight Departure Times

- Flight Delay Multiplier=



- Flight delay multiplier increases with departure time

Delays: Sensitivity to Flights subject to the Rule

- Apply 'Selective Rule' Based on Flight Departure Time
  - Apply rule to flights departing before 1PM, 3PM, 5PM, 7PM, anytime

Metric	Planned Flight Departure Time				
	1:00pm	3:00pm	5:00pm	7:00pm	Anytime
Increase in Average Delay to A-Passengers (%)	50.9%	51.6%	52.5%	99.7%	117.9%
Increase in Average Delay to All Passengers (%)	0.0%	0.0%	0.1%	0.5%	0.38%
Increase in Total Passenger Delay (passenger*min)	4,175,467	6,878,525	10,007,443	32,758,390	57,269,910
Reduction in Tarmac Time (passenger*min)	3,792,431	6,563,478	10,285,142	15,540,033	19,263,340
Total Delay Increase / Tarmac Time Saving	1.101	1.048	0.973	2.108	2.973

The Rule to Minimize Total Passenger Delays

- A Combined Policy
  - Set tarmac-time limit at 3.5 hours
  - Applicable only to flights departing before 5 pm

Metric	Post-Rule Baseline	Combined Policy
Increase in Average Delay to A-Passengers (%)	117.9%	**55.6%**
Increase in Average Delay to All Passengers (%)	0.4%	**0.0%**
Increase in Total Delay to All Passengers (passenger*min)	57,269,910	**2,210,119**
Reduction in Tarmac Time (passenger*min)	19,263,340	**4,594,842**
Total Delay Increase / Tarmac Time Saving	2.973	**0.481**

One minute tarmac time saving is only at the cost of **0.5 minute** increase in passenger delay

Tarmac Delay Rule Analysis: Conclusion

- Delays in the national aviation system
  - Flight delays are not a good proxy for passenger delays
  - Essential to consider network structures and flight schedules (cancellations, passenger connections, airport congestion levels), load factors
- The Tarmac Rule
  - The rule is an effective deterrent to keeping passengers on the tarmac for lengthy periods of time
  - The rule is an ineffective mechanism for reducing passenger delay, and overall, can lead to significant increases in delays for passengers
  - Through modified rules, can strike different balances between the conflicting objectives of reduced frequency of long tarmac times and reduced total passenger delays

Questions?

A Discrete Choice Approach to Simulating Airline Passenger Itinerary Flows

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Airline Passenger Delay Estimation Problem

- Airline passenger delays cost billions of dollars annually in US
- Passenger delay cost estimates for 2007 differ widely
  - US Senate Joint Economic Committee[1]: **$12 Bn**
    (ignores flight cancellations and missed connections)
  - Sherry and Donohue[2]: **$8.5 Bn**
    (ignores all passenger connections)
  - Air Transport Association: **$5 Bn**
    (???)
- Flight delay: poor surrogate of passenger delays[3]
  - We must account for cancellations and missed connections
- But, its very difficult to estimate passenger delays due to lack of disaggregate passenger data

Passenger Delay Calculator (PDC) Algorithm

- Developed by Bratu and Barnhart (2005)
  - Sort all disrupted passengers by time of disruption
  - Greedily allocate each passenger on the shortest path to trip destination
- But, it works only if disaggregate passenger itinerary flows are known
- Public data: aggregate
  - T100 Segment data: aggregated monthly by carrier-segment
  - DB1B Route data: aggregated quarterly by carrier-route
- How to disaggregate such data?
  - e.g. On a particular day, how many passengers planned to take 7:05 am AA flight from BOS to ORD followed by 11:15 am AA flight from ORD to LAX?

Outline

- MNL model for itinerary flow estimation
- Delay calculation and validation
- Passenger delay results
  - Aggregate passenger delays for 2007
- Simplified 1-step approach for delay estimation
  - To bypass the complicated allocation and reaccommodation procedure
- Key findings
  - Develop insights into factors affecting passenger delays

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Multinomial Logit Model

- Model specification:

$$u(x_i) = \sum_{d=1}^{7}\sum_{n=1}^{6} \beta_{dn}^{\text{day-time}} \mathrm{I}\,(x_i^{\text{day}} = d)\mathrm{I}\,(x_i^{\text{time}} \in \mathrm{T}_n) + \sum_{m=1}^{3} \beta_m^{\text{connect}} \left(\min\{x_i^{\text{connect}}, c_m\} - c_{m-1}\right)^+ + \beta^{\text{cancel}} x_i^{\text{cancel}} + \beta^{\text{seats}} x_i^{\text{seats}}$$

- Utility:
  - Week divided into 42 4-hour time periods: 0-1 dummy for each time period
  - Piecewise linear function of connection times
  - Flight cancellation 0-1 dummy[4]
  - Aircraft size[5]
- Model estimated using proprietary booking data from a large legacy carrier for the 4th quarter of 2007

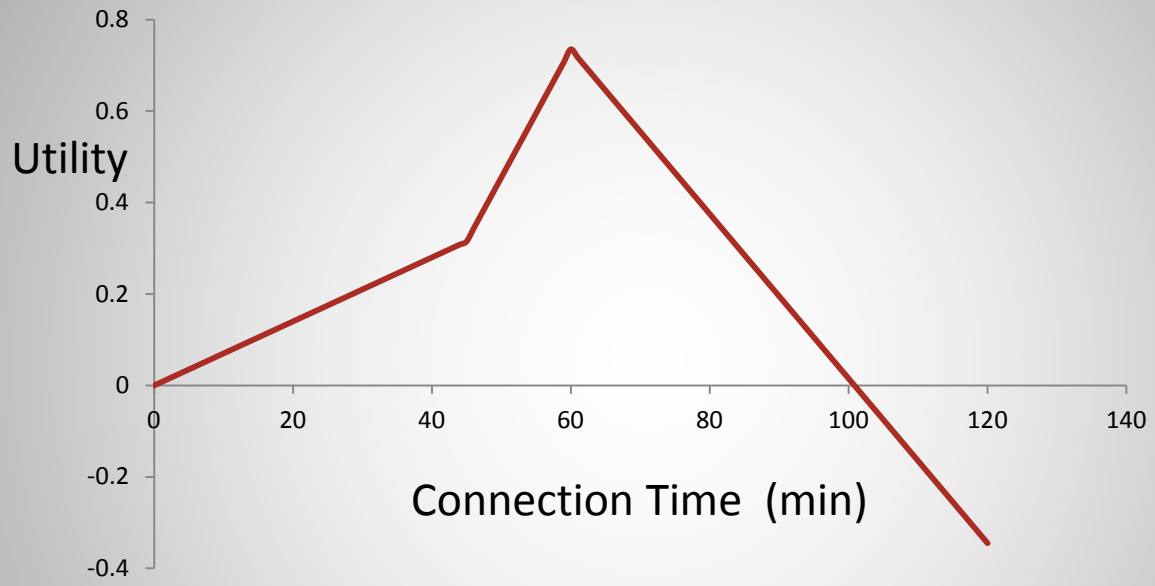
Summary of Estimation Results

- 45 out of 46 parameter estimates significant with at least 99% confidence level
- Likelihood ratio test: overall model is statistically significant with extremely low p-value ($<10^{-30}$)
- Highest utility for travel on Sundays, Thursday and Friday evenings, and Monday mornings
- Lowest utility for late night and pre-dawn travel

Parameter Description	Estimate	Std Error	p-value
Connection time (minutes) ≤ 45	0.007	0.00013	0.00
Connection time (minutes) > 45 and ≤ 60	0.028	0.00055	0.00
Connection time (minutes) > 60	-0.018	0.00004	0.00
Flight cancellation	-0.143	0.00956	0.00
Seating capacity	0.005	0.00010	0.00

Estimation Results Contd.

- Maximum utility at 60 min connection time, lower to longer and shorter connections



- Positive coefficient of aircraft size: passengers prefer traveling on larger aircraft
- Negative coefficient of cancellation dummy: airlines preferentially cancel flights with fewer passengers

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Passenger Allocation and Delay Calculation

- From the estimated choice probabilities, passengers are allocated to itineraries through a single sampling (subject to flight seating capacity constraints)
- Passenger delays calculated using an extended multi-carrier version of the passenger delay calculator (Bratu and Barnhart, 2005)
- Validation against sampling error:

Aggregation Level	Minimum	Maximum	Average	Median
Daily	0.0034%	2.0780%	0.3948%	0.3309%
Monthly	0.0149%	0.1611%	0.0729%	0.0599%
Annual	0.0472%	0. 0472%	0. 0472%	0. 0472%

Delay Validation

- Three major causes of passenger delays:
  - Flight delays
  - Flight cancellations
  - Missed connections

	Passenger Counts			Delays (Hours)		
Cause	Booking Data	Estimated Flows	Percentage Difference	Booking Data	Estimated Flows	Percentage Difference
Flight Delays	7,113,553	7,141,404	0.39%	1,968,253	2,007,925	2.02%
Flight Cancellations	114,654	119,174	3.94%	933,486	962,681	3.13%
Missed Connections	80,439	77,082	4.17%	558,722	583,296	4.40%
Total	7,308,646	7,337,660	0.40%	3,460,460	3,553,903	2.70%

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Passenger Delay Results

- Total passenger delay in the US in 2007 = 244,482,655 hrs
- Assuming $37.6/hr value of passenger time (same as the one used in JEC report), the total cost of passenger delays

  = $9.19 Bn
- Out of all passenger delay,
  - (only) 52% due to flight delays
  - 30% due to cancelled flights
  - 18% due to missed connections
- Avg. flight delay = 15.32 min
- Avg. passenger delay = 30.15 min
- Ratio of average passenger delay to average flight delay = 1.97

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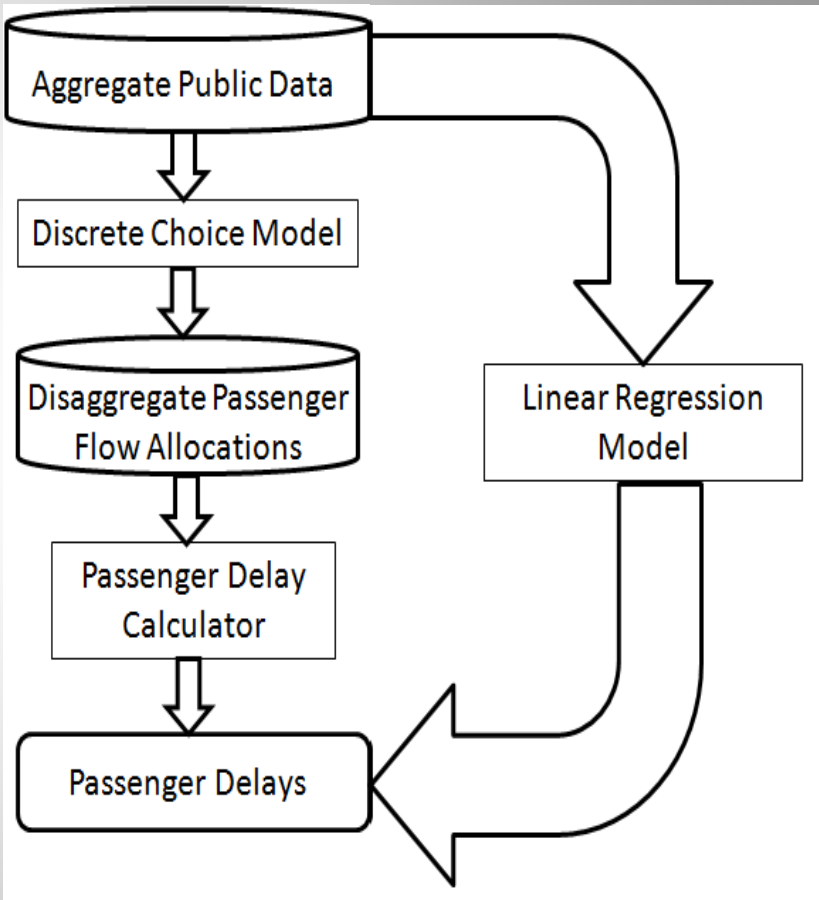

Parameter Estimates

- 20 airlines x 365 days in the year = 7300 observations

Parameter Description	Estimate	Std Error	p-value
Intercept	-1.34	0.24	0.00
Average flight delay	1.00	0.01	0.00
Fraction of cancelled flights	458.77	2.92	0.00
Fraction of cancelled flights *x* High load factor dummy	96.79	4.62	0.00
Fraction of connecting passengers	10.14	0.50	0.00
Fraction of connecting passengers *x* Fraction of flights with at least 60 minutes of delay	139.14	4.53	0.00

- All parameter estimates are statistically significant with at least 99.99% confidence level
- Model R^2 value of **95.06%**

Error Comparison at Different Aggregation Levels

- Regression-based estimation has slightly larger error than the complicated process

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Key Findings #1

- *The ratio of average passenger delay to average flight delay is maximum for regional carriers, and minimum for low-cost carriers, owing primarily to their cancellation rates and connecting passenger percentages*
  - Overall ratio = 1.97
  - Overall Cancellation rate = 2.4%
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Cancellation Rate	3.4%	2.2%	1.2%
% Connecting Passengers	39.6%	31.0%	17.0%

Key Findings #5

- *Average evening passenger delay (37.8 min) is 86.8% greater than average morning passenger delay (20.3 min)*
  - Main reason is that the average evening flight delay (18.5 min) is 89.4% greater than average morning flight delay (9.8 min)
  - But fraction of disrupted passengers is only 18.9% greater in evening (3.52%) than in the morning (2.96%)
  - But greater ease of rebooking for morning passengers is evident as average delay to disrupted passengers in the evening (532.6 min) is 66.3% greater than that for morning passengers (320.3 min)

Key Findings #6

- *Southwest Airlines has the lowest average passenger delay, nearly 55% lower than its competitors, even though its average flight delay is only 36.3% lower. Primary reason is fewer disruptions.*
  - *1.0% cancellations as compared to 2.8% for other carriers*
  - *0.4% missed connections as compared to 1.4% for other carriers*

  …because of,

  1) Fewer connecting passengers : 15.5% compared to 30.0% for other carriers

  2) Longer connections: 41.9% connections longer than 1.5 hours, compared to 36.1% for other carriers

Thank you very much!!

References

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