Optimal Air Traffic Delays

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Joint work with Marc Ivaldi, Emile Quinet and Etienne de Villemeur
Commercial flights and delays at the 15 biggest airports in France
Legislation

  - Increase monetary compensations for denied boarding
  - Includes compensations for some kind of delays
  - Include compensations for long delays

- Airlines: increase in costs that will be translated to an increase in price.
Two issues

- How do we measure delays?
- Are delays so bad?
Definition of delays

- Difference between scheduled arrival time and real arrival time
- Buffer time or buffer delays: extra time added to the minimum required travel time
- Few studies about buffer time:
Buffer time

$\phi(\varepsilon)$

$T_{ij}$  \quad $\xi$  \quad $\varepsilon$

Buffer time  \quad Observed delays
## Empirical Studies

<table>
<thead>
<tr>
<th></th>
<th>ITA</th>
<th>Madrid Airport</th>
<th>Westminster Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market and time coverage</td>
<td>Europe 1999</td>
<td>Madrid Airport July 1997-2000</td>
<td>Europe 2004</td>
</tr>
<tr>
<td>Studied costs</td>
<td>Passengers and airlines</td>
<td>Passengers and airlines</td>
<td>Airlines</td>
</tr>
<tr>
<td>Delays</td>
<td>Schedule and buffer</td>
<td>Schedule</td>
<td>Schedule and buffer</td>
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<tr>
<td>Estimated Costs</td>
<td>Airlines</td>
<td>2364-2916 €/hour</td>
<td>5000 €/hour</td>
</tr>
<tr>
<td></td>
<td>Passengers</td>
<td>44.6-60 €/hour</td>
<td>15,9 €/hour</td>
</tr>
</tbody>
</table>
Theoretical Models of Congestion

- Modeling the queues due to congestion
- Brueckner (2002): carriers internalize the congestion they impose in themselves
- To study delay costs, we should not consider the whole delay.
Model: Definition of delays

- **Optimal delay**
  - Value of delays that maximizes social welfare
  - Social welfare = Firm’s profits + Consumer Surplus

- **Equilibrium delay**
  - Value of delays that maximizes firm’s profit
Methodology

- **Step 1: Computation of equilibrium delays**
  - The observed data are assumed to obey the equilibrium conditions
  - Invert the relationship to obtain the parameters of demand
  - Recover welfare function from the demand function

- **Step 2: Computation of optimal delays**
  - Maximization of welfare

- **Step 3: Evaluation of the cost of delays**
  - Welfare at optimum-Welfare at equilibrium
Estimation of the optimal delay in the case of a specific network
Components and assumptions of the model

- Hub-and-spokes network
  \[ C_{ij}(X_{ij}) = F + (\alpha + \beta X_{ij})T_{ij} \]

- Stochastic delay \( \varepsilon_{ij} \sim \Phi(\varepsilon_{ij}) \)

- Airline introduce \( \zeta_{ij} \) to control for delays

- Passengers connect at the hub

- Airline introduces \( \delta \) and can introduce \( \gamma \)
  \[ \gamma \leq \delta \]
Demand functions

- Firm is a monopoly
- Faces 6 demands

\[ X_{12} = a_{12} + b_{12} \left( P_{12} + v \left( T_{12} + \zeta_{12} + r \int_{\xi_{12} + s_d}^{\infty} \left( \varepsilon - \zeta_{12} \right) \phi_{12} (\varepsilon) d\varepsilon \right) \right) \]

- Firm maximize profits with respect to \( P_{ij}, \zeta_{ij}, \delta \) and \( \gamma \)
Demand functions

\[
X_{23} = a_{23} + b_{23} \left( P_{23} + v \right) \left( T_{23} + \zeta_{23} + r \left( \int_{\zeta_{12}+\delta}^{\infty} (\epsilon_{12} - \zeta_{12} - \delta + \epsilon_{23} - \zeta_{23}) \phi_{23}(\epsilon_{23}) \phi_{12}(\epsilon_{12}) \, d\epsilon_{23} \, d\epsilon_{12} \right) + \int_{0}^{\infty} \phi_{12}(\epsilon_{12}) \, d\epsilon_{12} + \int_{\zeta_{12}+\delta+\gamma}^{\infty} \phi_{23}(\epsilon_{23}) \, d\epsilon_{23} \right) \right)
\]

\[
X_{123} = a_{123} + b_{123} \left( P_{123} - C_{ij} \Pr\,\text{loose} + vE_{t_{123}} \right)
\]

\[
E_{t_{123}} = T_{12} + \zeta_{12} + T_{23} + \zeta_{23} + \delta + \delta + \left( \int_{\zeta_{12}+\delta}^{\infty} (\epsilon_{12} - \zeta_{12} - \delta + \epsilon_{23} - \zeta_{23}) \phi_{23}(\epsilon_{23}) \phi_{12}(\epsilon_{12}) \, d\epsilon_{23} \, d\epsilon_{12} \right) + \int_{0}^{\infty} \phi_{12}(\epsilon_{12}) \, d\epsilon_{12} + \int_{\zeta_{12}+\delta+\gamma}^{\infty} \phi_{23}(\epsilon_{23}) \, d\epsilon_{23} \right) \right) \right)
\]

\[
+ E\,w_{t}(1 - \Phi_{12}(\zeta_{12} + \delta + \gamma))
\]
## Data

<table>
<thead>
<tr>
<th>Direct Flights</th>
<th>Toulouse-Paris</th>
<th>Paris-Nice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total passengers</td>
<td>177414</td>
<td>166831</td>
</tr>
<tr>
<td>Total number of flights</td>
<td>1432</td>
<td>1228</td>
</tr>
<tr>
<td>Average Passengers per flight</td>
<td>123.9</td>
<td>135.9</td>
</tr>
<tr>
<td>Travel time (minutes)</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>Frequencies&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.5</td>
<td>20.1</td>
</tr>
<tr>
<td>Airplane&lt;sup&gt;b&lt;/sup&gt;</td>
<td>A320</td>
<td>A320</td>
</tr>
<tr>
<td>Capacity&lt;sup&gt;c&lt;/sup&gt;</td>
<td>161.9</td>
<td>168.1</td>
</tr>
<tr>
<td>Average occupation</td>
<td>76.5%</td>
<td>80.8%</td>
</tr>
</tbody>
</table>

<sup>a</sup> Average frequency of flights per day;  
<sup>b</sup> Most frequent plane;  
<sup>c</sup> Average capacity of the used planes on the route
Results

- **Calibration**

  \[ \begin{aligned}
  v &\in (0.5, 0.9) \\
  r &\in (0.95, 1.96) \\
  v_r &\in (0.84, 0.93)
  \end{aligned} \]

- **Optimal delays and optimal buffer time**
  - Buffer decreases more than 50%
  - Extra delays decreases and dissapears in most of the cases
Conclusions

- Under the assumptions of linear demand, monopoly and same value of time for all the passengers we obtain that the buffer time as well as extra delays introduced by the airline should decrease.
- The introduction of compensation for long delays lead airlines to increase their prices. Overall effect over welfare is always negative.