Airline Emission Charges: Effects on Airfares, Service Quality, and Aircraft Design

Jan K. Brueckner / University of California - Irvine

Anming Zhang / University of British Columbia

January 2009

Outline

- Introduction
- Model and Analysis
- Welfare Analysis
- Effect on Airline Networks
- Empirical Evidence
- Conclusion

Introduction

- Aircraft emissions targeted as a means of reducing GHG
- In 2012 EU's "ETS" requires airlines to hold emission permits

  - Similar to existing "cap-and-trade" schemes to polluters in industrial & energy sectors (Europe, US)
- Equivalent to a carbon-tax scheme, effectively adding to fuel price

Research questions:

- How will airlines respond to a policy-induced increase in the effective price of fuel?
- What will happen to airfares?
- How will service quality (flight frequency, load factor) change?
- How will aircraft design (fuel efficiency, seat capacity) evolve in response to changes in the derived demands of airlines?
- Will airline networks change?

Model and Analysis

- Each airline incurs fuel cost & capital cost
- Fuel cost depends on aircraft fuel efficiency
- Fuel efficiency: fuel consumption per seat per flying hour, e
- Capital cost depends on aircraft size s and fuel efficiency, $g(e,s)$

$$f[res+g(e,s)]k(d) \tag{1}$$

- Passengers choose between two competing airlines based on airfares & service quality
- They value flight frequency f, and dislike high load factor l
- Inelastic demand for travel at the industry level

$$q_1 = \frac{1}{2} - \frac{1}{\alpha}\left(p_1 - p_2 + \frac{\gamma}{f_1} + \lambda l_1 - \frac{\gamma}{f_2} - \lambda l_2 \right) \qquad (2)$$

- Analysis based on a special, though realistic, function form relating aircraft capital cost to seat capacity & fuel efficiency

$$g(e,s)=\frac{\beta+\varepsilon s}{e} \qquad (3)$$

- Consider decisions faced by airline 1, choosing p_1, e_1, f_1 and l_1 to maximize profit

$$\begin{aligned}
\pi_1 &= p_1 q_1 - f_1\left(r e_1 s_1 + \frac{\beta + \varepsilon s_1}{e_1} \right) k(d) \\
&= \left(p_1 - \frac{r e_1 + (\varepsilon / e_1)}{l_1} k(d) \right) q_1 - f_1 \frac{\beta}{e_1} k(d) \\
&= \left(p_1 - \frac{r e_1 + (\varepsilon / e_1)}{l_1} k(d) \right) \left[\frac{1}{2} - \frac{1}{\alpha} \left(p_1 - p_2 + \frac{\gamma}{f_1} + \lambda l_1 - \frac{\gamma}{f_2} - \lambda l_2 \right) \right] - f_1 \frac{\beta}{e_1} k(d)
\end{aligned} \tag{4}$$

- Given model symmetry, equilibrium values will be symmetric across carriers, leading to following FOCs:

$$p = \frac{\alpha}{2} + \frac{re + (\varepsilon / e)}{l} k \qquad (9)$$

$$e^2 = \frac{\varepsilon + 2\beta fl}{r} \qquad (10)$$

$$f^2 = \frac{\gamma e}{2\beta k} \qquad (11)$$

$$l^2 = \frac{re^2 + \varepsilon}{\lambda e} k. \qquad (12)$$

- The equilibrium, (p*, e*, f*, l*), is the solution to (9)-(12)

$$r^2e^4 - r\cdot(2\varepsilon + \mathrm{K})e^2 + \varepsilon\cdot(\varepsilon - \mathrm{K}) = 0; \qquad \mathrm{K} \equiv 2\gamma\beta / \lambda \tag{13}$$

$$e^* = \left[\left(r(2\varepsilon+\mathrm{K}) \pm \sqrt{r^2(2\varepsilon+\mathrm{K})^2 - 4r^2\varepsilon(\varepsilon-\mathrm{K})}\right)/\,2r^2\right]^{1/2} = \left[\left(2\varepsilon+\mathrm{K} \pm \sqrt{(8\varepsilon+\mathrm{K})\mathrm{K}}\right)/\,2r\right]^{1/2} \tag{14}$$

$$\frac{de^*}{dr} = -\frac{e^*}{2r} < 0 \tag{15}$$

From (11), $f^2 = \dfrac{\gamma e}{2\beta k} \Rightarrow f^* = \sqrt{\gamma e^* / 2\beta k}$

$$\frac{df^*}{dr} < 0 \tag{16}$$

$$\frac{d(f^*l^*)}{dr} = \frac{1}{2\beta}\left(2r\frac{de^*}{dr} + e^*\right) = 0 \tag{17}$$

$$\frac{dl^*}{dr} = -\frac{l^*}{f^*}\frac{df^*}{dr} > 0 \tag{18}$$

Since $s^* = 1/2\, f^* l^*$, (17) implies $\frac{ds^*}{dr} = 0$ (19)

- Impact of *r* decomposed into four parts:
  - a positive direct effect ($e^*k/l^*>0$ multiplying *r**)
  - a negative indirect effect via the use of more fuel-efficient planes, which leads to fuel savings (rk/l^* times de^*/dr)
  - a positive indirect effect via the use of more fuel-efficient planes, which results in higher aircraft leasing cost (this effect operates through e^* in the denominator of the upper ratio term in (9))
  - a negative indirect effect via a higher load factor, which leads to downward pressure on per-passenger cost (this effect operates through l^* in the large ratio expression in (9))

$$\frac{dp^*}{dr} > 0 \qquad (20)$$

- **Proposition 1.** *An increase in r, or an equivalent imposition of airline emission charges, will lead to a higher fare, lower flight frequency, a higher load factor, more fuel-efficient aircraft, and an unchanged aircraft size.*

Welfare Analysis

- Social welfare function:

$$W = 2\pi + y - p - \gamma / f - \lambda l - \mu(2fesk) \qquad (21)$$

where *y* is passenger income and the last term represents emission damage

Effect of on Airline Networks

- The last part investigates the effect of a higher fuel price on airline network structure, reflected in the choice between hub-and-spoke and fully-connected networks.
- By concentrating passengers on fewer routes, a hub-and-spoke network allows better exploitation of the economies from larger aircraft, but its greater trip circuity has an offsetting effect on costs.
- The analysis investigates how this trade-off is affected by a higher fuel price, reaching a conclusion that is interestingly ambiguous.
- Thus, according to the model, airline emission charges need not systematically affect current network structures.

$$\pi_1^{HS} = 3\left\{\left[p_1 - \frac{4}{3}\frac{re_1 + (\varepsilon / e_1)}{l_1}k\right]q_1 - \frac{2}{3}f_1\frac{\beta k}{e_1}\right\} \qquad (22)$$

$$p_{HS} = \frac{\alpha}{2} + \frac{4}{3}\frac{re_{HS} + (\varepsilon / e_{HS})}{l_{HS}}k \qquad (23)$$

$$e_{HS}^2 = \frac{\varepsilon + \beta f_{HS} l_{HS}}{r} \qquad (24)$$

$$f_{HS}^2 = \frac{3}{4}\frac{\gamma e_{HS}}{\beta k} \qquad (25)$$

$$l_{HS}^2 = \frac{4}{3}\frac{re_{HS}^2 + \varepsilon}{\lambda e_{HS}}k \qquad (26)$$

$$e_{HS} = \left[\left(2\varepsilon + (K/2) + \sqrt{[8\varepsilon + (K/2)](K/2)}\right)/\,2r\right]^{1/2} \qquad (28)$$

$$e_{HS} < e_{FC} < \sqrt{2}e_{HS} \qquad (29)$$

$$\frac{f_{FC}^{2}}{f_{HS}^{2}} = \frac{2}{3}\frac{e_{FC}}{e_{HS}} < \frac{2}{3}\sqrt{2} < 1 \qquad (30)$$

$$\frac{s_{HS}}{s_{FC}} = \frac{re_{FC}^{2} - \varepsilon}{re_{HS}^{2} - \varepsilon} > 1 \qquad (31)$$

$$\Downarrow$$

$$f_{FC} < f_{HS}$$

- **Proposition 2.** *Under the assumed network structure, the HS network has more fuel-efficient aircraft than the FC network. In addition, aircraft are larger and flight frequency is higher in the HS network than in the FC network.*

Figure 3. Comparison of load factors under two networks, $\theta \equiv \varepsilon / \mathrm{K}$

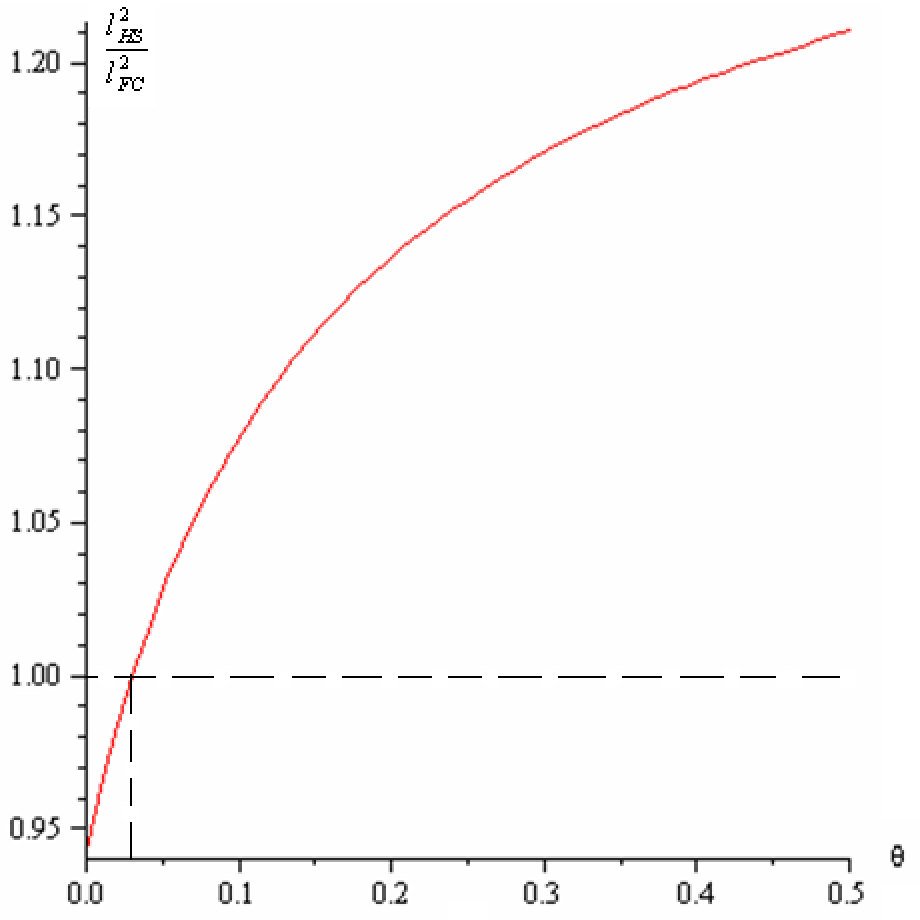
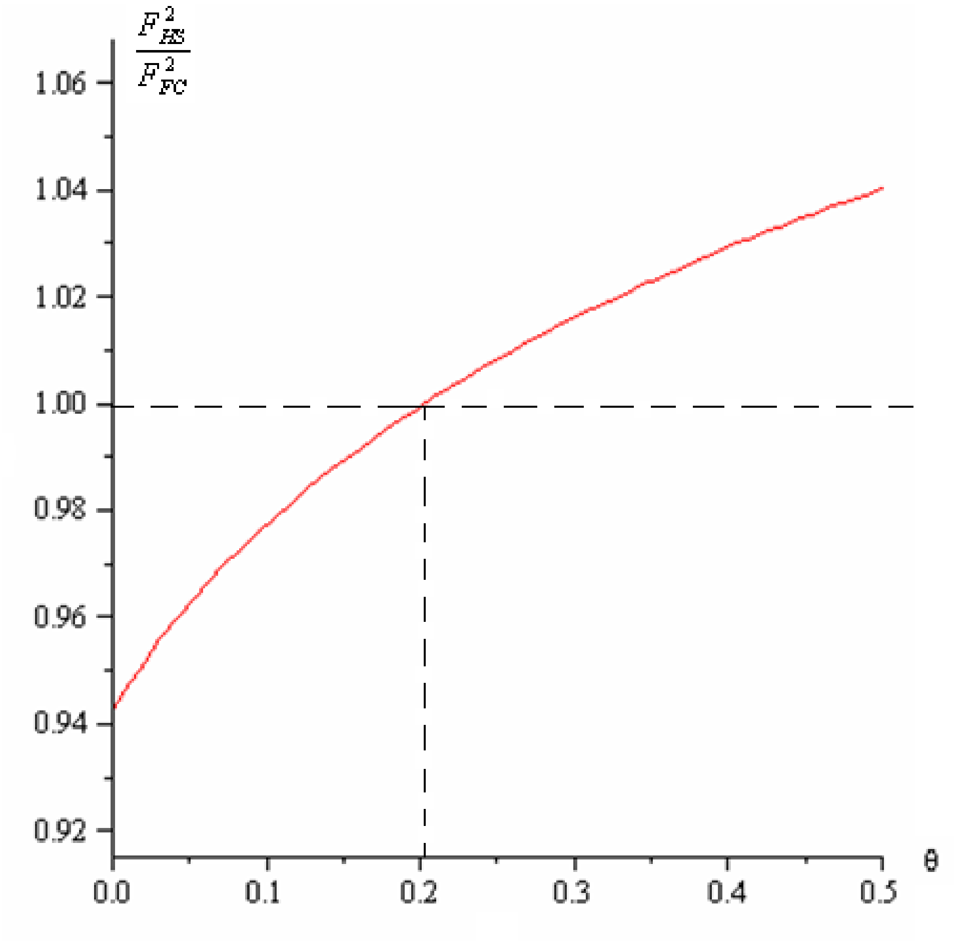


Figure 1. Effect of emissions charge on airline networks, $\theta \equiv \varepsilon / \mathrm{K}$

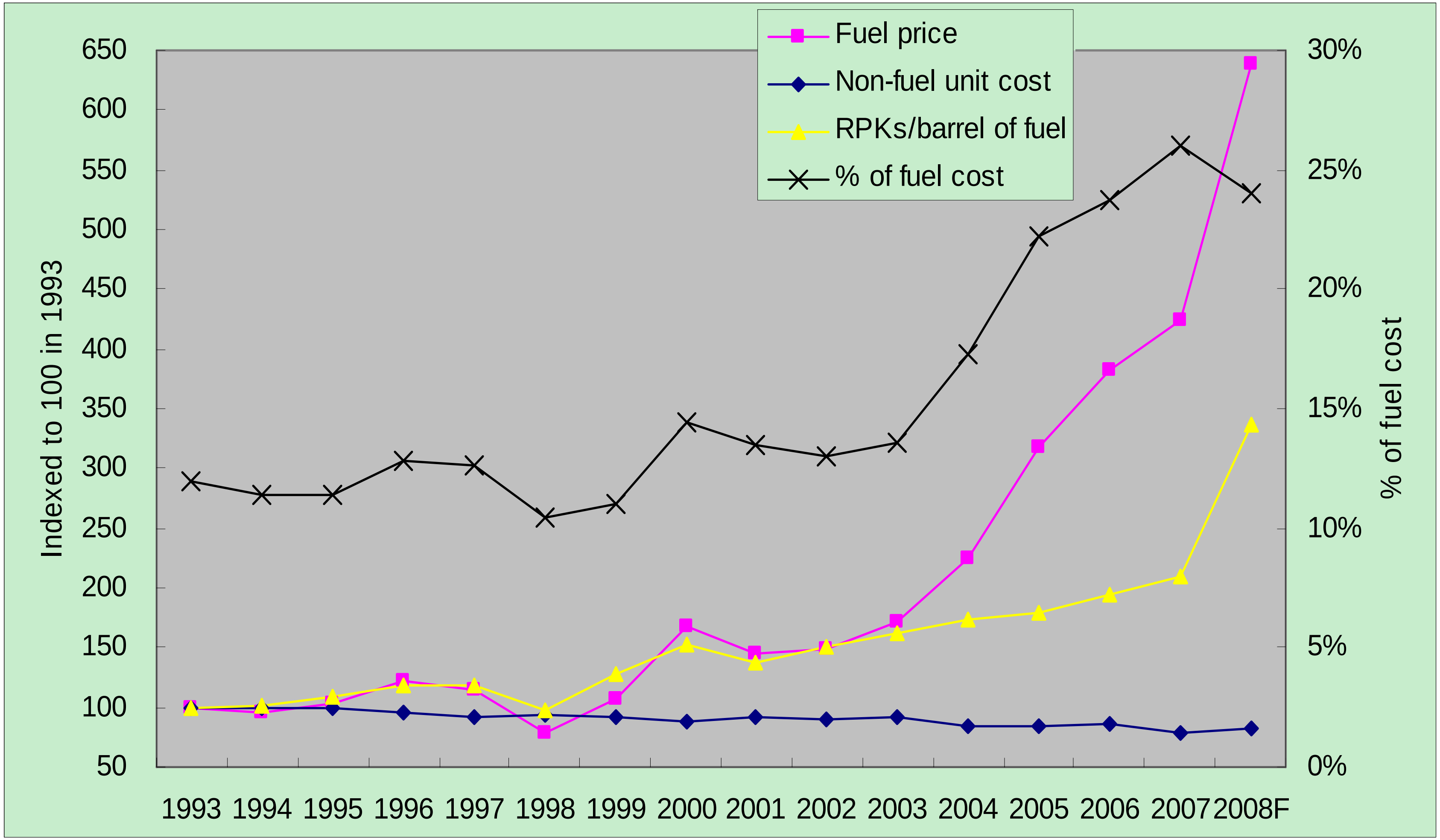


- **Proposition 3.** *The imposition of emission charges* (*an increase in the fuel price*) *favors the HS network when the cost parameter* ε *is small relative to* $K \equiv 2\gamma\beta / \lambda$ *with the FC network favored otherwise.*

- When size economies, as measured by β/ε, are sufficiently strong (when ε/β is sufficiently small), an increase in fuel price favors HS network

- When the demand ratio γ/λ – *ratio* of the cost of frequency delay and the cost associated with a higher load factor – is sufficiently large, an increase in fuel price favors FC network

Empirical Evidence: Fuel price, % fuel cost, fuel productivity, and non-fuel unit cost



Source: ICAO

- Emission charges may be viewed as leading to a 24% increase in the effective price of fuel

  - relevant magnitude can be gained using data and calculations: Scheelhasse and Grimme (2007)

- This increase is much smaller than the seven-fold rise over the 1993-2008 period but appreciable nevertheless

Conclusion

- Emission charges raise fares, reduce flight frequency, increase load factors, and raise aircraft fuel efficiency, while having no effect on aircraft size
- Emission charges have negative impact on passengers (and airlines)
- These adjustments represent efficient changes that move society closer to a social optimum
- The effect on optimal structure of airline networks is ambiguous
- Hub-spoke network tends to result in more efficient & larger aircraft, and higher load factor, than fully-connected network

- Analysis of emission charges on aviation is a high-priority undertaking, and this paper has offered a first step
- Further work
  - Incorporate an elastic demand for travel at the industry level
  - Use a general form for key function relating aircraft capital cost to seat capacity and fuel efficiency

Thank you