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Environmental impact of aircraft emissions and aviation fuel tax in Japan

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ABSTRACT

This investigation analysed the growing impact of commercial aviation on CO_2 emissions, as well as its potential impact on climate change. It reviewed the effects of the Japanese Aviation Fuel Tax (*koukuukinenryouzei*), which has been levied on fuel loaded into all domestic flights in Japan since 1972. Using a Bayesian structural time series model, based on monthly observations of fuel consumption between 2004 and 2013 provided by the Ministry of Land, Transport, Infrastructure and Tourism - Japan, this research estimated the effect that this tax has had on the national demand for aviation fuel. It was established that the fuel tax has unequivocally reduced the amount of CO_2 emissions from aircraft.

1. Introduction

Aviation is a vital component of most economies and it represents one of the greatest developments of the 20th Century. There is an indisputable expectation that the industry will continue to grow, particularly given the rapid development of low-cost carriers. It is anticipated that the amount of CO_2 emissions related to aviation will also increase rapidly, keeping pace with the expansion of the industry. Given the constraints on CO_2 emissions are becoming tighter, as evidenced by the agreement of the Paris Climate Change Conference in 2015, it is crucial that the implications of the expansion of aviation with regard to global CO_2 emissions, and the effects of an incentive-based tool represented by a fuel tax for reducing CO_2 emissions, should be evaluated carefully. To the best of the authors' knowledge, however, there have been relatively few studies exploring the effectiveness of jet fuel tax on the reduction of aircraft CO_2 emissions.

The purpose of the present paper is to address this problem by analysing data relevant to the aviation fuel tax adopted in Japan. Specifically, it investigates the effects of a reduction in aviation fuel tax on CO_2 emissions by the aviation sector. Because of the 30% reduction in tax implemented by the Japanese government in April 2011, it is possible for us to compare the amount of CO_2 emissions before and after the tax adjustment. We find that the amount of CO_2 emissions from Japanese domestic flights would increase significantly compared with a situation where such a tax reduction was not implemented, reflecting the effectiveness of fuel tax for reducing CO_2 emissions by aircraft. This finding is of great importance because an increase in the amount of CO_2 emissions is considered unavoidable, especially in a region that has a rapidly expanding airline market.

We investigated the Aviation Fuel Tax of Japan (*koukuukinenryouzei*) by considering both its impact on the national demand

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Abbreviations: BMF, Federal Ministry of Finance (Germany); BOJ, Bank of Japan; DEA, Danish Energy Agency; ENV, Ministry of the Environment Japan; EPA, Environmental Protection Agency; IATA, International Air Transport Association; ICAO, International Civil Aviation Organization; IEA, International Energy Agency; IPCC, Intergovernmental Panel on Climate Change; JAA, Japan's Aeronautic Association; MLIT, Ministry of Land, Transport, Infrastructure and Tourism Japan; MOF, Ministry of Finance Japan.

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for aviation fuel and its indirect contribution to Japan's environmental efforts for reducing the amount of CO_2 emissions, using a Bayesian time series approach that contrasted the results before and after the 30% tax reduction. Through the application of causal impact analysis, based upon Brodersen et al. (2015), this study constructed a scenario that predicted the market's response in the absence of the tax reduction, which allowed an estimation of the quantity of additional fuel consumed between April 2011 and December 2013. Thus, we estimated the causal impact of the 30% reduction in the aviation fuel tax, which to the best of our knowledge, has not been undertaken before.

The causal impact analysis method adopted in this paper is an analysis of a causality mechanism that measures the difference between the observed values of fuel consumed after the tax was adjusted and the (unobserved) values that would have been obtained had the tax not changed. In accordance with the recent interest in “big data” sets and predictive analysis, we adopted a modern approach of using Google Correlate™ to generate a collection of time series variables showing high correlation with the data before the intervention, and then we combined them into a single synthetic control that was used to estimate the causal impact. Thus, the modelling of the counterfactual of the time series observed both before and after the tax cut can be achieved. The key to the selection of the control variables is that they should not be affected directly by the intervention, such that it is possible to assume that the relationship that existed before the tax change would continue afterward. This is because they account for the variance components that are shared by the series, including those effects of other possible unobserved causes that otherwise would be ignored by the model. Because these control series are chosen purely in terms of how well they explain the pre-intervention values, no attention is given to their external characteristics (Brodersen et al., 2015).

The structure of the remainder of this paper is as follows. In Section 2, we review briefly the preceding research. Although some papers have dealt with the environmental impact of the aviation industry, there has been little empirical research similar to that conducted in the current study. Section 3 provides a brief overview of Japan's aviation industry, and it explains the aviation fuel tax that has been adopted. In Section 4, we present the model specifications and demonstrate how we proceeded with the analysis. We explain the estimation results in Section 5, which includes a policy implementation proposal to limit and mitigate the impact of air travel on the environment. We emphasise that aviation fuel tax is effective for reducing the amount of CO_2 emissions from aviation; however, in Japan, it was not introduced primarily for that purpose. Finally, our conclusions are given in Section 6.

2. Preceding research

The first extensive investigation of the environmental impact of aviation emissions was the Intergovernmental Panel on Climate Change Special Report on “Aviation and the Global Atmosphere” (IPCC, 1999). It revealed that global passenger aviation had grown at a high rate of 9% annually since 1960 (2.4 times the average Gross Domestic Product (GDP)). Furthermore, the report found that emission reductions from technological and operational improvements (i.e., air transport management and airframe/engine design) had not kept pace with the increasing demand for air transport (IPCC, 1999). The report projected that between 1990 and 2015, global passenger air travel would grow by approximately 5% annually. This is similar to predictions by other studies that have estimated the growth of world aviation at 4.5–5.5% annually over future 15–20-year periods (Lee et al., 2001, 2004; Macintosh and Wallace, 2009; Lee, 2010; Mayor and Tol, 2010; Chèze et al., 2011, 2013; Airbus, 2015; Boeing, 2015). Based on these figures, current global air passenger traffic will have more than doubled by the early 2030s (IATA, 2015a; ICAO, 2013) with commensurate increases in jet fuel demand (Mazraati, 2010) and greenhouse gas emissions. Indeed, the demand for aviation fuel is currently at a record high, having increased from 4.2% of the world's oil-refining output in 1973 to 6.5% in 2012 (IEA, 2014b). Furthermore, CO_2 emissions from air transport have grown by 86.4% between 1990 and 2012 (IEA, 2014a).

This study focuses on the analysis of CO_2 emissions from aircraft and on specific mitigating policies. However, it is important to mention that substantial research has been conducted on the effects of non-CO_2 emissions from aviation and their aggregated impact on radiative forcing[1] (IPCC, 1999; Sausen et al., 2005; Sewill, 2005; Stordal et al., 2005; Forster et al., 2006; Marais et al., 2008; Lee et al., 2009). Non-CO_2 emissions refer to other particles (e.g., ozone, water vapour, and soot aerosols) released by the combustion of aviation fuel at high altitudes, as well as the formation of linear condensation trails (contrails) and aviation-induced cirrus clouds (Wuebbles et al., 2007; Brooker, 2009; Lee et al., 2009; McCarthy, 2010). The combined effects of CO_2 and non-CO_2 emissions makes the total contribution of aviation to global warming 2.5–4.0 times that of CO_2 emissions alone.

Despite the rapid pace of growth of aviation, aircraft fuel has remained almost ubiquitously tax-free, as defined in the “Policies on Taxation in the Field of International Air transport” (ICAO, 1994): “…fuel should remain exempt from customs and other duties (…), levied by any taxing authority within a State, whether national or local” (op cit.). Consequently, as with other measures proposed to mitigate aviation pollution, e.g., the short-lived inclusion of air transport emissions in the EU Emissions Trading System in 2012, carbon taxation has encountered tremendous resistance from the airline industry and governments.

There is clear evidence that taxation has affected fuel consumption in other sectors and therefore, its importance as an instrument of climate policy is unquestionable. For example, Li et al. (2014) analysed how gasoline taxes affect consumption in the United States. They found that a five-cent tax increase reduced short-term gasoline consumption by 1.3% in comparison with a 0.6% variation attributable to an equivalent five-cent increase in the tax-exclusive gasoline price, highlighting the “salience” of carbon taxes over price movements. Similarly, Rivers and Schaufele (2015) examined the short-term decline in gasoline demand following the imposition of a carbon tax in British Columbia. They concluded that the tax yielded a greater change in demand (is more salient) than equivalent market price movements. It was found that for the period 2008–2012, the imposition of the carbon tax resulted in a reduction of CO_2 emissions from gasoline of 2.4 Mt CO_2.

Research on the effects of carbon taxes on fuel consumption, market behaviour, and the benefits that accrue in the form of reduced CO_2 emissions can be traced back to before the Kyoto Protocol. A paper by Pearce (1991) showed the advantages of carbon taxes over the alternatives of command and control policies, especially the “double dividend” characteristic of tax, which not only corrects the externality of the excessive use of environmental services, but also allows governments to use income to finance reductions in incentive-distorting taxes such as corporate tax. Obviously, the same argument could be considered applicable to aviation fuel tax.

It must be noted, however, that there might be loopholes in

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[1] Radiative forcing is a measure of the thermal balance of Earth between incoming and outgoing solar energy (Chandler, 2010). In short, radiative forcing is a means by which to measure global warming.

taxation imposed on carbon emissions. For example, in Germany and Denmark, energy-intensive businesses have well-defined tax exemptions (BMF, 1999, 2006; DEA, 2012). If a carbon tax were applied to aviation, then unless this tax was common and equal among countries, airlines could change their operational behaviour to remain competitive (e.g., changing airports of choice and/or relocating to "low-tax" countries). Therefore, any tax applied regionally rather than globally could cause the taxed region to lose market share to non-taxed regions (Pearce and Pearce, 2010; Tol, 2007). However, such a problem would not arise if aviation fuel tax were imposed on domestic flights, which is the reason we consider only aviation fuel tax on domestic flights in this paper.

Felder and Schleiniger (2002) analysed the trade-off between efficiency and the political expediency of certain environmental policies in Switzerland by considering different measures that compensated sectors for paying environmental taxes and thus, minimising intersectoral transfers. Their study evaluated a series of tax reform scenarios with different clauses related to the nature of the tax (e.g., uniform, exempted for energy-intensive sectors, and differentiated across sectors) and revenue use (e.g., lump sum to households, labour subsidies, and no subsidy). Then, they compared the trade-off results in terms of price-ratio distortions. Although their results are not directly applicable in terms of the scope of this study, a similar analysis of the trade-off between efficiency and political expediency could provide a solution to the controversy surrounding the existing tax on aviation fuel in Japan.

3. Brief overview of Japan's aviation industry

3.1. *Circumstances of Japan's aviation industry*

Unless indicated otherwise, the data concerning Japanese domestic aviation were provided by the Civil Aviation Bureau of the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT). First, we present a brief overview of Japan's aviation industry.

Servicing 91 million passengers in 2013, Japan operates one of the largest domestic aviation networks in the world, which has experienced sustained growth over the past 20 years (Fig. 1). It comprises 19 trunk lines and over 200 local routes, with an average of 2250 daily services. Between 1991 and 2013, Japan's domestic Revenue Tonne Kilometres (RTK) grew at an average annual growth rate of 13%, and the volume of passengers increased by 23 million. Japanese domestic aviation consumed over 3.2 Mt of jet fuel in 2013 (MLIT, 2014).

The Japanese aviation sector is a well-organised network with modern and fuel-efficient aircraft (Fig. 2). For the purposes of this research, we consider that a modern fleet would offer the lowest boundary to the extent of CO_2 reduction. Thus, broadly speaking, any country that was to apply a similar measure for CO_2 reduction adopted in this paper should expect at least similar or greater reductions in CO_2 emissions.

Japan's original environmental commitment as part of the Kyoto Protocol was to achieve, by 2020, a target reduction of 25% in greenhouse gases based on 1990 levels. However, this target was subsequently modified and the current objective is a 3.8% reduction on 2005 levels, which is also to be achieved by 2020.[2] After the 2011 Tohoku Earthquake, Japan's nuclear program suffered a national breakdown and fossil fuel generation assumed the position as lead supplier servicing the country's large energy demand.

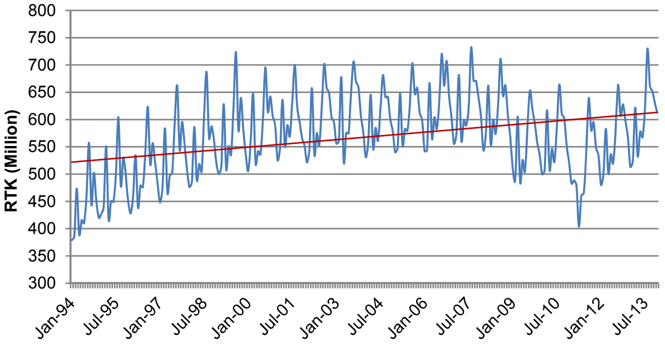

Fig. 1. Evolution of Japanese domestic aviation: Monthly observations of Revenue Tonne Kilometres (RTK) of the domestic flights in Japan (1994–2013). The chart shows traditional seasonality peaking during the months of Japanese holidays. The sharp drop in 2011 corresponds to the occurrence of the 2011 Tohoku Earthquake. Source: Authors from MLIT, 2014.

Consequently, Japan's greenhouse gas emissions started to grow with a 1.2% increase between 2012 and 2013 (ENV, 2014). Japan's total CO_2 emissions from fossil fuels were 1408 Mt in 2013 (op cit.), making it the fifth largest in the world (IEA, 2014a).

Although domestic aviation accounted for <1% of Japan's total CO_2 emissions in 2012, it is a considerably large figure in absolute terms. As a reference, CO_2 emissions from Japanese domestic aviation were about 1.3 times the national CO_2 emissions of Costa Rica one year earlier (World Bank, 2015). Furthermore, it must be highlighted that there was an increase in CO_2 emissions from the aviation sector after 2011, which correlates with the adjustment of the domestic aviation fuel tax (Fig. 3). The following sections quantify this effect and assess the sensitivity of aviation's CO_2 emissions to a tax on fuel. Incidentally, for domestic aviation we used a factor of 2.576 kg/l in order to estimate the generation of CO_2. This factor is reported under the Mobile Combustion CO_2 Emission Factors by the US Environmental Protection Agency (EPA) (EPA, 2014).

During the 20-year period of 1994–2013, the real-term price of jet fuel quadrupled, approximately doubling each year, except for the steep drop in 2008 following the Lehman Brothers shock. Indeed, the soaring price of jet fuel has increased the industry's operational costs on the global scale, with the percentage of airlines' operational costs attributable to fuel increasing from 13.6% in 2003 to 33.1% in 2013 (IATA, 2015b). Fig. 4 illustrates the change in monthly prices of jet fuel, as reported by the Bank of Japan (BOJ).

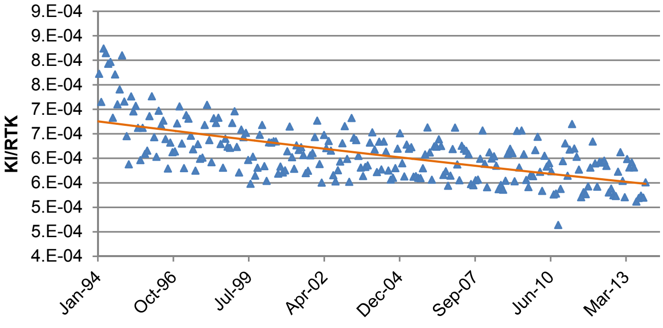

Fig. 2. Evolution of fuel efficiency in Japanese domestic aviation. Scatter graph representation of the sustained decline of the ratio between consumed fuel and distance flown (Kl/RTK) for domestic flights (1994–2013). Source: Authors from MLIT, 2014.

To compare the change in aviation fuel price with the actual cost

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[2] After this paper was completed, the 2015 United Nations Conference on Climate Change (COP21) stipulated Japan's environmental target as a 26% reduction by 2030. See http://www.nikkei.com/article/DGXLASGG30H1T_Q5A430C1MM8000/.

of flying, we present the trend of domestic aviation prices. It is interesting to observe that despite the increase in the price of jet fuel and therefore, of airlines' operational costs, the price of airline tickets has remained relatively unaltered for the same period. Fig. 5 shows the behaviour of domestic air ticket prices from 1994 to 2013. The data have been adjusted to remove the seasonal component, which is very strong in Japanese aviation during the holiday months of April, July, and December.

3.2. *Aviation fuel tax of Japan*

The aviation fuel tax is an indirect tax imposed on aviation fuel loaded onto aircraft, including helicopters, in the territory of Japan. Taxpayers are required to file a return and pay the tax on a monthly basis, following the loading of fuel on their aircraft. Aviation fuel tax is an excise tax for which international flights are exempt in Japan. Eleven-thirteenths of the revenue from the tax is credited to the general accounts of the State and then transferred to the Airport Construction and Improvement Account within the Special Accounts for Social Infrastructure Improvement (*kuukouseibitokubetsukaikei*). The remaining two-thirteenths of the revenue are granted to local governments for expenditures related to airports (MOF, 2010).

Persons liable to pay the aviation fuel tax are as follows:

(1) Owners of aircraft.
(2) Where it is clearly shown by the contract that persons other than owners are “users of aircraft” as prescribed by the Civil Aeronautics Act, these users of aircraft instead of owners.
(3) Where owners or users of aircraft have no residence or office in Japan, pilots-in-command instead of owners or users of aircraft.
(4) Persons other than owners, users, and pilots-in-command who make test flights or repairs of aircraft.
(5) Persons who make repairs of or conduct test runs of aircraft engines themselves (in this case, the tax is imposed on the quantity of aviation fuel consumed for repairs or test runs).

It is important to note that the Japanese aviation fuel tax was never recognised as an environmental tax. Instead, it was enacted for the purposes of development, expansion, and/or maintenance of regional airports and airfields. During the 1970s and 1980s, this proved a successful measure and the Japanese aviation network benefited from considerable development; however, the need for additional infrastructure has diminished and the existing airports are deemed capable of being run autonomously.

In April 2011, the Japanese aviation fuel tax underwent a 30% cut, which was implemented as a Government response to the filing for bankruptcy protection by Japan Airlines and constant pressure from Japan's Aeronautic Association (JAA) for the revision of fuel tax charges. The current fuel tax is applied to all domestic flights under the structure displayed in Table 1 (JAA, 2013).

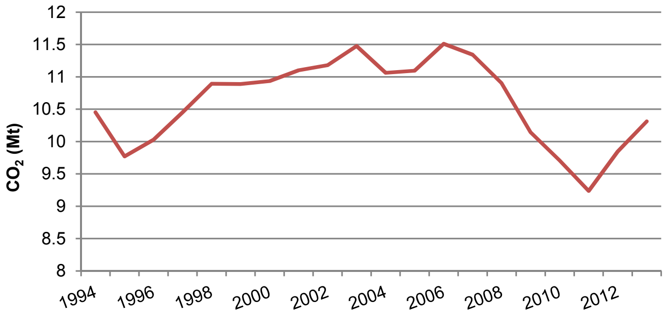

Fig. 3. CO_2 emissions from domestic aviation in Japan. Annual estimation using data from jet fuel consumed by local flights at a factor of 2.576 kg/l (EPA, 2014), between 1994 and 2013, in megatonnes (Mt). Source: Authors from MLIT, 2014 and EPA, 2014.

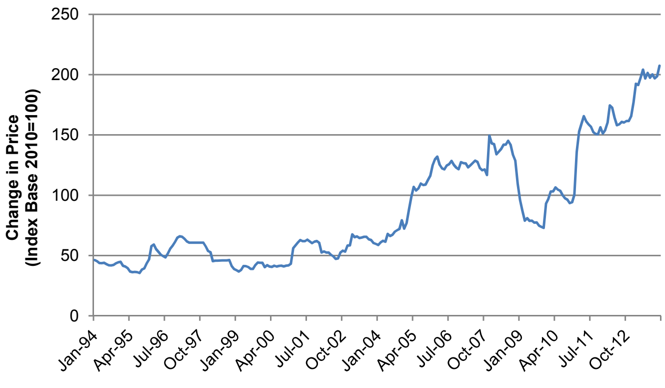

Fig. 4. Jet fuel price change in Japan 1994–2013. Source: Authors from BOJ, 2015.

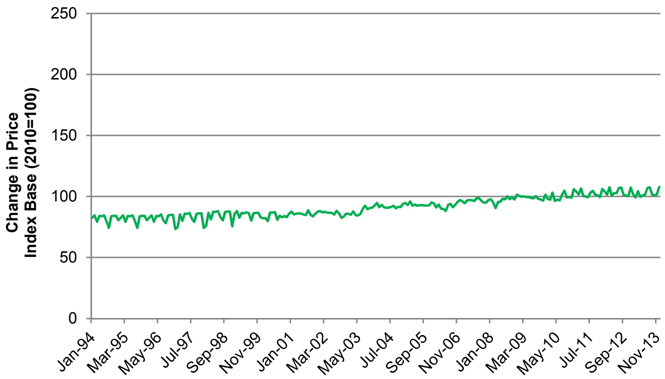

Fig. 5. Domestic airline ticket price change in Japan 1994–2013. Source: Authors from BOJ, 2015.

In 2014, the Government decided to extend the tax reform until April 2017.

4. Model specification

We constructed an empirical model following Brodersen et al. (2015). In their model, a local linear trend component is defined as

$$\mu_{t+1} = \mu_t + \delta_t + \eta_{\mu,t} \tag{1}$$

$$\delta_{t+1} = \delta_t + \eta_{\delta,t} \tag{2}$$

where $\eta_{\mu,t} \sim N(0, \sigma_\mu^2)$, $\eta_{\delta,t} \sim N(0, \sigma_\delta^2)$, μ_t represents the value of the trend at time *t*, and δ_t is the expected increase in μ between times *t* and *t* + *1*, i.e., the slope at time *t*.

Seasonality is captured in the model through the following component

$$\gamma_{t+1} = -\sum_{s=0}^{S-2} \gamma_{t-s} + \eta_{\gamma,t} \tag{3}$$

where *S* represents the number of seasons and γ_t represents their joint contribution to the observed data.

This model employs a “Spike-and-Slab” prior on the set of regression coefficients, which allows the model to choose (average

Table 1
Tax structure of the aviation fuel tax in Japan. Source, Authors from MLIT, 2014.

Route	Original tax rate (¥/Kl)	Adjusted tax rate (2011–2017) (¥/Kl)
Domestic flight (base)	26,000	18,000
Lines to Okinawa	13,000	9000
Lines to "Remote Islands"	19,500	13,500

Table 2
Causal impact results. The "Average" column in Table 2 represents the average value of monthly jet fuel consumption after April 2011. The "Absolute Effect" is determined as the difference between the predicted and actual value, i.e., the additional jet fuel that was consumed following the reduction in tax.

	Average	Cumulative
Actual	3.20E+05	1.10E+07
Prediction (SD)	291100 (4942)	9606291 (163080)
95% CI	[281270, 300512]	[9281894, 9916889]
Absolute effect (SD)	28186 (4942)	930123 (163080)
95% CI	[18773, 38016]	[619525, 1254520]
Relative effect (SD)	9.7% (1.7%)	9.7% (1.7%)
95% CI	[6.4%, 13%]	[6.4%, 13%]
Posterior tail-area probability	0.00111	
Posterior probability of a causal effect	99.88901%	

over) an appropriate set and to relieve a posteriori uncertainty about which covariates to include and how strong an influence they should have, which avoids overfitting.

As for the evaluation (pointwise) of the impact,

$$\phi_t^{(\tau)} := y_t - \tilde{y}_t^{(\tau)} \tag{4}$$

is established in order to obtain results from the a posteriori casual effect, for each draw τ and for each time point $t = n + 1, \ldots, m$.

It is also important for this research to estimate the cumulative effect of the intervention over time. This cumulative sum of causal increments is estimated by

$$\sum_{t'=n+1}^{t} \phi_{t'}^{(\tau)} \quad \forall t = n+1, \ldots, m \tag{5}$$

when y represents a flow quantity measured over an interval of time (in this case, one month).

5. Estimation results

The treatment variable consisted of monthly observations of jet fuel consumed (in kilolitres) by domestic flights in Japan between January 2004 and December 2013 (120 observations). The 30% tax reduction became effective at the start of the fiscal year in April 2011; therefore, the counterfactual time series was constructed with a set of covariates that explained the behaviour of fuel consumption until this point, using the causal impact (CausalImpact R Package) model.

Because the idea behind the causal impact approach is to find a suitable set of regressors that is able to explain the pre-intervention part of the time series appropriately, we do not commit to a fixed set of covariates. Instead, the model is allowed to choose from an array of candidate controls, which are selected without reference to external characteristics and chosen purely in terms of how well they explain the behaviour of jet fuel consumption in Japan before the tax change. In this study, we used data based on web search queries, provided by Google Correlate™ (https://www.google.com/trends/correlate). As long as the variables employed are strictly not affected by the intervention, the model will construct a synthetic control variable that is based on a combination of markets that explain the outcome data before the 30% tax reduction, while automatically balancing the goodness of fit and model complexity (see Brodersen et al., 2015).

It is noticeable that the cumulative effect in the lower panel of Fig. 6 is negative during the first months following the intervention. This could reflect a response to two different effects. The first is the time lag in the decision to increase consumption. Despite the relatively cheaper price of jet fuel, there is an associated delay before an airline decides to increase its number of flights, add to its fleet of aircraft, or diversify its routes to avail itself of the relatively more beneficial financial conditions. The second reason is the occurrence of the 2011 Tohoku Earthquake, which occurred just one month before the tax structure was adjusted. As shown in Figs. 1 and 3, the totals of RTK and jet fuel consumption experienced sharp declines in 2011 because of the reduction in leisure and business travel in Japan.

The model was adjusted for seasonality, defining the duration of a seasonal component as one month.[3] With an average 28,186 Kl of additional jet fuel used per month, we approximated the annual extra fuel consumption as 338,232 Kl. Using the EPA factor, this corresponds to 871.29 Kt CO_2. The "Cumulative" column in Table 2 sums all the individual time points after the intervention, which renders the total additional fuel consumed between the tax adjustment in April 2011 and the final observation in December 2013. The total extra fuel consumed during this period was 930,123 Kl, which converts to 2.4 Mt CO_2. In relative terms, the response values showed an increase of 9.7% in fuel consumption. The 95% confidence interval of this percentage was [+6.4%, +13%], which means that the positive effect observed during the intervention period was statistically significant and unlikely to be due to random fluctuations.

To better illustrate these results, we refer to Japan's CO_2 levels during the tax reduction years. In 2013, the emissions from domestic air travel were 10.31 Mt CO_2, of which our estimated additional production of 871.29 Kt CO_2 represented 8.45%, or alternatively, an increase of 9.23% in the emissions by domestic flights in that year had the tax not changed. In fact, this is the lowest

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[3] The R Package requires an integer for seasonal adjustment. Therefore, because the jet fuel observations were on a monthly basis, shorter Japanese holidays such as the Golden Week were taken as one entire month.

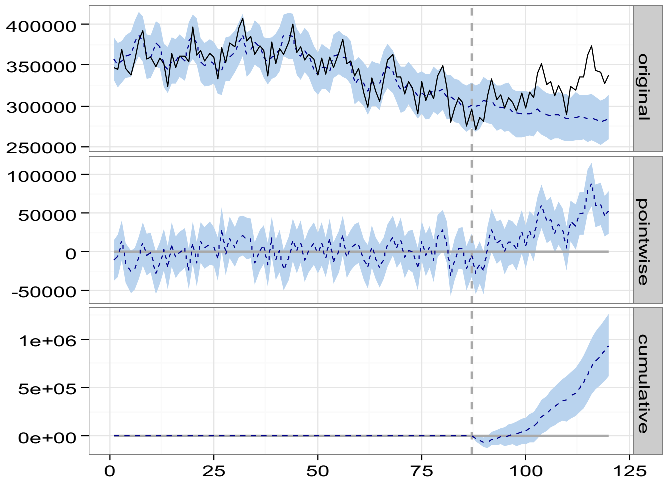

Fig. 6. Visualisation of the causal impact object. It contains three panels and a straight vertical line that indicates the moment of the tax reduction, i.e., April 2011. The solid line in the upper panel shows the original data and the dotted line represents the counterfactual prediction. The middle panel displays the difference between the observed and predicted data in panel one. The lower panel sums the values of the middle panel, resulting in a plot of the cumulative effect of the intervention, i.e., the additional fuel consumed as a response to the tax adjustment. Source: Authors with Causal Impact R Package.

estimation for any increase for the post-intervention years, as additional CO_2 emissions for 2011 and 2012 were 9.24 (10.42%) and 9.85 Mt (9.71%), respectively, consistent with an annual rate of increase of 9.7% as estimated by the model. The same standard can be applied to the cumulative estimation of additional CO_2 generated between 2011 and 2013 due to the tax adjustment. During these years, the total emissions from domestic aviation were 29.4 Mt CO_2, and our estimation shows an additional production of 2.4 Mt (representing growth of 8.89%) in comparison with a “business as usual” scenario had the tax not been modified. At the national level, Japan's total CO_2 emissions during the 3 years following the tax reform were 4.16 Gt CO_2 (ENV, 2014), of which domestic aviation represented a minor, although significant, 0.71%. Japan is currently the world's fifth largest emitter of CO_2 and the number one net importer of oil products (IEA, 2014a, 2014b).

6. Conclusions

Although the aviation sector is currently a relatively small contributor to global CO_2 emissions, it is expected that it will emit substantially more CO_2 in the future; therefore, it should not be ignored when considering measures to prevent global warming. This research has shown scientific evidence that illustrates the rapid growth of CO_2 emissions attributable to the development of the aviation sector, and it has demonstrated conclusively that aviation fuel tax can realise a significant reduction in the CO_2 emissions from aircraft, in a way that to the best of the authors' knowledge has not been done before.

This research estimated the quantity of aviation-related CO_2 emissions that could be discouraged by the application of a fuel tax. Just as other means of transportation are almost universally bound to an environmental tax, there is no justification in terms of environmental economics for this particular sector to remain unaccountable for a problem that is of general concern.

The investigation has shown that large-scale reductions of CO_2 emissions could be achieved if measures similar to the Japanese Aviation Fuel Tax were replicated in other regions of the world. Japan, as a regional leader committed to the environment and to efforts to reduce CO_2 emissions, should consider the results of this paper to demonstrate the environmental implications to other Asian economies that are experiencing a boom in their regional and low-cost aviation sectors.

Considering the continued opposition to the existing fuel tax from Japanese domestic airlines, it is unlikely that jet fuel could be added to the current structure of environmental taxes in Japan. Nevertheless, this paper proposes an alternative to environmental tax reform that comprises a simple price-elasticity approach comparing the effect of CO_2 reductions under implicit and pure carbon taxes and the figures estimated in this study. Naturally, public acceptance remains the main obstacle to such restructuring, especially by those sectors that are dependent on fossil fuels and sensitive to international competitiveness, such as airlines (Yokoyama et al., 2000).

The results of this study might appear unfeasible to the aviation industry in Japan, because the abolishment of the reduction in fuel tax would mean an increased cost for business. However, to promote sustainable development, the balance between environmental protection and business prosperity must be maintained. This paper offers a measured and balanced view of the environmental concerns associated with aviation emissions of CO_2. It is a matter of an equilibrated solution between the need for air travel and the severe impact of flying on climate change.

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