The environmental challenge in aviation: Can airport charges be part of the solution?

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September 2024

Introduction (1): Motivation

- Aviation has a remarkable **environmental footprint**
  - ◎ **Globally** ‣ WWF ‣ EU
    - ⟶ 3% of global CO_2 emissions
    - ⟶ 6% of CO_2 warming-equivalent emissions
  - ◎ **Locally**: NO_x and noise ‣ ICAO

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  - ◎ **Locally**: NO_x and noise ▸ ICAO
- Whole sector called into question ▸ health effects
  - ◎ Social movements like "flight shame"
  - ◎ Political initiatives like France's short-haul flight ban

Introduction (2): Motivation

- Technological innovation?
  - ◎ Electric-powered aircraft ×
  - ◎ Hydrogen-powered aircraft ×
  - ◎ Biofuels × (AIRBUS has interesting SAF projects...)

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- Technological innovation?
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  - ◎ Biofuels × (AIRBUS has interesting SAF projects...)
- **Market-based measures**
  - ◎ Increasing costs for airlines and/or PAX
  - ◎ Incentives for fleet renewal: new aircraft quieter and cleaner
  - ⟹ **airport charges can combine both!**

Introduction (3): Motivation

- **Aim of the paper**: strategic role of airport charges

Introduction (3): Motivation

- **Aim of the paper**: strategic role of airport charges
- **Methodology**
  - ⊚ Theoretical model
    - ⟶ effect of charges on p, f, and e
    - ⟶ welfare analysis
    - ⟶ interplay btw emission and non-emission charges
  - ⊚ Empirical application
    - ⟶ effect of charges on p and f (short-run)
    - ⟶ effect of charges on share of new aircraft ⟶ e (long-run)

Introduction (4): Literature

- **Theory**
  - ◎ Brueckner and Flores-Fillol (2007): duopoly p-and-f competition
  - ◎ Brueckner (2010) extends the analysis to n firms
  - ◎ Brueckner and Zhang (2010) extend the analysis to emissions

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- **Empirics**
  - ◎ Literature focused on determinants of charges

    Van Dender (2007), Bel and Fageda (2010), Bilotkach *et al.* (2012)...
  - ◎ On effects of EU ETS

    De Jong (2022), Fageda and Teixidó (2022 and 2023)...
  - ◎ On effects of flight-ticket taxes

    Borbely (2019), Falk and Hagsten (2019), and Bernardo *et al.* (2022)
  - ◎ On effects of charges on p and f $\longrightarrow$ Doi (2022)

Introduction (5): Main findings

- **Theory**

  ◎ Emission and non-emission charges $\uparrow \Longrightarrow p \uparrow$ and $f \downarrow$

  Only emission charges $\uparrow \Longrightarrow e \downarrow$

  ◎ Welfare analysis: overprovision of (polluting) f when e cause severe social damage

  ◎ Revenue-neutral airports can compensate rises in emission charges by lowering non-emission charges $\Longrightarrow$ incentives

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- **Conclusion**

  $\Longrightarrow$ **emission charges can contribute to sustainable aviation**

  $\Longrightarrow$ **there is room for increases in emission charges**

Plan of the talk

Model (1): Preferences and budget constraint

- $n \geqslant 2$ firms competing in p and f
- Preferences and budget constraint

$$U\left(a_i t_i, x\right) = \ln a_i t_i + x$$

$$x + z_i t_i = y$$

so that

$$t_i = \frac{1}{z_i}$$

- Finally, the indirect utility function becomes

$$U = \ln \frac{a_i}{z_i} + y - 1$$

Model (2): Total demand for carrier i

- An individual consumer will choose carrier i whenever

$$\ln \frac{a_i}{z_i} + y - 1 \geqslant \ln \frac{a_j}{z_j} + y - 1 \implies a_j \leqslant a_i z_j / z_i$$

- Brand loyalty

  ⊚ is consumer-specific and ranges between 0 and $\bar{a}_i \equiv \alpha$ for each carrier $i = 1, 2, ..., n$

  ⊚ follows a uniform distribution with density λ / α^n, where $\lambda > 0$ is market size

- Therefore, total demand for carrier i is

$$q_i = \int_{a_1=0}^{a_i z_1 / z_i} \int_{a_2=0}^{a_i z_2 / z_i} \cdots \int_{a_i=0}^{\alpha} \cdots \int_{a_n=0}^{a_i z_n / z_i} \underbrace{\frac{\lambda}{\alpha^n z_i}}_{t_i \frac{\lambda}{\alpha^n}} da_1 da_2 \cdots da_i \cdots da_n = \frac{\lambda \Pi_{j \neq i} z_j}{n z_i^n}$$

Model (3): Full price

- Full price

$$z_i = p_i + \frac{\gamma}{f_i}$$

- Schedule delay decreasing with $f \Longleftarrow$ Brueckner (2004), Brueckner and Flores-Fillol (2007 and 2020), and Bilotkach *et al.* (2010)

schedule delay

Model (4): Cost

- Supply and demand related by

$$\ell s_i f_i = q_i$$

- Airline i's *cost per flight*

$$C_i = \tau_p \ell s_i + \tau_f s_i + r_f e_i s_i + \frac{\varepsilon_f s_i}{e_i} + \theta$$

τ_p related to PAX per flight (ℓs_i); τ_f related to aircraft size/weight (s_i), and r_f related to aircraft emissions ($e_i s_i$)

- C_i / s_i falls with aircraft size $\Longrightarrow$ economies of traffic density
- *Total cost* for airline i

$$TC_i = C_i f_i = \left(\tau + r e_i + \frac{\varepsilon}{e_i} \right) q_i + \theta f_i$$

with $\tau \equiv \tau_p + \frac{\tau_f}{\ell}$, $r \equiv \frac{r_f}{\ell}$, and $\varepsilon \equiv \frac{\varepsilon_f}{\ell}$

Model (5): Profit

Carrier i's profits are

$$\pi_i = p_i q_i - TC_i = \left(p_i - \tau - re_i - \frac{\varepsilon}{e_i}\right) q_i - \theta f_i$$

or

$$\pi_i = \frac{\left(p_i - \tau - re_i - \frac{\varepsilon}{e_i}\right) \lambda \Pi_{j \neq i} \left(p_j + \frac{\gamma}{f_j}\right)}{n \left(p_i + \frac{\gamma}{f_i}\right)^n} - \theta f_i$$

Model (6): Environmental externality

Aircraft emissions produce a social damage

$$E = \eta_f \sum_{i=1}^{n} e_i s_i f_i = \frac{\eta_f}{\ell} \sum_{i=1}^{n} e_i q_i = \eta \sum_{i=1}^{n} e_i q_i$$

with $\eta \equiv \frac{\eta_f}{\ell}$

plan of the talk

Equilibrium and comparative statics (1): Equilibrium

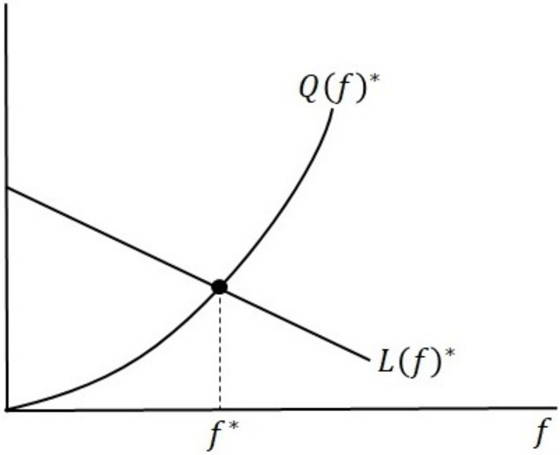
FOCs and applying symmetry

$$e^* = \frac{\varepsilon^{1/2}}{r^{1/2}}$$

$$p^* = \frac{n}{n-1}\left(\tau + 2r^{1/2}\varepsilon^{1/2} + \frac{\gamma}{nf^*}\right)$$

$$\underbrace{\frac{\lambda\,(n-1)}{\theta n^2} - f^*}_{L(f)^*} = \underbrace{\frac{\tau + 2r^{1/2}\varepsilon^{1/2}}{\gamma}\,(f^*)^2}_{Q(f)^*}$$

Equilibrium and comparative statics (2): Equilibrium



Equilibrium and comparative statics (3): Comp. statics

Proposition

The equilibrium frequency varies with respect to the parameters as follows

$$\frac{\partial f^*}{\partial \tau} < 0,\ \frac{\partial f^*}{\partial r} < 0,\ \frac{\partial f^*}{\partial \varepsilon} < 0,\ \frac{\partial f^*}{\partial \theta} < 0,\ \frac{\partial f^*}{\partial n} < 0,\ \frac{\partial f^*}{\partial \gamma} > 0, \textit{ and } \frac{\partial f^*}{\partial \lambda} > 0$$

Equilibrium and comparative statics (4): Comp. statics

Direct effect on p^* holding f^* fixed AND *indirect effect* on p^* through f^*

Proposition

The equilibrium fare varies with respect to the parameters as follows

$$\frac{\partial p^*}{\partial \tau} > 0,\ \frac{\partial p^*}{\partial r} > 0,\ \frac{\partial p^*}{\partial \varepsilon} > 0,\ \frac{\partial p^*}{\partial \theta} > 0,\ \frac{\partial p^*}{\partial n} < 0,\ \frac{\partial p^*}{\partial \gamma} > 0, \text{ and } \frac{\partial p^*}{\partial \lambda} < 0$$

Equilibrium and comparative statics (5): Comp. statics

Proposition

The equilibrium emissions vary with respect to emission charges and capital cost as follows

$$\frac{\partial e^*}{\partial r} < 0 \text{ and } \frac{\partial e^*}{\partial \varepsilon} > 0$$

plan of the talk

Welfare analysis (1): Local approach

- Local approach as in Brueckner (2010)

- Two steps

  ◎ Step #1: Effect of changes of p, f, and e on airline profits, consumer utility, and environmental externality

  ◎ Step #2: Relate changes $\rightarrow$ socially-optimal p, f, and e

Welfare analysis (2): Step #1 - Overall airline profits

$$\frac{\partial n\pi}{\partial p} = \frac{\lambda}{p + \frac{\gamma}{f}} - \lambda \frac{p - \tau - re - \frac{\varepsilon}{e}}{\left(p + \frac{\gamma}{f}\right)^2}$$

$$\frac{\partial n\pi}{\partial f} = \lambda \frac{\left(p - \tau - re - \frac{\varepsilon}{e}\right) \frac{\gamma}{f^2}}{\left(p + \frac{\gamma}{f}\right)^2} - n\theta$$

$$\frac{\partial n\pi}{\partial e} = \lambda \frac{\frac{\varepsilon}{e^2} - r}{p + \frac{\gamma}{f}}$$

Welfare analysis (3): Step #1 - Overall consumer utility

- $U = \ln \frac{a_i}{z_i} + y - 1 \longrightarrow$ overall utility decline in \$ due to higher z

$$\lambda \frac{\partial y}{\partial z} = \lambda \frac{\partial U / \partial z}{\partial U / \partial y} = -\frac{\lambda}{z} = -\frac{\lambda}{p + \frac{\gamma}{f}}$$

- Changes in overall utility due to change in either p or f are

$$\underbrace{\lambda \frac{\partial y}{\partial z}}_{-\frac{\lambda}{p+\frac{\gamma}{f}}} \underbrace{\frac{\partial z}{\partial p}}_{1} = -\frac{\lambda}{p + \frac{\gamma}{f}} < 0$$

$$\underbrace{\lambda \frac{\partial y}{\partial z}}_{-\frac{\lambda}{p+\frac{\gamma}{f}}} \underbrace{\frac{\partial z}{\partial f}}_{-\frac{\gamma}{f^2}} = \frac{\lambda \frac{\gamma}{f^2}}{p + \frac{\gamma}{f}} > 0$$

Welfare analysis (4): Step #1 - Externality

- Externality

$$E = \eta \sum_{i=1}^{n} e_i q_i = \eta n e q = \frac{\lambda \eta e}{p + \frac{\gamma}{f}}$$

- Thus

$$\frac{\partial E}{\partial p} = -\frac{\lambda \eta e}{\left(p + \frac{\gamma}{f}\right)^2} < 0$$

$$\frac{\partial E}{\partial f} = \frac{\lambda \eta e \frac{\gamma}{f^2}}{\left(p + \frac{\gamma}{f}\right)^2} > 0$$

$$\frac{\partial E}{\partial e} = \frac{\lambda \eta}{p + \frac{\gamma}{f}} > 0$$

Welfare analysis (5): Step #2 - Socially-optimal e

- Profit gain derived from a rise in e should compensate its environmental damage

$$\frac{\partial n\pi}{\partial e} - \frac{\partial E}{\partial e} = 0$$

- Thus

$$e^{SO} = \frac{\varepsilon^{1/2}}{(r+\eta)^{1/2}}$$

- Equilibrium vs. SO

$$e^* > e^{SO} \text{ for } \eta > 0 \quad \text{while} \quad e^* = e^{SO} \text{ for } \eta = 0$$

Welfare analysis (6): Step #2 - Socially-optimal p

- Profit gain derived from a rise in p and the mitigation of the externality should cancel consumers' utility loss

$$\frac{\partial n\pi}{\partial p} + \lambda \frac{\partial y}{\partial z}\frac{\partial z}{\partial p} - \frac{\partial E}{\partial p} = 0$$

- Thus (using e^{SO})

$$p^{SO} = \tau + 2\,(r+\eta)^{1/2}\,\varepsilon^{1/2}$$

- Equilibrium vs. SO

$$p^* > p^{SO} \text{ for } \eta = 0 \quad \text{while} \quad p^* < p^{SO} \text{ for } \eta >> 0$$

Welfare analysis (7): Step #2 - Socially-optimal f

- Utility gain as f varies should cancel the aggravated externality, while accounting for the changes profits

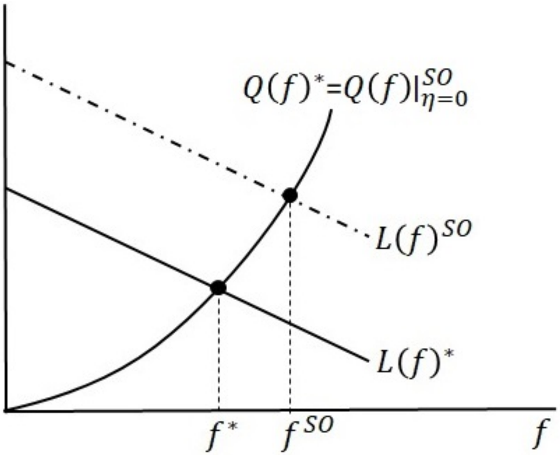
$$\frac{\partial n\pi}{\partial f} + \lambda \frac{\partial y}{\partial z}\frac{\partial z}{\partial f} - \frac{\partial E}{\partial f} = 0$$

- Thus (using e^{SO} and p^{SO})

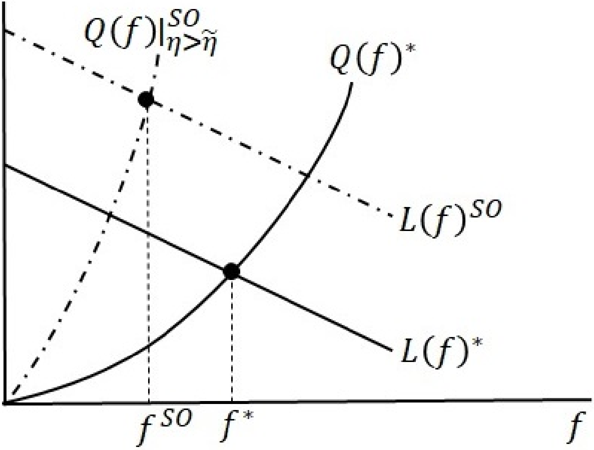
$$\underbrace{\frac{\lambda}{\theta n} - f^{SO}}_{L(f)^{SO}} = \underbrace{\frac{\tau + 2\left(r+\eta\right)^{1/2}\varepsilon^{1/2}}{\gamma}\left(f^{SO}\right)^2}_{Q(f)^{SO}}$$

- Equilibrium vs. SO (next slide)

Welfare analysis (8): Step #2 - Socially-optimal f



Welfare analysis (9): Step #2 - Socially-optimal f



Welfare analysis (10): Recap

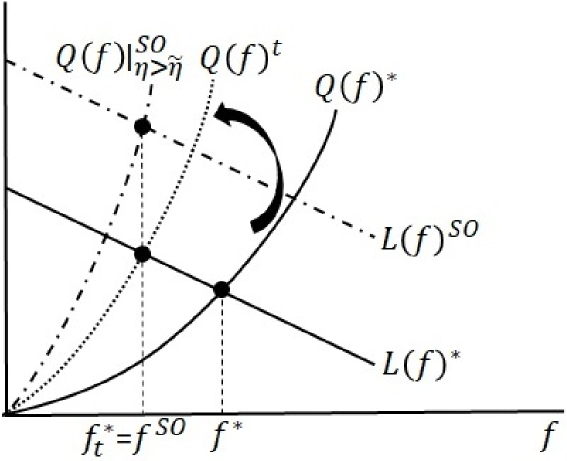
Proposition

The comparison ofequilibrium and SO values for p, f, and e yields:

i) When there is no environmental externality, there is no inefficiency associated to emissions, fares are too high, and there is an underprovision of flight frequency, i.e., $e^* = e^{SO}$, $p^* > p^{SO}$, and $f^* < f^{SO}$ for $\eta = 0$.

ii) Instead, when aircraft emissions cause severe social damage, emissions are too high, fares too low, and there is an overprovision of flight frequency, i.e., $e^* > e^{SO}$, $p^* < p^{SO}$, and $f^* > f^{SO}$ for $\eta > \widetilde{\eta} >> 0$.

Welfare analysis (11): Optimal emission tax



Welfare analysis (12): Optimal emission tax

Corollary

When aircraft emissions cause severe social damage and there is an overprovision of flight frequency, an optimal emission tax could be designed to alter carriers' behavior and achieve the efficient flight frequency.

- Optimal tax: $0 < t < \eta \Rightarrow f^* = f^{SO}$ BUT $e^* > e^{SO}$
- If $t = \eta \Rightarrow e^* = e^{SO}$ BUT $f^* < f^{SO}$

plan of the talk

Airport choices (1): Airport profits

$$\Pi = \tau \sum_{i=1}^{n} q_i + r \sum_{i=1}^{n} e_i q_i = \frac{\lambda}{z^*}\left(\tau + r^{1/2}\varepsilon^{1/2}\right)$$

- $z^* = p^* + \frac{\gamma}{f^*}$ depends on the parameters of the model
- Given that $\frac{\partial f^*}{\partial \tau} < 0$, $\frac{\partial f^*}{\partial r} < 0$, $\frac{\partial p^*}{\partial \tau} > 0$ and $\frac{\partial p^*}{\partial r} > 0$
  $\Longrightarrow \frac{\partial z^*}{\partial \tau} > 0$ and $\frac{\partial z^*}{\partial r} > 0$ *pass-through rates of τ and r to full prices*
- It can be shown that

$$\frac{\partial z^*}{\partial \tau} > \frac{\partial z^*}{\partial r} > 0 \text{ for } r < \varepsilon$$

Airport choices (2): Rate of substitution

- For revenue-neutral airports, rate of substitution btw τ and r is

$$\frac{\partial r}{\partial \tau} = -\frac{\partial \Pi / \partial \tau}{\partial \Pi / \partial r} = -\frac{z^* - \frac{\partial z^*}{\partial \tau}\left(\tau + r^{1/2}\varepsilon^{1/2}\right)}{\frac{\varepsilon^{1/2}}{2r^{1/2}} z^* - \frac{\partial z^*}{\partial r}\left(\tau + r^{1/2}\varepsilon^{1/2}\right)} < 0$$

- $r \uparrow \Longrightarrow$ *higher* $\tau \downarrow$ whenever $\left|\frac{\partial r}{\partial \tau}\right| < 1$

- $\left|\frac{\partial r}{\partial \tau}\right| < 1$ more likely whenever $\left(\frac{\partial z^*}{\partial \tau} - \frac{\partial z^*}{\partial r}\right) \uparrow$

Airport choices (3): Compensation

Proposition

The higher the pass-through rate of non-emission charges τ as compared to the pass-through rate of emission charges r, the more a revenue-neutral airport can reduce τ to compensate for an increase in r. In this situation, the airport would obtain the same revenue and the airlines would pay the same overall charges. Furthermore, the airport would generate incentives for airlines to renew their fleet by adopting newer and cleaner aircraft.

Caveats: $r < \varepsilon$ AND symmetric airlines

plan of the talk

Goals and data (1): Goals

Effect of r and τ on

- p and $f \Longrightarrow$ short-run
- e (share new aircraft) $\Longrightarrow$ long-run

Goals and data (2): Data

- Unit: Airline-route level
- Sample: Routes from European airports
- Period: 2013-2022
- Variables:

  ◎ p, f, τ, r, vintage, noise charges, NO_x emissions $\leftarrow$ RDC Aviation

  ◎ $CO_2 \leftarrow$ Eurocontrol SET

  price of $CO_2 \leftarrow$ Intl. Carbon Action Partnership

  ◎ population $\leftarrow$ UN

  ◎ income pc $\leftarrow$ WB

plan of the talk

Equations (1): Short-run

$$log(Y_{it}) = \alpha + \beta_1 log\left(non\text{-}emission_{it}\right) + \beta_2 emission_{it} + \psi X_{it} + \rho_i + \phi_t + \epsilon_{it}$$

- $Y \Longrightarrow f$ and p
- $non\text{-}emission \Longrightarrow \tau \Longrightarrow$ per-passenger and per-flight
- $emission \Longrightarrow r \Longrightarrow NO_x$-related
- $X \Longrightarrow$ population, income, CO_2 costs, fuel costs, dummy monop
- $\rho \Longrightarrow$ route-airline FE
- $\phi \Longrightarrow$ year FE

Equations (2): Long run

$$share\_new_i = \alpha + \beta_1 non - emission_i + \beta_2 emission_i + \psi X_i + \epsilon_i$$

- *share_new* $\Longrightarrow$ flights with newer aircraft (after 2010)
- $X \Longrightarrow$ population, income, CO_2 costs, fuel costs, HHI, distance
- Additional specification with interaction btw *emission* and *noise*

plan of the talk

Results (1): Short run

	Fares	Frequencies
log(non-emission)	0.207***	-0.0756***
	(0.0227)	(0.0149)
emission (elasticity)	0.009***	-0.015***
	(0.0012)	(0.0021)
Observations	53,553	95,206
Route-airline pairs	13,374	19,647
Years	8	10
R-squared	0.943	0.894

- Subsamples (f and p): EEA, no 2020, no LHR, per PAX/per seat
- Subsamples (p): booking period, monop/competiton, network/LCCs, dense/thin

per PAX/per seat

Results (2): Long run

non-emission	0.000138	0.000121
	(0.000215)	(0.000215)
emission	0.00561***	0.00233
	(0.000625)	(0.00175)
emission X noise		0.00334*
		(0.00174)
Observations	19,780	19,780
Years	1 (mean values 2013-2022)	1 (mean values 2013-2022)
R-squared	0.093	0.094
Test [emission + emission X noise] =0		81.40***

Subsamples: EEA, no 2020, no LHR, hub, interhub, PSM

plan of the talk

Concluding remarks

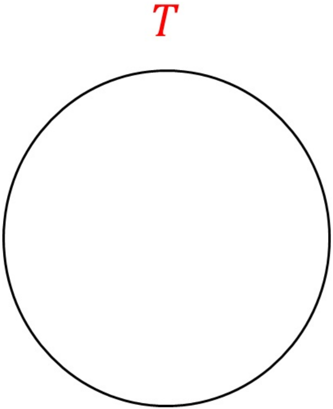
- Airport charges useful in the transition to sustainable aviation
- Airport charges (τ and r) $\Longrightarrow p \uparrow$ and $f \downarrow$ BUT modest effect of r
- Only emission charges $\Longrightarrow e \downarrow$
- Revenue-neutral airports can generate incentives to fleet renewal
- There is room for $r \uparrow$ as environmental concerns increase

Thank you for your attention!

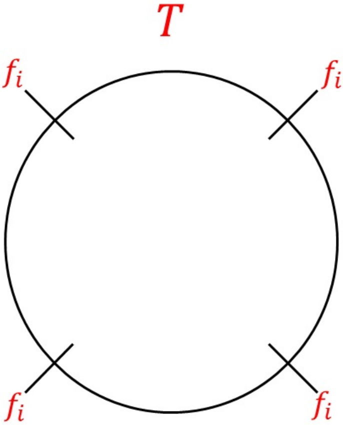
Acknowledgement of financial support for this research

- Spanish Ministry of Science, Innovation, and Universities: PID2022-137382NB-I00
- Generalitat de Catalunya: 2021SGR00729

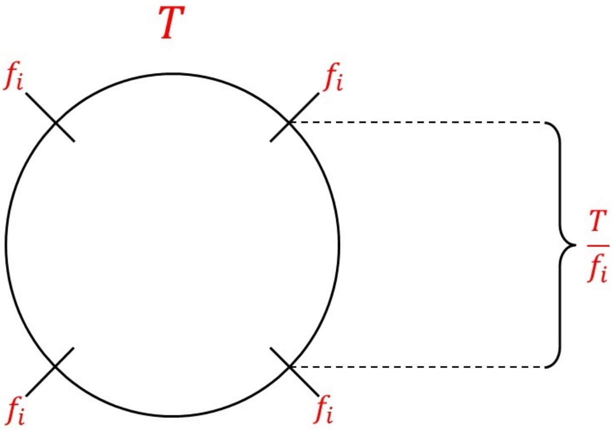
Schedule delay (1)



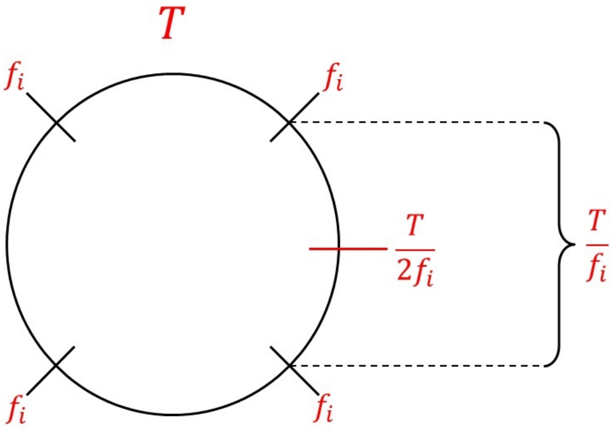
Schedule delay (2)



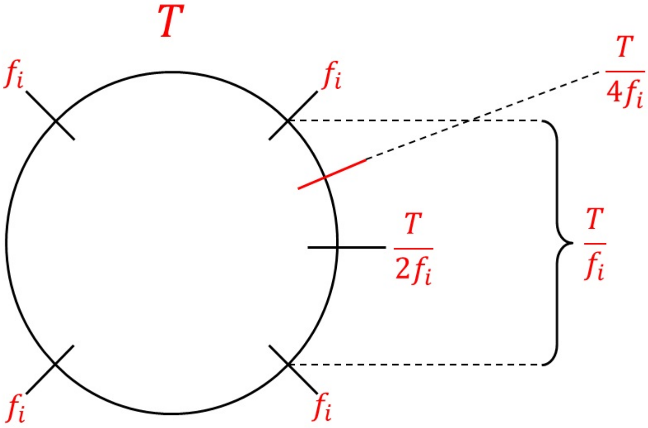
Schedule delay (3)



Schedule delay (4)



Schedule delay (5)



Schedule delay (6)

- Average schedule delay is

$$\frac{T}{4f_i}$$

- Disutility of schedule delay is

$$\frac{\delta T}{4f_i} \equiv \frac{\gamma}{f_i}$$

full price

Per PAX/per seat

	log(fare)	*log(frequency)*
log(per-seat charges)	-0.0139	-0.0429***
	(0.0140)	(0.00879)
log(per-passenger charges)	0.184***	-0.00333
	(0.0182)	(0.0215)
Observations	53,553	95,206
Route-airline pairs	13,374	19,647
Years	8	10
R-squared	0.943	0.894

empirical results