Transport Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

Airline fleet replacement funded by a carbon tax: An integrated assessment

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ARTICLE INFO

Keywords:
Aviation
Climate change
Carbon dioxide
Technology
Carbon tax
Fleet renewal

ABSTRACT

Stimulating fleet renewal and attaching a price to carbon dioxide emissions have both been suggested as ways of reducing aviation's environmental impact. One potential route for emissions reduction is to combine these policy options, by applying a carbon tax which is used to subsidize fleet renewal. Such a policy would have impacts on many aspects of the aviation system, including demand, fleet composition, traffic delays, and airfares. Therefore, its impacts need to be considered holistically, taking into account likely interaction and feedback effects. In this paper, we apply a model of the global aviation system, the Aviation Integrated Model (AIM), to assess the demand and emissions response from passenger aviation following the application of such an aviation sector policy. We find that by 2050, aviation lifecycle carbon dioxide emissions may be reduced by up to 34% compared to the no-policy case for a policy aimed at retiring aircraft over 20 years old.

1. Introduction

Between 1959 and 1995, energy use per revenue passenger-km of new aircraft declined on average by 3.5% per year, a total decrease of almost 75% (Lee et al., 2001; Greene, 1992). However, because of the long lifetime of aircraft, improvements in new aircraft can take a long time to percolate into the fleet in sufficiently large numbers to generate a significant system-level impact. It has been estimated that around a 10% decrease in present-day aviation carbon dioxide (CO_2) emissions could be achieved simply by replacing all current aircraft with the latest technology substitutes available (Dray, in this issue). Whilst this is not a practical policy option, a policy analogous to road vehicle scrappage schemes (e.g. van Wee et al., 2011) targeted only at older aircraft could be. Analyses of the marginal abatement costs of aviation emissions mitigation measures (e.g. Henderson, 2005; Morris et al., 2009) suggest that this type of fleet replacement could significantly decrease CO_2 emissions, but that it would also be relatively expensive compared to other presently-available mitigation measures such as operational changes or retrofits. Additional reductions in CO_2 emissions could be achieved by employing fuel-saving technologies. However, many airlines, particularly those in developing world regions, may have capital constraints that make investing in new technology aircraft difficult.

Another option for reducing aviation emissions is to attach a price to carbon. For example, the EU Emissions Trading Scheme (ETS) has included aviation from 2012 (EU, 2009). Under this scheme (at the time of writing), the vast majority of intra-EU flights are allocated a number of allowances up to an emissions cap based on year 2004–2006 CO_2 emissions. If aviation emissions continue to grow above this cap, airlines will have to purchase allowances from other sectors which are able to reduce their emissions at lower costs. Assessments of the impact of this scheme on EU aviation lead to the expectation that aviation may become a net purchaser of allowances, due to the relative difficulty of reducing CO_2 emissions (EU, 2006). Therefore, although the growth rate of aviation CO_2 emissions may not decline much under an ETS, airlines will effectively be funding more cost-effective reductions in emissions outside the aviation sector. In this scenario, the primary impact of emissions trading on aviation-specific emissions would then be an increase in ticket prices and hence a reduction of the demand growth for revenue passenger kilometers (RPK) flown. An alternative option would be an aviation-only ETS. Here, emissions permits would only be traded between airlines, so the desired emissions reductions would occur within the aviation sector rather than outside. Although carbon prices in an aviation-only trading scheme are likely to be much higher than those in a more open scheme, because of the greatly reduced number of lower-cost mitigation options, an aviation-only scheme may become relevant in the absence of a uniform global carbon tax. In such a case, the potentially emerging national or regional approaches to CO_2 mitigation would leave out international transportation such as aviation.

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[1] This work was funded by the UK research councils EPSRC and NERC.

http://dx.doi.org/10.1016/j.tranpol.2014.02.021
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In this paper, we consider a hybrid policy which takes elements from both policy types discussed above. We assume that a carbon tax is applied, globally, to passenger aviation. This tax is then used to subsidize fleet replacement of older aircraft in all parts of the world. Note that here the tax is not being used explicitly to internalize the cost of carbon emissions (in so far as that cost can be calculated), but rather to provide funding for a specified goal. However, many of the system impacts of attaching a price to carbon emissions will still apply. Under such a scheme, airlines would subsidize the fleet renewal among each other, but large airlines with old fleets would benefit the most. In the second step, we allow developing countries to be the exclusive beneficiaries of this fund, to which all airlines from all countries (developed and developing) continue to contribute. Such a policy can be considered as a sector-specific technology transfer to the more capital-constrained developing economies. It is important to note that these scenarios are only meant to improve our insight of such complex policy issues, and by no means are intended to represent any policy recommendation.

The policy impact on emissions will be a combination of several interlinked effects, including potential demand reduction from the depressing effect of increased ticket prices (in response to carbon taxation) and the smaller positive effect from reductions in ticket prices (in response to reduced airline fuel costs); more drastic changes in fleet technology composition; and possible reductions in the use of non-policy related technologies (for example, drop-in biofuels[3]). This means that integrated modeling which can address these interdependencies is needed to assess policy outcomes.

Global aviation is a large and complex system and its reaction in response to changes in boundary conditions reflects the many interactions between the interests and behaviors of passengers, airlines and policymakers. A policy intervention at any one component of the system may have complex effects elsewhere. For example, decisions about airport capacity can affect delay and demand, which can in turn affect the rate at which new technology enters the fleet (Dray, in this issue); and engine design aimed at producing lower noise levels can increase airport-area NO_X emissions (e.g. ICAO, 2007; Graham et al., in this issue; Wolfe et al., in this issue). Integrated modeling efforts seek to address these interlinked issues by joining separate models of individual elements of the aviation system together in a way that addresses the major feedbacks and dependences. One such integrated model is the Aviation Integrated Model, AIM (Reynolds et al., 2007), a UK Research Council-funded project aimed at developing a series of interlinked modules to describe the various local and global effects of aviation. In this paper we apply AIM to simulate the effects of the policy discussed above, providing insights into the likely demand and emissions response from passenger aviation.

2. Aviation Integrated Model

The basic structure of AIM is shown in Fig. 1. AIM consists of seven interconnected modules, programmed in a mixture of Java and Matlab. Each module concentrates on one aspect of the global aviation system. The Air Transport Demand module projects true origin–ultimate destination demand for air travel for a set of 700 global cities (1127 airports) – around 95% of global scheduled RPK. The Airport Activity Module assigns routing, aircraft types and a schedule based on regressions on historical data, and calculates delay and capacity requirements. The Aircraft Technology and Cost Module computes costs and emissions by aircraft type, fleet turnover, and cost-based airline decisions to invest in new technology. The Aircraft Movement Module calculates global emission locations, accounting for flight routing inefficiencies. Because airfare, a key determinant of air transportation demand, is determined by aircraft direct operating costs, these modules are run iteratively until a partial equilibrium between demand and supply is reached. Output is then passed to the Global Climate model, which calculates a range of climate metrics; the Air Quality and Noise module, which calculates regional and local impacts for selected airports; and the Regional Economics module, which calculates the economic impact of the obtained system equilibrium. The modules that are relevant for the analysis carried out in this paper are described in more detail in the sections below.

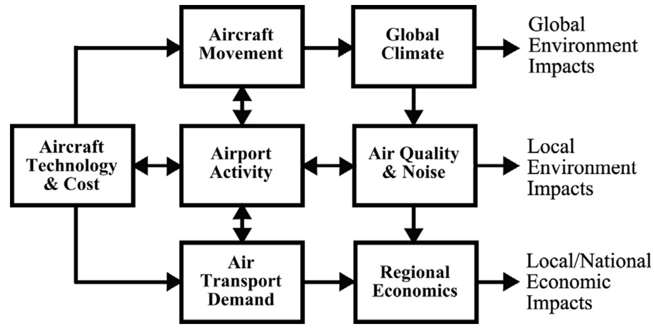

Fig. 1. AIM modular structure.

2.1. Aircraft Technology and Cost

The global fleet in AIM is represented by a set of six aircraft types by size class and technology age as shown in Table 1. The Aircraft Technology and Cost Module simulates fuel burn, emissions and operating costs by stage length and load factor, for airframe and engine technologies to 2050. Performance and emissions modeling for these aircraft below 3000 feet is based on ICAO reference data (ICAO, 2006a, 2009), adjusted for airport-specific taxi-out delay times. Above 3000 feet, performance during climb, cruise, descent, and airborne holding is modeled using the Eurocontrol Base of Aircraft Data model (Eurocontrol, 2004), adjusted for route-specific airborne delay and inefficiency from the Aircraft Movement Module. Operating costs are taken from published US airline cost data (US DoT, 2009) and adjusted for global differences (ICAO, 2006b). Fleet turnover is based on the historical behavior of the global fleet (Morrell and Dray, 2009). Adjustments to regional fleets were also made based on the historical behavior of second-hand aircraft sales between regions at different GDP levels (OAG, 2009).

The Aircraft Technology and Cost module includes the option for airlines to invest in current or future new technologies. Airline decisions are assumed to be made purely on a cost basis. For options involving alterations to existing technology, such as retrofits or increased maintenance, we assess cost-effectiveness using a three-year payback period. For new aircraft types, such as aircraft with open rotor engines or a blended wing body aircraft, we calculate cost-effectiveness using a Net Present Value (NPV) model (e.g. Morrell and Dray, 2009). The parameters used are derived from airline financial reports and vary with region, corresponding to effective payback periods of between 7.5 years (North America) and 6.2 years (Africa).

The emissions reductions from new technologies depend on which technologies are assumed to be available, when they become available, and what their assumed characteristics are. Some incremental improvements in engine and airframe technology will be non-optional, i.e. they will apply to all new aircraft models. Therefore we assume the fuel burn per RPK of all new aircraft models to decline by 1% per year— a rate which is consistent with recent historical trends (Lee et al., 2001; Graham

[3] Drop-in biofuels are biofuels which can be safely substituted for Jet A in the existing aircraft fleet, without the need for any design changes.

Please cite this article as: Dray, L., et al., Airline fleet replacement funded by a carbon tax: An integrated assessment. Transport Policy (2014), http://dx.doi.org/10.1016/j.tranpol.2014.02.021