Assessing Benefits from Aviation Capacity Investment:

An Equilibrium Approach

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Outline

- Background
- Equilibrium framework
- Equilibrium models
- Conclusion
Research background

- Dozens of billion-dollar investment under NextGen
- Additional runway construction and airport capacity expansion projects
  
  DOT (2009, 2010); Hansen (2010); FAA (2007)
Conventional method

Investment

Infrastructure
Capacity

Benefits

Airline Cost

Flight Delay

Passenger travel time
Problems with conventional method

*Ceteris paribus* assumption

- Except capacity and delay, all else unchanged
- Lack of consideration of demand adjustment and response from fare, flight traffic, aircraft size

**Prediction of the future**

- Excessive delays
- Trim flights in an arbitrary manner

**Benefits**

- Airline Cost
- Passenger travel time
- Flight Delay

**Infrastructure**

**Capacity**

**Investment**
Research Objective

Develop a new benefit assessment methodology that better captures the system response to capacity change
A congestion-free air transport system with economies of density

- Higher density
  - More flight-miles
    - Improved service quality
    - Reduced generalized cost
      - More demand
  - Lower unit cost
    - Lower fare
With congestion, the positive feedback loop is disrupted

- Higher density
- More flight-miles
- Improved service quality
- Lower unit cost
- Lower fare
- Reduced generalized cost
- More demand

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Demand as a function of passengers generalized cost

![Graph showing demand as a function of generalized cost. The graph includes two supply curves, S0 and S1, and a demand curve. The point B represents the intersection of the demand curve and the S0 supply curve, indicating the market equilibrium where demand equals the unconstrained supply. The point G represents the intersection of the demand curve and the S1 supply curve, indicating a higher cost and potentially lower demand.]

- **S0**: Unconstrained supply
- **S1**: Constrained supply 1
Capacity increase marks down the generalized cost

<table>
<thead>
<tr>
<th>S0: Unconstrained supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1: Constrained supply 1</td>
</tr>
<tr>
<td>S2: Constrained supply 2</td>
</tr>
</tbody>
</table>

Demand

Generalized cost ($/mile)

Demand

S0: Unconstrained supply
S1: Constrained supply 1
S2: Constrained supply 2

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Proposed framework

Operational
Performance

Investment
Infrastructure
Capacity
Proposed framework

- Passenger Demand
- Flight Traffic
- Operational Performance
- Airline Cost
- Air Fare

Investment

Infrastructure Capacity
Proposed framework

Previous studies only consider part of the system components and causal relationships, with focus on one single airport

Morrison and Winston (1983; 1989; 2007); Jorge and de Rus (2004); Miller and Clarke (2008), etc.
Introduction of basic concepts

Route
Segment
Market

Spoke city A
Spoke city B
Hub city C

Non-stop Route
One-stop Route

Spoke airport A
Spoke airport B
Hub airport C
Proposed framework

Maximizing Profit (Producer Surplus)

Passenger Demand → Airline Cost → Operational Performance → Flight Traffic → Passenger Demand

Break-even in the long run

Investment
Infrastructure Capacity
Production output
Air Fare

Airline Cost → Operational Performance

Maximizing Profit (Producer Surplus)

Production output
Proposed framework

- Passenger Demand
- Flight Traffic
- Operational Performance
- Airline Cost
- Air Fare
- Maximizing Profit (Producer Surplus)

Investment
Infrastructure Capacity
Production output
Component Estimation
Databases used

- DB1B Airline Origin Destination Survey Data
- T100 Flight Segment Traffic Data
- BTS Airline On-time Performance Data
- FAA Aviation System Performance Metric (ASPM) Data
- Bureau of Economic Analysis Regional Economic Accounts
System component estimation

- Passenger Demand
- Flight Traffic
- Air Fare
- Operational Performance
## System component estimation

### 3-Level NL (Hsiao and Hansen, 2011)
Dependent variable: route market share

### Selected estimation results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Est.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fare (hundreds of 2004 dollars)</td>
<td>-1.546***</td>
</tr>
<tr>
<td>ln(Frequency)—Direct (flights per quarter)</td>
<td>1.240***</td>
</tr>
<tr>
<td>ln(Max frequency of two segments)—Connecting (flights per quarter)</td>
<td>0.627***</td>
</tr>
<tr>
<td>ln(Min frequency of two segments)—Connecting (flights per quarter)</td>
<td>0.957***</td>
</tr>
<tr>
<td>Scheduled flight time—Direct (min)</td>
<td>-0.004*</td>
</tr>
<tr>
<td>Scheduled flight time—Connecting (min)</td>
<td>-0.006***</td>
</tr>
<tr>
<td>Positive hub arrival delay (_{t-1}) (min/flight)</td>
<td>-0.006***</td>
</tr>
<tr>
<td>Positive hub arrival delay (_{t-4}) (min/flight)</td>
<td>-0.007***</td>
</tr>
</tbody>
</table>

*** Significant at 1% level; * Significant at 10% level
System component estimation

<table>
<thead>
<tr>
<th>Passenger Demand</th>
<th>Flight Traffic</th>
<th>Air Fare</th>
<th>Operational Performance</th>
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</table>

Log-log model
Dependent variable: segment frequency
System component estimation

Log-log model
Dependent variable: segment frequency

Selected estimation results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Est.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment passenger volume</td>
<td>0.6483</td>
<td>0.000</td>
</tr>
<tr>
<td>Segment distance</td>
<td>-0.3657</td>
<td>0.000</td>
</tr>
<tr>
<td>Segment Herfindahl Hirschman Index (HHI)</td>
<td>-0.3166</td>
<td>0.000</td>
</tr>
<tr>
<td>Origin airport HHI</td>
<td>-0.0383</td>
<td>0.000</td>
</tr>
<tr>
<td>Destination airport HHI</td>
<td>-0.0419</td>
<td>0.000</td>
</tr>
<tr>
<td>Origin delay (four quarters lag)</td>
<td>-0.0221</td>
<td>0.053</td>
</tr>
<tr>
<td>Destination delay (four quarters lag)</td>
<td>-0.0238</td>
<td>0.038</td>
</tr>
<tr>
<td>R²</td>
<td></td>
<td>0.8947</td>
</tr>
</tbody>
</table>

Segment passenger volume: 0.65

Flight frequency increases at a slower rate than passenger volume.

Origin/Destination delay: ~0.02

10 percent increase in delay at one airport would decrease frequency by 0.2 percent.
System component estimation

<table>
<thead>
<tr>
<th>Passenger Demand</th>
<th>Flight Traffic</th>
<th>Air Fare</th>
<th>Operational Performance</th>
</tr>
</thead>
</table>

Log-log model  
Dependent variable: yield ($/passenger-mile)
System component estimation

Log-log model
Dependent variable: yield ($/passenger-mile)
2SLS

Selected estimation results: Non-stop routes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Est.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route passengers</td>
<td>-0.0194</td>
<td>0.014</td>
</tr>
<tr>
<td>Market distance</td>
<td>-0.6833</td>
<td>0.000</td>
</tr>
<tr>
<td>Origin delay (four quarters lag)</td>
<td>0.0499</td>
<td>0.000</td>
</tr>
<tr>
<td>Destination delay (four quarters lag)</td>
<td>0.0547</td>
<td>0.000</td>
</tr>
<tr>
<td>Route HHI</td>
<td>0.0438</td>
<td>0.009</td>
</tr>
<tr>
<td>Market HHI</td>
<td>0.0336</td>
<td>0.007</td>
</tr>
<tr>
<td>Origin airport HHI</td>
<td>0.0103</td>
<td>0.130</td>
</tr>
<tr>
<td>Destination airport HHI</td>
<td>0.0132</td>
<td>0.054</td>
</tr>
<tr>
<td>R²</td>
<td></td>
<td>0.8512</td>
</tr>
</tbody>
</table>

Route passengers: -0.02
Cost effect from economies of density dominates over demand effect

Origin/Destination delay: ~0.05
10 percent increase in delay at origin/destination airport would increase yield by 0.5 percent
System component estimation

<table>
<thead>
<tr>
<th>Passenger Demand</th>
<th>Flight Traffic</th>
<th>Air Fare</th>
<th>Operational Performance</th>
</tr>
</thead>
</table>

Log-log model
Dependent variable: yield ($/passenger-mile)
2SLS

Selected estimation results: One-stop routes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Est.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route passengers</td>
<td>0.0458</td>
<td>0.000</td>
</tr>
<tr>
<td>Sum of segment density</td>
<td>-0.0118</td>
<td>0.000</td>
</tr>
<tr>
<td>Circuity</td>
<td>-0.3154</td>
<td>0.000</td>
</tr>
<tr>
<td>Market distance</td>
<td>-0.6510</td>
<td>0.000</td>
</tr>
<tr>
<td>Origin delay (four quarters lag)</td>
<td>0.0219</td>
<td>0.000</td>
</tr>
<tr>
<td>Destination delay (four quarters lag)</td>
<td>0.0245</td>
<td>0.000</td>
</tr>
<tr>
<td>Hub delay (four quarters lag)</td>
<td>0.0221</td>
<td>0.000</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td>0.5164</td>
</tr>
</tbody>
</table>

**Sum of segment density: -0.012**
Economies of density contribute to lower fare

**Origin/Destination/Hub delay: ~0.02**
10 percent increase in delay at origin/destination/connecting airport would increase yield by 0.2 percent
System component estimation

Log-linear model
Dependent variable: average airport delay
System component estimation

Log-linear model
Dependent variable: average airport delay

**Selected estimation results**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Est.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of time under IFR conditions (IFR)</td>
<td>1.1283</td>
<td>0.000</td>
</tr>
<tr>
<td>IFR&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-0.7089</td>
<td>0.000</td>
</tr>
<tr>
<td>Average wind speed</td>
<td>0.0168</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Traffic volume/airport capacity (VC)</strong></td>
<td>1.0192</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>VC&lt;sup&gt;2&lt;/sup&gt;</strong></td>
<td>1.1747</td>
<td>0.000</td>
</tr>
<tr>
<td>Traffic volume</td>
<td>-0.0017</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Standard deviation of scheduled flights (peakedness)</strong></td>
<td>0.1774</td>
<td>0.000</td>
</tr>
<tr>
<td>R&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td>0.5064</td>
</tr>
</tbody>
</table>

**VC: 1.0192; VC<sup>2</sup>: 1.1747**
Increase in VC ratio increases delay

**Std. dev. of scheduled flights: 0.1774**
Increase in schedule peakedness increases delay
Summary of component model estimation

- All else being equal, higher delay leads to
  - Lower one-stop route demand (higher hub delay)
  - Lower total market demand
  - Lower flight frequency
  - Higher air fare

- Delay effect on fare and frequency not substantial – demand will be the main driver in equilibrium
System Integration
Network topologies

- 50 spoke cities uniformly located on the circle
- Hub city at the center
- \( R = 400 \) miles
- Each city has one airport
- Air service provided between any two airports
- Population
  - 10m for the hub city
  - 2m for spoke cities
Proposed framework

- Existence: Brouwer’s fixed point theorem guarantees at least one solution exists
- Uniqueness & convergence: different starting values converge to the same equilibrium
Initial equilibrium: results (I)

**Demand**

- Non-stop Route
- One-stop Route
- Total

**Air Fare**

- Non-stop Route: Spoke-Spoke
- One-stop Route: Spoke-Hub-Spoke
Initial equilibrium: results (II)

Flight frequency

Number of passengers per flight

Segment Distance (miles)

Flight Frequency

Number of Passengers per Flight
Initial equilibrium: results (III)

Airport delays

Average delay (min/flight)

<table>
<thead>
<tr>
<th></th>
<th>Hub</th>
<th>Spoke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay (min/flight)</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>

The graph shows the comparison of average delays between Hub and Spoke airports.
Equilibrium shift due to capacity increase

- Five scenarios: increase hub capacity by 10, 20, 30, 40, 50%
- Compute new equilibrium under each scenario

![Graph showing airport delays under different capacity increase scenarios.](Image)
Equilibrium shift: demand and fare

**Demand**

- Baseline
- 50% Capacity Increase
- Non-stop Cluster
- One-stop Cluster

**Air Fare Change**

- Capacity Increase Direction: One-stop Cluster
- Capacity Increase Direction: Non-stop Cluster
Equilibrium shift: frequency and number of passengers per flight
Equilibrium shift: consumer benefits

System-wide consumer benefit gains (million$/qtr)

<table>
<thead>
<tr>
<th>capacity increase percentage</th>
<th>Logsum measure</th>
<th>Rule of half: same proportional route price change</th>
<th>Rule of half: same absolute route price change</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>51.8</td>
<td>55.2</td>
<td>55.3</td>
</tr>
<tr>
<td>20%</td>
<td>96.7</td>
<td>104.2</td>
<td>104.4</td>
</tr>
<tr>
<td>30%</td>
<td>139.8</td>
<td>150.9</td>
<td>151.3</td>
</tr>
<tr>
<td>40%</td>
<td>180.2</td>
<td>194.7</td>
<td>195.3</td>
</tr>
<tr>
<td>50%</td>
<td>218.4</td>
<td>236.1</td>
<td>236.9</td>
</tr>
</tbody>
</table>
Sensitivity analysis: consumer benefit gains

<table>
<thead>
<tr>
<th>Capacity increment</th>
<th>90000</th>
<th>110000</th>
<th>130000</th>
<th>150000</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
<td>46.2</td>
<td>38.1</td>
<td>33.0</td>
<td>29.0</td>
</tr>
<tr>
<td>16000</td>
<td>40.2</td>
<td>36.5</td>
<td>31.6</td>
<td>27.9</td>
</tr>
<tr>
<td>24000</td>
<td>38.9</td>
<td>33.6</td>
<td>30.1</td>
<td>26.3</td>
</tr>
<tr>
<td>32000</td>
<td>36.8</td>
<td>32.5</td>
<td>28.5</td>
<td>24.9</td>
</tr>
<tr>
<td>40000</td>
<td>35.0</td>
<td>31.2</td>
<td>27.0</td>
<td>23.6</td>
</tr>
<tr>
<td>48000</td>
<td>33.3</td>
<td>29.2</td>
<td>25.6</td>
<td>22.4</td>
</tr>
</tbody>
</table>

Diminishing return to baseline capacity and capacity investment
Comparison with conventional method: passenger benefits

Baseline hub capacity: 1000 ops/day; increase by 50%

<table>
<thead>
<tr>
<th>Time</th>
<th>Income per capita</th>
<th>Population</th>
<th>Flight traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 5</td>
<td>10%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Year 10</td>
<td>21%</td>
<td>11%</td>
<td>22%</td>
</tr>
</tbody>
</table>

Assumptions about growth

Conventional method underestimates consumer benefit gain

Equilibrium approach: Logsum
Conventional method: (delay savings) * VOT * (number of passengers)
Conclusions

- This research proposes an equilibrium framework to assess benefits from aviation infrastructure investment

- Major findings
  - Capacity change engenders system equilibrium shift, leading to adjustment in passenger demand, air fare, flight frequency, number of passengers per flight, and delay
  - The effect of delay on fare and frequency is limited; demand is the main driver in system equilibrium shift
  - Equilibrium approach is able to capture benefits beyond delay reduction
Thanks you!
Question?