Delay Reduction Service in the ATM

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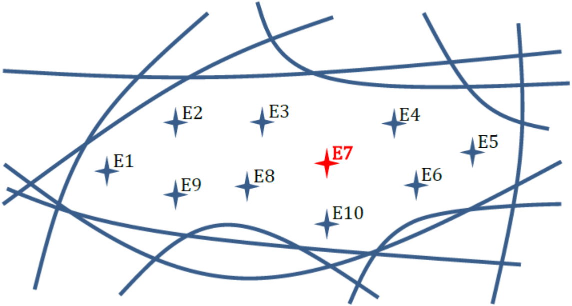
Background

- Aviation in future EU: rapid growth and severe air traffic delay.
- Delay harms society: airlines and passengers.
- Single European Sky ATM Research programme (SESAR) founded by European Union and EUROCONTROL: satisfying future safety needs and **reducing delay**s.
- Air Navigation Service Provider (regulator) can provide **delay reduction service**.

Delay Reduction Service: An Example

- Airline will contact regulator when facing potential delay.
- Regulator can find out several equilibria satisfying all constraints.
- By costly calculation, evaluation, and coordination, regulator can determine the equilibrium which can reduce delay most and then implement it.



Delay Reduction Contract: A Real Problem

- In the short run, delay reduction service can be provided for free because of generous funds of SESAR.
- In the long run, however, regulator will face financial constraints.
- Delay reduction contract: authority is thinking about asking airlines to pay for funding the service.

Research Question and Contribution

- Research question: study the optimal design of delay reduction contracts.
- Build a model which fits characteristics of EU air transport sector.
  - Slot controls and thus no congestion of flights at all major European airports $\Rightarrow$ A delay function only including exceptional event delay.
  - Grandfather right and "use it or lose it" rule in EU slot allocation mechanism $\Rightarrow$ Fixed number of flights.
- Derive optimal contracts analytically.
  - With or without using public funds.
- Study the effects of some relevant exogenous variables on optimal contracts.
  - Safety standard and passenger's value of time.

The Model: Harm of Delay to Passengers

- Passenger utility: $v = y - p + b + a(s) - \alpha D(s)$.

  s: safety standard.

  α: passenger's value of time.

  $D(s)$: expected delay per flight, i.e., exceptional event delay.

$$D(s) = 2\left[\underbrace{\sum_{k=0}^{+\infty} \frac{\left(\frac{\beta T}{f}\right)^k e^{-\left(\frac{\beta T}{f}\right)}}{k!} kg(s)}_{\text{i}} + \underbrace{\gamma\beta\left(\frac{T}{f}\right)^{-1} g(s)}_{\text{ii}}\right].$$

  i: delay due to exceptional events in own slot.

  ii: delay induced by the delayed flights in previous slots.

- Outside option: $v_0 = y + z$.

The Model: Harm of Delay to Airline

- Monopoly airline's profit:

$$
\begin{aligned}
\pi(\theta, s) &= p(s)\,q(s) - (\tau q(s) + cf + \theta f D(s)) \\
&= \underbrace{-\frac{1}{4}\eta\left[2(\xi - \tau + a(s) - z) - \alpha D(s)\right]\alpha D(s)}_{\text{demand side delay cost}} \\
&\quad - \underbrace{\theta f D(s)}_{\text{supply side delay cost}} \\
&\quad + \frac{1}{4}\eta(\xi - \tau + a(s) - z)^2 - cf.
\end{aligned}
$$

θ: airline's value of time; may be unobservable to regulator; common knowledge: $\theta \in \left\{\overline{\theta}, \underline{\theta}\right\}$.

The Model: Delay Reduction

- Delay reduction contract (r, t).

  r: degree of delay reduction service.

  t: transfer.

- An airline who signs a delay reduction contract (r, t) decreases its delay from $D(s)$ to $D(s)[1 - \sigma \ln(1 + r)]$ where $\sigma \in [0, \overline{\sigma}]$.

  σ: a parameter which measures the effectiveness of service.

The Model: Benefit of Service

$$\Pi(\theta, s, r) = \underbrace{\pi(\theta, s)}_{\text{initial profit}} + \underbrace{\frac{1}{4}\eta\alpha^2 D(s)^2 \sigma^2 [\ln(1+r)]^2 + q(s)\alpha D(s)\sigma \ln(1+r)}_{\text{demand side delay reduction benefit}}$$
$$+ \underbrace{\theta f D(s)\sigma \ln(1+r)}_{\text{supply side delay reduction benefit}}$$

$$CS(s, r) = \underbrace{cs(s)}_{\text{initial consumer surplus}}$$
$$+ \underbrace{\frac{1}{2}\left\{\frac{1}{4}\eta\alpha^2 D(s)^2 \sigma^2 [\ln(1+r)]^2 + q(s)\alpha D(s)\sigma \ln(1+r)\right\}}_{\text{consumer delay reduction benefit}}$$

The Model: Regulator's Problem

- Regulator's cost: $C_{reg}(s,r) = m(s)\,r$.
- Regulator maximizes social welfare:

$$W = CS(s,r) + \Pi(\theta,s,r) - C_{reg}(s,r) - \lambda\left(C_{reg}(s,r) - t\right)$$
$$\text{s.t. } t \leqslant C_{reg}(s,r).$$

- $t = C_{reg}(s,r)$: without using public funds.
  - Separating contracts: not incentive-compatible $\Rightarrow$ pooling contract.
- $t < C_{reg}(s,r)$: with using public funds.
  - Separating contracts: incentive-compatible.
  - $\overline{r}^{FB} = \overline{r}^{SB} > \underline{r}^{FB} > \underline{r}^{SB}$.

The Effect of Safety Standard on Degree

- Notations
  - Safety elasticity of delay (cost): ε_{gs} (ε_{ms});
  - Marginal benefit (cost) of society: MB (MC).
- $s \uparrow \Rightarrow g(s) \uparrow$
  - $\Rightarrow MB \uparrow$ (direct effect, given $q(s)$ fixed);
  - $\Rightarrow q(s) \downarrow \Rightarrow MB \downarrow$ (indirect effect, allow $q(s)$ changes).
- $s \uparrow \Rightarrow a(s) \uparrow \Rightarrow q(s) \uparrow \Rightarrow MB \uparrow$.
- $s \uparrow \Rightarrow m(s) \uparrow$, i.e., $MC \uparrow$.
- Overall effect:

$$\frac{\partial \overline{r}^{SB}}{\partial s} \geqslant 0 \Leftrightarrow \varepsilon_{gs} - \varepsilon_{ms} \geqslant -A \cdot \frac{\partial \overline{V}\left(s, \overline{r}^{SB}\right)}{\partial s},$$

where $A \equiv \frac{(3+2\lambda)\eta\alpha D(s)\sigma s}{2(1+\lambda)\left(1+\overline{r}^{SB}\right)m(s)} > 0$.

The Effect of Passenger's Value of Time on Degree

- $\alpha \uparrow$
  - $\Rightarrow MB \uparrow$ (direct effect, given $q(s)$ fixed);
  - $\Rightarrow q(s) \downarrow \Rightarrow MB \downarrow$ (indirect effect, allow $q(s)$ changes).
- Overall effect:

$$\frac{\partial \bar{r}^{SB}}{\partial \alpha} \geqslant 0 \Leftrightarrow \alpha \leqslant \overline{\overline{\alpha}}^{SB} \equiv \frac{\xi - \tau + a(s) - z}{2D(s)\left[1 - \sigma \ln\left(1 + \bar{r}^{SB}\right)\right]}.$$