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Environmental Temporal Technology Transfers in CO_2 Reductions for Airlines

Kenneth Button[1], Gianmaria Martini[2], Davide Scotti[2·]

[1] School of Public Policy, George Mason University, Arlington, VA 22201, USA
[2] Department of Economics and Technology Management, University of Bergamo, Viale Marconi 5, 24044 Dalmine, Italy

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Abstract

This paper looks at aircraft as a case study in order to examine some of the forces that influence environmentally beneficial technology changes. The reasons for the gradual reduction in CO_2 per seat in aircraft design are examined in terms of the costs of aviation fuel, the movement towards fuel trading, and endogenous technical progress in the technology of the industry. The results suggest a significant role played by technology transfer from one model of aircraft to another in influencing the fuel efficiency of aircraft, with rising fuel prices over the long-term also being significant.

Keywords: airline manufacturing; environmental policy; aviation economics.

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1. Introduction

The concern here is with the economic forces that have influenced the evolution of the fuel economy, and *ipso facto* the CO_2 emissions, of the global airliner fleet. Aviation has been variously estimated to be contributing between 2 and 3% of climate-change gas emissions, and the UN International Civil Aviation Organization (ICAO) estimate emissions my grow three- to seven-fold by 2050 based on current trends. A major challenge is to disconnect the fuel consumption per passenger and the demand for air travel at a time when increasingly liberalized markets are pushing up the demands for airline services.

One thing that the airline industry has been claiming is that part of this disconnecting is taking place as airline seats are being flown more fuel efficiently. There has been a steady stream of new aircraft and modifications to the existing fleet over time that have built on previous experiences to improve fuel consumption; basically there has been environmental temporal technology transfers (TTT). Here we examine whether these shifts have been largely market driven by actual and anticipated kerosene (aviation fuel) prices or by halo effects led by a concern that policies, such as the European Union's

· Corresponding author: Davide Scotti (davide.scotti@unibg.it)

emission trading system (ETS), stemming from the Kyoto Protocol may force aircraft and engine manufacturers into sudden, and more costly actions[1]. Or whether there is an underlying, embodied TTT effect, with manufactures continually seeking more fuel efficiency.

2. Background

On 14 March 2013, 32 leading US economist, including eight Nobel Prize winners, urged the US President to adopt market based instruments to reduce carbon emissions from aviation. This is very much in line with the broader recommendations of the *Stern Report* (Stern, 2007) that provided a powerful economic case for using economic measures to reduce CO_2 emissions[2]. It also follows on from the faltering effort of the European Union to embrace aviation within its ETS, the progress of which has been slowed by opposition from countries such as the US[3]. The development of such a program has been shunted over to the ICAO with a remit for the latter to launch a global scheme by 2020.

This is in the context, however, of an industry that is expanding rapidly, and that has seen a gradual improvement in the technical environmental efficiency of its hardware, and of its use. The issues we focus on here are the factors that have been influencing the environmental improvements found in individual airframe models and engine design.

In recent years there have been significant increases in kerosene prices and this may be expected to have influenced the market for airframes and aero engines. But also, given the costs of sudden technical change, the possibility of having specific environmental policies imposed on the aviation sector may be seen as possibly stimulating preemptive actions by the manufacturers to enhance the fuel efficiency of their products. But we are also interested in seeing if there is embodied technical progress being pushed through the sector as lessons are learned from the technologies used in previous aircraft and engine designs and up-grades.

3. Data and models

Information about the aircraft models and variants is taken from the ICAO Engine Emissions Data Bank and covers aeroplanes that have been developed between 1975 and 2013. As can be seen in Figure 1 there has both been improvements in terms of the CO_2 emissions per seat for new models of aircraft (NEW) and for their up-grades (UPG), and this extend, although the pattern is not consistent, across the various sizes of

[1] Some airlines have introduced voluntary carbon offsetting schemes, but these have not been enthusiastically received in many markets and are not considered here (Gössling *et al*, 2007). In addition, environmental improvements can result from modifying the networks of services flown, the number of seats configured on a plane, the fleet composition, the speed the aircraft is flown and load factors, (Janic 2003), again these are outside of our concern; we are only interested in hardware development.

[2] A critique of Stern's position is to be found in Weitzman (2007)

[3] This is despite the fact that its impact on airlines' costs is unlikely to be large (Anger-Kraavi and Köhler, 2013).

aircraft[4]. There are also a number of outliers with newer models having higher CO_2 emissions than the trend. These tend to involve Russian built aircraft and engines that, until after 1989 were not subject to market pressures for change.

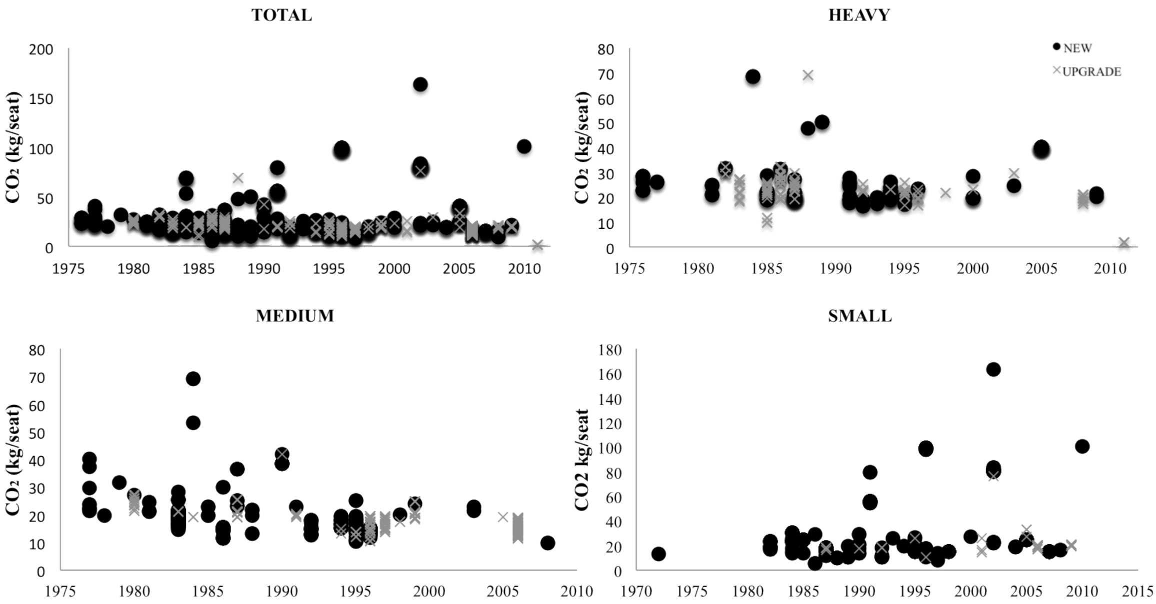

Figure 1. Trends in aircraft model and up-grade CO_2 emissions (1975-2013)

In addition to a time trend to reflect potential temporal technology transfers, a number of control variables are introduced to allow for lagged changes in fuel prices[5], a possible halo effect from the potential anticipatory long-term impacts of the Kyoto Protocol, and exogenous shifts in the technology function for aircraft brought about by the end of the USSR. Specifically the model specified by small, medium and large aircraft is;

$$\ln(CO_2/seats) = a_0 + a_1\ln(time) + a_2\,(price_{jet\,fuel}) + a_3\,(Kyoto) + a_4\,(Russia) \qquad (1)$$

where: $CO_2/seats$ is the carbon emissions per seat by aircraft categories of hardware introduced and still used in Europe; time is a trend with 1972=1; $price_{jet\ fuel}$ is the average kerosene price in US cents/gallon over the previous five years adjusted by the US inflation rate to 2009 prices; Kyoto is a dummy variable reflecting the signing of the Kyoto Protocol in 1997; and Russia is a dummy indicating whether the aircraft is Russian built.

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[4] The categories are derived from ICAO classifications to more closely reflect emissions factors. A heavy aircraft has a maximum takeoff weight exceeding 136,000 kilograms and/or is double-aisled, a medium one has a maximum takeoff weight of 40,000 to 136,000 kg and/or is single aisled fuselage, and a small one a maximum takeoff weight of 17,000 to 40,000 kg and/or is single aisled.

[5] Although fuel prices are more likely to have an immediate effect on airline operations, see Smirti Ryerson and Hansen (2013).

4. Results

The models parameters are estimated using ordinary least squares and reported in Table 1. The patterns that emerge exhibit only a limited amount of consistency, and the overall fits are not always good, at least as measured by the R^2s. One thing that is clear from the positive parameters associated with relevant dummy variable, however, is that Russian aircraft are consistently less fuel efficient.

Table 1. Factors affecting aircrafts' CO_2 emissions.

	Total	Heavy	Medium	Small
Ln(Time)	-0.537***	-0.382***	-0.535***	-0.465**
Kyoto	0.311***	0.330***	0.273***	0.598***
Russia	0.732***	1.010***	0.698***	-0.167
Ln (Price)	-0.383***	-0.300***	-0.243***	-0.619***
Constant	6.325***	5.526***	5.535***	7.329***
R^2	0.181	0.338	0.540	0.121

* Statistically significant at the 10% level, ** at the 5% level, and *** at the 1% level

There are some differences between the smaller aircraft and the large with the greater number of new models introduced in the latter class as opposed to up-grades of existing models, and by the relatively recent entry of regional jets into the commercial airline fleet. In addition, the number of heavy and medium airframe manufacturers in the market fell over the period due to consolidations and withdraws, whereas there was an increase in small aircraft manufacturers; Embraer, the largest manufacturer of small jest only moved into this market in the 1990s and Bombardier only slightly later.

Despite these differences there is a similar strong relationship between emission reductions and time supporting the notion of a TTT effect for both heavy and medium planes, where production has become more concentrated[6], and small aircraft. Furthermore, the fuel price effect takes the expected sign with CO_2 levels falling as prices rise, and is significant overall. The idea of a Kyoto halo concept seems not to be valid; the parameters are positive and significant for the main airline classes.

5. Conclusions

The analysis of the changes in the technical fuel efficiency of airline models and variants indicates that a relevant part of the driving force has come from temporal technology transfers from one generation of hardware to the next. Moreover, there is indication as to a powerful effect being exerted by the price of kerosene.

What the paper has not done is to examine the impacts of the increased market flexibility accompanying market liberalization that has significantly increased the load

[6] In particular there was the merger of Boeing and Macdonald Douglas in 1997 and the withdrawal of Lockheed from the commercial aviation sector in 1994. Airbus has added competition in the later part of the period.

factors of airlines and influenced fleet compositions and pattern of use. Thus while the CO_2 emissions per seat have fallen, the fall has been even greater per seat or passenger mile and this has been influenced more by operational decisions that aircraft technology[7].

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[7] Smirti Ryerson and Hansen (2013) discuss the implications of fuel prices on airline operations.