Game Theory & Transportation Markets: overcoming regulatory failure

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Motivation

- Present system in EU is composed of 37 national providers
  - Compared to FAA, EU system is 34% more costly (2011)

**Barriers to Cost Efficiency:**
- Ownership form: governmental organizations
- Fragmentation: missing economies of scale
- Protectionism: power of Labor Unions & member states
- Weak regulation: failure to implement FABs or strict price-caps

**Barriers to Increasing Capacity:**
- New technologies estimated cost: 30 billion euro
- Relatively low congestion currently
- Opposition to change / fear of technology
European Air Traffic Control System: weak regulators?

• European Union:
  – 2004 Law: cooperation between air traffic control providers through functional airspace blocks (FAB)
  – 2009 Law: economic regulation passed from Member States to European Union
    • price cap replacing cost plus approach
    • data collected regularly since 2002 enabling benchmarking approach
European Air Traffic Control System: too many suppliers?

- European Union:
  - 2004 Law: cooperation between providers through functional airspace blocks (FAB)
  - Reduce suppliers from 37 to 9 FAB
how could cost efficiency and technology adoption be encouraged simultaneously?

– changes in ownership form
  • horizontal integration
  • vertical integration
  • commercialization / privatization

– changes in pricing regulation
  • strict individual price-caps
  • peak / off peak charges
  • hybrid price-caps

– changes in capacity
  • adopting new technologies
Outline of talk

• Literature search
• Model to analyse change in ownership form
  • 2-stage network congestion game with auctioning
    • 1st stage: air navigation service providers
    • 2nd stage: airlines
  • Numerical results for West European case study

• Conclusions & Future Research
  • Theoretical
    • sub-game perfect outcome different to Wardrop & potential game solutions
  • Case study
    • privatization or commercialization will reduce charge by around 50%
    • regulator still needs to set minimum capacities

Adler, Hanany & Proost
Literature Search

- **Air Traffic Control**
  - On the US system:
  - On the European system:
    - Lulli & Odoni (2007)
    - Castelli, Labbe and Violin (2013), Jovanovic et al. (2014)
    - Button and Neiva (2014)

- **Network congestion games**
  - Network Equilibria:
    - Wardrop (1952)
  - Sub-game Perfect Nash Equilibria:
    - Selten (1975), Myerson (2013)
2 stage network congestion game

- **Stage 1: Providers set prices, labor & technology levels**
  - En-route providers set peak/off-peak charges
    - may be price capped according to regulatory rules
    - capacity = f(labor levels, technology investment, size of airspace)
  - Terminal providers limit flights in peak
    - form of slot allocation

- **Auction:**
  - sealed bid, lexicographic
    - 1st peak price; 2nd off-peak price; 3rd home bias; 4th capacity
  - complete information
  - combinatorial with inter-dependent valuations
Air navigation service provider objective function

- Business as Usual
  - government organization
  - set charges according to price caps
  - maximize labor
  - examples: DFS (Germany) and DSNA (France)

- Non-profit public companies
  - set charges to cover costs
  - maximize capacity according to company charter
  - airlines on Board of public company
  - example: NavCanada

- For-profit private companies
  - maximize profits
  - example: NATS (public-private partnership in UK)
Business as usual

- **Objective function**
  - Maximize labor rents

- **Constraints**
  - Production function
  - Zero profits
  - Price caps
  - Lower bounds on labor & technology

\[
\begin{align*}
\text{Max } & \quad l_s \\
\zeta(l_s)^\alpha(t_s)^\beta & = k_s \\
\sum_{b \in B^E} h_{sb} \left( \sum_w \tau_{sbw} F_{bw}^* \right) - c_s^{st} l_s - c_s^{st} t_s & = 0 \\
0 & \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau_{sb}^0 \quad \forall \ s, b \\
l_s & \geq l', t'' \geq t_s \geq t' \quad \forall \ s
\end{align*}
\]
For-profit auctions

• Objective function: maximize profit

\[
\text{Max } - c_s^{sl} l_s - c_s^{st} t_s \\
+ \sum_{b \in B^E} \left\{ \sum_w \tau_{sbw} (F_{bw}^* + \max\{0, \varphi_{bw}^+ (F_{bw}^* - f_{bw}^0)\} - \max\{0, \varphi_{bw}^- (f_{bw}^0 - F_{bw}^*)\}) \right\} \text{ if } Y_b = \{s\} \\
\text{otherwise}
\]

• Constraints
  – Maximum # auctions
  – Production function
  – Lower bounds on labor & technology

\[
\sum_{b \in B^E} X_{sb} \leq v^E \ \forall \ s
\]

\[
\zeta(l_s)^\alpha(t_s)^\beta \left( \sum_{b|Y_b=\{s\}} d_b \right)^\gamma = K_s^e
\]

\[
0 \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau_{sb}^0 \ \forall \ s, b
\]

\[
l_s \geq l', t'' \geq t_s \geq t' \ \forall \ s
\]
Non-profit auctions

- **Objective function: goal program**

\[
\max K^e_s - \xi \left| \sum_{b \in B^E} \sum_w (\tau_{sbw} F^*_{bw} - C_{s}^{Sl} l_s - C_{s}^{St} t_s) \right|
\]

- **Constraints**
  - Maximum # auctions
  - Production function
  - Lower bounds on labor & technology

\[
\sum_{b \in B^E} X_{sb} \leq u^E \ \forall \ s
\]

\[
\zeta (l_s)^{\alpha} (t_s)^{\beta} \left( \sum_{b \mid y_b = \{s\}} d_{b} \right)^{\gamma} = K^e_s
\]

\[
0 \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau^0_{sb} \ \forall \ s, b
\]

\[
l_s \geq l', t'' \geq t_s \geq t' \ \forall \ s
\]
2 stage network congestion game

- **Stage 2 - Airlines choose flight paths given schedules**
  - minimize only self-inflicted delays
  - cost components:
    - operational
    - congestion
    - air traffic control en-route charges
    - + revenue loss because flying off-peak lowers airfares
  - option to ‘not fly’ necessary for demand elasticity

- **Note:**
  - Congestion is non-linear
  - Closer to capacity: the higher the delays

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2nd stage airline cost minimization: non-linear in congestion

- Objective function: non-linear cost minimization

\[ w_l = \sum_w \sum_{b \in \mathcal{B}} \sum_{a \in \mathcal{A}} \left[ C_{la}^0 \left( 1 - \max \left( \eta \left( \frac{K_{lb}^c}{k_b^0} - 1 \right), 0 \right) \right) + C_{lw}^R \right] + \sum_{l' \in \mathcal{L}} \left( \sum_{o \in \mathcal{O}} f_{lodaw} \right) + \delta_a \sum_{od} f_{lodaw} + \sum_{od} C_{od}^H f_{lod}^H \]

- Constraints
  - Meet demand at source, sink & transshipment nodes
    \[ \sum_{od} f_{lodaw} \leq K_{law}, \quad \forall l \in L, \forall a \in A, \forall w \in \mathcal{W} \]
  - Limited capacity (by 1st stage analysis)

\[ \sum_w \left[ \sum_{j \mid (o,j) \in A} f_{lod(o,j)w} - \sum_{j \mid (j,o) \in A} f_{lod(o,j)w} \right] + f_{lod}^T = D_{lod}, \quad \forall l \in L, \forall o, d \]

\[ \sum_w \left[ \sum_{j \mid (d,j) \in A} f_{lod(d,j)w} - \sum_{j \mid (j,d) \in A} f_{lod(d,j)w} \right] + f_{lod}^T = D_{lod}, \quad \forall l \in L, \forall o, d \]

\[ \sum_{j \mid (j,i) \in A} f_{lod(j,i)w} - \sum_{j \mid (i,j) \in A} f_{lod(i,j)w} = 0, \quad \forall l \in L, w \in \mathcal{W}, \forall o, d, i \in N (i \neq o, d) \]
In stage 0, the government sets:

$v^E$ maximum number of auctions that en-route ATC providers are permitted to compete

$f_{bw}^0$ minimum level of service i.e. number of flights to be served with minimal delay in airspace $b$ in time window $w$

$\varphi_{bw}^+, \varphi_{bw}^-$ fraction increase (or decrease) in charge permitted for providing output above (or below) the minimum service level requirement in airspace $b$ in time window $w$
Case Study of Western Europe
### Results: no tender (1/3)

#### Business as usual

<table>
<thead>
<tr>
<th>ANSPs</th>
<th>UK</th>
<th>Netherlands</th>
<th>Germany</th>
<th>Belgium</th>
<th>France</th>
<th>Spain</th>
<th>Labour (000 €)</th>
<th>Tech level</th>
<th>Revenues (000 €)</th>
<th>Profits (000 €)</th>
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<tr>
<td>NATS</td>
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<td>DFS</td>
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<td>0.81</td>
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<td>1,472</td>
<td>1.00</td>
<td>1,071,714</td>
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<td>Belgocontrol</td>
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<td>0.95</td>
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<td>310</td>
<td>1.00</td>
<td>267,411</td>
<td>25,965</td>
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<td>DSNA</td>
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<td>2,442</td>
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<td>805</td>
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<tr>
<td><strong>Annual Totals</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>5,806</strong></td>
<td></td>
<td><strong>4,668,486</strong></td>
<td></td>
</tr>
</tbody>
</table>

- Labor rent seekers
  - Labor levels higher than the 5,000 currently employed; std. technology level
  - Profits approx. 20% as occurs today

-- Prices set at price cap
Results: with tender (2/5)

For Profit en-route providers

<table>
<thead>
<tr>
<th>For-profit</th>
<th>Price in € per peak / off-peak per seat per km</th>
<th>Labor</th>
<th>Tech level</th>
<th>Revenues (000 €)</th>
<th>Profits (000 €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014 ANSPs</td>
<td></td>
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<td></td>
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<tr>
<td>6. Germany</td>
<td>0.45 0.45 0.45 0.45</td>
<td>1,021</td>
<td>2</td>
<td>790,995</td>
<td>8,096</td>
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<td>7. Belgium</td>
<td>0.32 0.32 0.49 0.49</td>
<td>276</td>
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<td>9,242</td>
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<td>10. France</td>
<td>0.29 0.29 0.43 0.43</td>
<td>1,219</td>
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<td>44,963</td>
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<tr>
<td>Annual Totals</td>
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<td></td>
<td>2,034,225</td>
<td>62,302</td>
</tr>
</tbody>
</table>

- 3 companies remain
  - Germany/Holland; UK/Belgium; France/Spain
- New technologies adopted in full
- Revenues halved compared to current equilibria outcome
- Profits around 5%
### Results: with tender (3/3)

**Non-profit en-route providers**

<table>
<thead>
<tr>
<th>Non-profit</th>
<th>Price in € per peak / off-peak per km</th>
<th>Labor</th>
<th>Tech level</th>
<th>Revenues (000€)</th>
<th>Profits (000 €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSPs</td>
<td>UK</td>
<td>Holland</td>
<td>Germany</td>
<td>Belgium</td>
<td>France</td>
</tr>
<tr>
<td>1 UK</td>
<td>1.01</td>
<td>0.79</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5 Germany</td>
<td>0.15</td>
<td>0.15</td>
<td>0.81</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>7 Belgium</td>
<td></td>
<td></td>
<td>0.81</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>10 France</td>
<td></td>
<td></td>
<td>0.24</td>
<td>0.24</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>Annual Totals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 4 companies survive
  - UK; Germany/Holland; Belgium; France/Spain
- Charges
  - external regions more expensive, competitive regions cheaper than for-profit outcome
  - but overall revenues lower and not sustainable in longer term
- Mixed pattern of technology adoption & fewer controllers than for-profit (i.e. lower capacity)
General conclusions

• Modeling ATC via 2-stage game enables cost-benefit analysis including distributional effects across stakeholders

• Single European Skies Initiative:
  • Lower costs
    • defragmentation via FABS
    • price regulation
  • Increased capacity
    • SESAR

• How to achieve these goals? auction ATC provision en-route
  • similar to that of airport terminal provision in Spain, Sweden, UK...
  • leads to defragmentation of European airspace
    • around 5 companies will survive if market share cap of 20%
  • charges as much as halved
    • potentially removes need for price regulation
Specific Conclusions

• Auction Rules:
  – Very important: multiple bidders
  – Pressures on capacity thus need to set minimum levels
  – Should permit charges to increase/decrease as function of service levels

• Regulation:
  – Safety regulators (EASA, NSA…) need to continue
  – Data collection (STATFOR) would need to continue to check capacity levels
  – Economic regulator (PRB) may be less necessary

• Ownership form:
  – For Profits: most effective solution
  – Non-Profits: provides a solution between current equilibria outcome and for-profit potential solution