Decomposition of Lifecycle CO_2 Emissions Associated with International Flights of the Japanese Airline Industry

by

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Abstract

We estimated the CO_2 emissions from aviation associated with more than 40 thousand international flights of major airline companies in Japan (Japan Airlines (JAL) and All Nippon Airways (ANA)), and identified the driving forces of these CO_2 emissions by using index decomposition analysis during the study period between 2005 and 2015. The results show that introducing the Boeing 787 with a better fuel efficiency than those of conventional models, led to CO_2 emissions reductions by both companies between 2005 and 2015, amounting to 1.6 million tonnes-CO_2. However, the Boeing 787 reduction effect was completely canceled out by both total number of flights effect and distance effect for airline operations of both companies. We conclude

that an environmental and business strategy of introducing greener aircrafts such as the Boeing 787 with a better fuel efficiency was not enough for climate mitigation.

Keywords: CO_2 emissions, aviation sector, international flights, index decomposition analysis

1. Introduction

The IPCC 4th Assessment Report (2007) explained that CO_2 emissions by the aviation industry account for approximately 2% of global greenhouse gas emissions, and the amount of annual CO_2 emissions from aviation is rapidly increasing by 3-4%/yr. In Japan, the transportation sector emitted 200 million tonnes-CO_2, accounting for 20% of total CO_2 emissions, in 2015 (MLIT, 2015). Although the CO_2 emissions from air transportation are a mere 5% of transport emissions in Japan, these values include only CO_2 emissions associated with domestic flights, not international flights (MLIT, 2015). Therefore, the CO_2 emissions from aviation reported by the Japanese government were considerably underestimated.

The International Civil Aviation Organization (ICAO) decided to introduce a global market-based measures (GMBM) scheme called the "Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)" to complement the Global Carbon Reduction Target (ICAO, 2018). During the first phase from 2021 to 2026, airlines have to reduce CO_2 emissions relative to the average baseline emissions for 2019 and 2020. If they exceed the amount of CO_2 emissions set as their upper limit, then they have to buy an allowance (ICAO, 2018). During the second phase from 2027 to 2035, all member states of ICAO except for countries with only low levels of CO_2 emissions and developing countries have to participate in this scheme (ICAO, 2018). Japan is a participant in this scheme from the first phase (ICAO, 2018). In summary, the scheme sets an upper limit on the CO_2 emissions associated with international flights, so to reduce CO_2 emissions, the airlines have to operate in an environmentally friendly manner.

From the demand-side perspective, it is important to note that the World Tourism Organization (UNWTO) estimated that the tourism industry contributed 7% to the global GDP in 2018, and global tourism will continue to grow hereafter at a rate of 3-5% annually (UNWTO, 2017). With this background, previous studies analyzed the environmental burdens associated with the increasing tourism demand (Peeters and Dubois, 2010; Gossling and Peeters, 2015; Lenzen *et al*. 2018). In a recent important study, Lenzen *et al*. (2018) estimated the carbon footprint of global tourism and revealed that the global demand for tourism drove 8% of global greenhouse gas (GHG) emissions in 2013. In particular, the aviation industry was identified as one of the most critical contributors to the carbon footprint triggered by the tourism demand (Lenzen *et al*., 2018).

The previous studies at the industry level (Peeters and Dubois, 2010; Gossling and Peeters, 2015; Lenzen *et al*. 2018) limited themselves to addressing the important question of how airline companies can mitigate CO_2 emissions under their actual flight schedules with currently operated aircraft. Meanwhile, Schefczyk (1993) and Carlos and Nicolas (2009) analyzed airline operational performance by using data envelopment analysis (DEA) (Farrell, 1957; Charnes *et al*., 1978). Arjomandi and Seufert (2014) and Liu *et al*. (2017) analyzed the performance of airlines by using an environmental DEA approach which considers the outputs of CO_2 emissions as undesirable. In the case of Liu *et al*. (2017), the performance of 12 Chinese airlines was analyzed from 2007 to 2013 and the amount of CO_2 emissions was found to have decreased by about 12% through technological innovation.

Previous studies estimated the CO_2 emissions from the passenger transport sector and freight transport sector (Scholl *et al*., 1996; Kveiborg and Fosgerau, 2007; Jiyong *et al*., 2012; Cristen *et al*., 2013) and examined the factors for change for the CO_2 emissions from these sectors (Lakshmanan and Han, 1997; Lee *et al*., 1997; Mazzarino, 2000; Kwon, 2005; Lu *et al*., 2007; Timilsina and Shrestha, 2009; Papagiannaki and Diakoulaki, 2009; Wang *et al*., 2011; Andreoni and Galmarini, 2012; Achour and Belloumi, 2016; Fan and Lei, 2017). For an important study, Andreoni and Galmarini (2012) identified the drivers for the change in the CO_2 emissions associated with aviation activities for both passenger and freight in 27 European countries from 2001 to 2008. According to their study, the expansion of the market scale of the aviation sector is the most important factor for the increase in CO_2 emissions (Andreoni and Galmarini, 2012).

Andreoni and Galmarini (2012, p. 596) stated, "*Unfortunately, since Eurostat data are not disaggregated by the passenger and freight transports, the decomposition analysis presented in this paper cannot disaggregate between travelers and goods.*" However, in order to recommend a valid method for reducing the CO_2 emissions from the aviation sector, the most important thing is to estimate CO_2 emissions disaggregated according to origin between travelers and goods. The number of travelers tends to increase, and setting the upper limit on the CO_2 emissions associated with international flight will start in 2021, so the aviation sector, especially airlines, need to participate in reduction activities targeted at international aviation.

To the best of our knowledge, although there have been many studies on the CO_2 emissions from all activities of the aviation sector and the operational performances of individual airlines, there have been few studies that estimated the amounts of CO_2 emissions from individual airlines or considered the effect of the operational situation, for example, the number of flights.

In this study, focusing on the two major Japanese airlines, Japan Airlines (JAL) and All Nippon Airways (ANA), we first create a detailed database of the direct flights of the international passenger transport sector departures and arrivals in Japan in terms of the numbers of flights and aircraft in 2005, 2010, and 2015. We estimate the amount of the direct CO_2 emissions from the airlines activities. Second, using a new decomposition analysis framework, we analyze the change factors for direct CO_2 emissions. Finally, we discuss what the individual airlines should do in order to decrease CO_2 emissions by the aviation sector.

The remainder of this paper is organized as follows: Section 2 explains the methodology proposed in this study, Section 3 presents the data used in this study, Section 4 discusses the results, and finally Section 5 offers a conclusion.

2. Methodology

This study estimates the CO_2 emissions associated with the international flights of travelers between Japan and all other countries and analyzes the driving factors of change in the CO_2 emissions by employing the index decomposition method (Ang and Choi, 1997; Ang *et al.*, 1998; Ang and Zhang, 2000; Ang *et al.*, 2003; Ang and Liu, 2007).

The amount of *direct* CO_2 emissions in year t associated with jet fuel combustion due to international flights to a specific region i operated by airline company s is calculated as

$$Q_i^s(t) = \frac{Q_i^s(t)}{f_i^s(t)} \times \frac{f_i^s(t)}{d_i^s(t)} \times \frac{d_i^s(t)}{b_i^s(t)} \times \frac{b_i^s(t)}{\sum_k b_k^s(t)} \times \sum_k b_k^s(t)$$

$$= EI_i^s(t) \times FE_i^s(t) \times AD_i^s(t) \times RS_i^s(t) \times TN^s(t) \quad (1)$$

where s is either JAL or ANA in this study and i indicates a region in which the company is operating (1. Asia, 2. North America, 3. Oceania, and 4. Europe in this study). Regarding the other notation used in Eq. (1), $EI_i^s(t)$ is the CO_2 emission intensity (t-CO_2/L) at the region level, which indicates the CO_2 emissions per unit of aviation fuel consumption associated with international flights to region i. $FE_i^s(t) = \frac{f_i^s(t)}{d_i^s(t)}$ represents the fuel efficiency (L/km), that is, the amount of aviation fuel consumption ($f_i^s(t)$) per flight distance for region i ($d_i^s(t)$). It should be noted that we used the "catalog-based" fuel efficiency (L/km) of aircraft models flying between international airports in Japan and international airports in the specific region and estimated the annual total jet fuel combustion (L) for each air route by multiplying catalog-based fuel efficiency by cumulated round-trip flight distance for the air route within one year. The annual total aviation fuel combustion for each region i was estimated by summing up jet fuel combustion over all air routes between international airports in Japan and the international airports in the region. We finally defined the region-specific average fuel efficiency, $FE_i^s(t)$, by dividing the annual total aviation fuel combustion for region i by the annual total of all cumulated round-trip flight distances for the air routes between international airports in Japan and the international airports in the region. If the airline company introduces a greener aircraft with better fuel efficiency (i.e., a lower value of $FE_i^s(t)$) for air routes to the region, then the aviation fuel combustion for the region will decrease.

Continuing, in Eq. (1), we defined the variable $AD_i^s(t) = \frac{d_i^s(t)}{b_i^s(t)}$, where $b_i^s(t)$ represents the number of flights for international air routes to region i in year t. Note that if the total of the cumulated round-trip flight distances for the air routes for region i is shortened by changing the configuration of destination cities within the region, then this will affect aviation emissions. For example, if a company decreases the number of shorter flights to Beijing and conversely increases the number of longer routes to Delhi, then the aviation emissions within the region (i.e., Asia in this study) will increase. In Eq. (1), we further define the variable $RS_i^s(t) = \frac{b_i^s(t)}{\sum_k b_k^s(t)}$, where $\sum_k b_k^s(t)$ sums over all flights for the international air routes for all regions operated by airline company s in year t. Accordingly, $RS_i^s(t)$ indicates the relative importance of the air routes for region i among those for all regions.

Thus, the total CO_2 emissions for airline company s can be estimated by using the following five factors: emission intensity (EI), fuel efficiency (FE), average distance (AD), regional share of all flights by number (RS), and total number of flights (TN).

$$Q^s(t) = \sum_i Q_i^s(t) = \sum_i EI_i^s(t) FE_i^s(t) AD_i^s(t) RS_i^s(t) TN^s(t) \quad (2)$$

Noting that the emission intensity for jet fuel combustion is fixed over time, the decomposition analysis framework for the change in the aviation emissions between years 0 and t can be formulated by using the logarithmic mean Divisia index (LMDI) method (see Ang *et al*., 1998) as follows.

$$\Delta Q_i^s = Q_i^s(t) - Q_i^s(0)$$

$$= \omega_i \ln \frac{FE_i^s(t)}{FE_i^s(0)} + \omega_i \ln \frac{AD_i^s(t)}{AD_i^s(0)} + \omega_i \ln \frac{RS_i^s(t)}{RS_i^s(0)} + \omega_i \ln \frac{AN_i^s(t)}{AN_i^s(0)}$$

$$= Q_{i,FE}^s + Q_{i,AD}^s + Q_{i,RS}^s + Q_{\mathrm{i},TS}^s \quad (3)$$

where $\omega_i = \frac{\Delta Q_i^s}{\Delta \ln Q_i^s} = \frac{Q_i^s(t) - Q_i^s(0)}{\ln Q_i^s(t) - \ln Q_i^s(0)}$. It should be noted that $\omega_i = Q_i^s(t) = Q_i^s(0)$ if $Q_i^s(t)$ is equivalent to $Q_i^s(0)$. The four terms on the right-hand side of Eq. (3) represent the influences of the four drivers affecting the change in the aviation CO_2 emissions of the airline company.

3. Data

For this study, we collected the following detailed data of the international flights and aircraft models for two Japanese airline companies (JAL and ANA) and the three years of 2005, 2010, and 2015.

(1) Number of international flights per week (JTB Corporation, 2005, 2010; MLIT, 2015)
(2) Aircraft models used in the international flights (JTB Corporation, 2005, 2010; MLIT, 2015)
(3) Round-trip distance between each departure city and arrival city (ICAO, 2018)
(4) Fuel efficiency of each aircraft model (The Boeing Company, 2018; Airbus, 2018; The Douglas Aircraft Company, 2018)
(5) Emission intensity of jet fuel combustion (Ministry of the Environment, Japan, 2018)

The database used in this study is provided in the supporting Excel file. It should be noted that the fuel efficiency of each aircraft model in liter per kilometer was calculated by dividing catalog-based maximum fuel capacity (L) by catalog-based maximum range of the aircraft (Km) (SI). The emission intensity of jet fuel combustion is 2.46 (t-CO_2/L) (Ministry of the Environment, Japan, 2018). Using the database, we estimated the direct CO_2 emissions of two Japanese airline companies (JAL and ANA) associated with international flight activities for the three years of 2005, 2010, and 2015.

The number of flights data is provided in per-week form, and the timetable of each airline company is revised twice a year. Therefore, we convert the per-week values into annual values while assuming that the summer timetable from April to October has 30 weeks and the winter timetable from November to March has 22 weeks.

4. Results

4.1 Present situation in Japanese aviation sector

The sales for international passenger flights of JAL and ANA in 2005 were 690 billion yen and 230 billion yen, respectively (JAL, 2005; ANA, 2005), whereas their sales in 2015 were 45 billion yen and 52 billion yen, respectively (JAL, 2015; ANA, 2015). These figures show the following: (1) total sales for the two airlines increased by 5.4% during the study period between 2005 and 2015, (2) market share for international passenger flights of ANA increased from 25% to 53% during the study period, whereas that of JAL sharply decreased from 75% to 47% due to a business bankruptcy in January 2010. It should be noted that the market share is calculated by dividing the sales for international passenger flights of each airline company by total sales for the two airlines.

The primary reason for the rapid decline in the market share for JAL is the following: the total number of flights has changed from 577 flights per week in 2005 to 457 flights per week in 2010 and 482 flights per week in 2015 (Figure 1). Thus, there was a decreasing trend over the ten years because of the business bankruptcy in January 2010 and since then has been working to improve its management; for example, unprofitable routes have been abandoned or had their numbers of flights decreased (JAL, 2015). On the other hand, over the same ten years, the total number of flights by ANA has increased from 225 flights per week in 2005 to 329 flights per week in 2010 and 511 flights per week in 2015 (Figure 1).

It is important to see how the changes in the market shares for JAL and ANA have affected overall CO_2 emissions for the aviation sector in Japan. As a result, CO_2 emissions from their international flights slightly decreased by 0.4 Mt-CO_2 during the period between 2005 and 2015, accounting for 3% of the aviation emissions in 2005 (Figure 2). Subsequently, we evaluated environmental efficiency at sector level defined by dividing the total sales for the aviation sector in billion JPY by the CO_2 emissions for the aviation sector in Mt-CO_2. We found that a rapid change in the Japan's aviation market has consequently contributed to increasing the environmental efficiency by 9% during this decade, implying that the aviation sector in Japan has changed toward producing more with less CO_2 emissions since 2005 and achieved 'decoupling' of outputs and energy-related CO_2 emissions.

To discuss why the decoupling has been achieved in the aviation sector of Japan, it is important to looking at the changes in CO_2 emissions at company level. The CO_2 emissions associated with international flights of JAL decreased about 4.11 Mt-CO_2 in 2015 relative to 2005 (Figure 2). This decrease is also assumed to be an effect of the total number of flights being decreased by the bankruptcy. On the other hand, the CO_2 emissions associated with the international flights of ANA increased 3.75 Mt-CO_2 in 2015 relative to 2005 due to an increase in the number of international flights since 2010 (Figure 2). The number of departures and arrivals for Narita International Airport increased and also the Tokyo International Airport (i.e., Haneda International Airport) close to Tokyo metropolitan area opened its new international terminal in 2010 and the facility factors became tailwind for the increase in the number of international flights for ANA.

[INSERT FIGURE 1 ABOUT HERE]

[INSERT FIGURE 2 ABOUT HERE]

4.2 Decomposition analysis

Using a decomposition analysis, we identify the contribution of each *technological* factor to the change in CO_2 emissions at company level and further argue why the decoupling in the aviation sector of Japan has been achieved during the study period.

4.2.1 Fuel efficiency (FE) effect

Looking at the fuel efficiency (FE) effect for JAL between 2005 and 2010, FE was a factor that contributed to the decrease in CO_2 emissions in Asia, North America, and Oceania (Figure 3). In particular, the Asia region had a decrease in CO_2 emissions of about 0.7 Mt-CO_2 due to the FE effect of improving the fuel efficiencies of aircraft between 2005 and 2010. Before bankruptcy in January 2010, JAL mainly used jumbo jets, as represented by the Boeing 747, which uses a large amount of fuel in each flight and has poor fuel efficiency of 16.6 (L/Km), resulting in higher

CO_2 emissions. However, after bankruptcy in January 2010, JAL introduced relatively fuel efficient aircraft, for example, the Boeing 767, so they could decrease CO_2 emissions per flight.

Between 2010 and 2015, JAL introduced a new aircraft model, the Boeing 787, which has an about 50% better fuel efficiency of 8.4 (L/Km) relative to conventional aircraft (e.g., Boeing 747) for North America and Europe. These regions have long-distance routes, so the reduction of CO_2 emissions associated with international flights to North America and Europe during the five years (i.e., Boeing 747 effect) was significant, amounting to one million tonnes-CO_2 (Figure 4).

[INSERT FIGURE 3 ABOUT HERE]

[INSERT FIGURE 4 ABOUT HERE]

For ANA, FE was a factor that contributed to the decreases in CO_2 emissions in Asia and Europe, whereas there was an increase in North America between 2005 and 2010 (Figure 5). In this paper, we are considering four regions (Asia, North America, Europe, and Oceania); however, ANA did not have any flights to Oceania in 2005 and 2010, so we are analyzing only three regions for this section. The increase of CO_2 emissions in North America reflects changes to aircraft. In contrast, JAL introduced larger aircraft in 2010 than those used in 2005. These new aircraft had 20% poorer fuel efficiency, which induced an increase in CO_2 emissions.

Similarly, between 2010 and 2015, FE contributed to an increase of CO_2 emissions in Asia and decreases in North America and Europe (Figure 6). For ANA, Oceanian routes were not operated in 2010, however they were operated only in winter in 2015, so the CO_2 emissions from

Oceanian routes in 2015 were allocated to the other four change factors equally (Ang and Liu, 2007) (Figure 6). Unlike the results for between 2005 and 2010, the results for Asia and North America were opposite in sign (Figures 5 and 6). It is assumed that the reduction of CO_2 emissions from North America was due to introducing the Boeing 787 for North America, whereas FE contributed to an increase in Asia. This new relatively fuel-efficient aircraft was also introduced on these routes, but its fuel efficiency was worse than that of the Airbus 320, which was being used on those routes. However, because the Boeing 787 has many more seats than conventional aircraft and its flight range is quite long, ANA decided to gradually retire the Airbus 320 (ANA, 2012).

[INSERT FIGURE 5 ABOUT HERE]

[INSERT FIGURE 6 ABOUT HERE]

4.2.2 Average distance (AD) effect

The AD effect reflects the flight structure of the region. If the AD effect is positive, then the average distance in the region is longer; similarly, if the AD effect is negative, then the average distance in the region is shorter. For example, a positive AD effect means that the number of long flights in the region increases.

The average distance (AD) effect for JAL between 2005 and 2010 contributed to decreases of CO_2 emissions in Asia and Europe and to increases in North America and Oceania (Figure 3). In North America, routes which did not exist in 2005 were later added (MLIT, 2015). The biggest reason for this positive effect was the Haneda to San Francisco route, which is the longest in this region. On the other hand, in Asia, the AD effect is negative; this result was brought about by reducing the numbers of flights along the Singapore and Denpasar routes, which are relatively long routes in Asia. Therefore, the average distance in Asia decreased, making the AD effect negative.

The average distance (AD) effect for JAL between 2010 and 2015 is a factor that contributed to a decrease of CO_2 emissions in Europe and increases in other regions (Figure 4). In Asia and North America, the biggest reason for the positive effects was the introduction of new long-distance routes. For example, in Asia, a Jakarta route and a Singapore route, both of which are relatively long, were added. In North America, a Boston route which became one of the longest routes flown by JAL was added, so CO_2 emissions due to the AD factor increased.

In the case of ANA between 2005 and 2010, AD is a factor that contributed to increases in Asia and North America and a slight decrease in Europe (Figure 5). Like JAL, ANA added new long-distance routes, for example, Mumbai and Kuala Lumpur routes in Asia and a Chicago route, which has a round-trip distance of more than 20 thousand kilometers, in North America. Similarly, between 2010 and 2015, AD contributed to an increase of CO_2 emissions in Asia, larger than in any other regions (Figure 6).

4.2.3 Regional share (RS) effect

Next, we assess the regional share of all flights by number (RS) effect for JAL and ANA. It should be noted that RS, as the percentage share of number of flights for a particular region, captures the relative importance of the region.

RS for JAL between 2005 and 2010 is a factor that contributed to an increase of CO_2 emissions in Asia and decreases in North America, Europe, and Oceania (Figure 3). Thus, the obtained results show that the importance of Asian routes increased in 2010 relative to 2005. Comparing numbers of flights, Asia had a decrease from 358 flights per week in 2005 to 322 flights per week in 2010. However, the total number of flights for JAL decreased from 577 flights per week in 2005 to 457 flights per week in 2010, resulting in the percentage of Asian routes increasing. In contrast, in 2010, European routes constituted about half of all routes in 2005. However, by 2010, not only did the total number of flights decrease, but the percentage of European routes decreased.

Looking at the regional share (RS) effect for JAL between 2010 and 2015, RS is a factor that contributed to increases of CO_2 emissions in North America and Europe and decreases in Asia and Oceania (Figure 4). The numbers of flights increased in the regions other than Oceania, with the percentage of North America routes increasing about 1.2-fold relative to 2010.

In the case of ANA between 2005 and 2010, all regions had increases in numbers of flights in 2010 relative to 2005, but the increases in Asia and North America were relatively large compared to the increase in Europe, so the RS effect for Europe was negative. On the other hand, between 2010 and 2015, RS contributed to a decrease in Asia and increases in North America and Europe (Figure 6). The numbers of flights increased in all regions, but North America and Europe increased about 2-fold compared to 2010. This increase was bigger than the increase of the total number of flights, so the RS effect was positive.

4.2.4 Total number of flights (TN) effect

Finally, we assess the total number of flights (TN) effect for JAL. TN is a factor that contributed to decreases of CO_2 emissions in all regions between 2005 and 2010 (Figure 3). After the bankruptcy in 2010, the non-profitable routes of JAL were abandoned or their numbers of flights were decreased. Therefore, the total number of flights for all regions for international routes decreased in 2010 relative to 2005. This result shows that a reduction of CO_2 emissions for this period was brought about by the TN effect. On the other hand, in the case of ANA, TN is a factor that contributed to increases of CO_2 emissions in all regions between 2005 and 2010 (Figure 4). The total number of flights for all regions for international routes increased in 2010 relative to 2005, so CO_2 emissions also increased.

It is assumed that the increase in the total number of flights by ANA was caused by the decrease of the total number of flights by JAL due to that latter's bankruptcy in 2010. The total number of flights by JAL decreased from 577 flights per week in 2005 to 457 flights per week in 2010, whereas the total number of flights by ANA increased from 255 flights per week in 2005 to 329 flights per week in 2010. This change shows that ANA had to make up for the deficit in the supply due to the decrease by JAL. Therefore, the increase of the total number of flights by ANA was caused by ANA maintaining the supply of the Japanese aviation industry, as well as a change in management to focus on international flights.

The total number of flights by JAL greatly decreased from 2005 to 2010, but it increased by about 30 flights per week from 2010 to 2015. In 2015, JAL was still under monitoring, but they were able to increase the total number of flights little by little in accordance with the increasing demand. Similarly, in the case of ANA, TN contributed to increases in all regions (Figure 6). The numbers of flights in the four regions increased by 1.5- to 2-fold, and the total number of flights increased by about 200 flights per week. Therefore, TN is the biggest factor explaining the increases of CO_2 emissions from ANA.

5. Discussion and Conclusions

This study estimated the CO_2 emissions from aviation associated with the international flights of Japan Airlines (JAL) and All Nippon Airways (ANA), and identified the driving forces of these CO_2 emissions by using index decomposition analysis. From the results, we found that changes in aircraft models and the total number of flights affected the total CO_2 emissions from aviation. Introducing the Boeing 787, which has a better fuel efficiency than those of conventional models, led to remarkable CO_2 emissions reductions by both companies between 2005 and 2015, amounting to 1.6 million tonnes-CO_2.

However, CO_2 emissions from ANA increased by 3.17 million tonnes-CO_2 during the period from 2005 to 2015, due to an increase of the total number of flights, which was the largest driving force. On the other hand, the average-distance effect was dominant in the increase of CO_2 emissions in the case of JAL during the period from 2005 to 2015 and it amounts to 0.56 million tonnes-CO_2. It is important to note that the Boeing 787 reduction effect was canceled out by the both TN and AD effects in the Japanese aviation industry.

It is estimated that Tokyo International Airport (Haneda Airport) has the capacity to increase the number of international flights handled 1.7-fold for 2020, the year that the Tokyo Olympic Games will be held, compared with 2015 (MLIT, 2017), which would boost the number of international flights in Japan and the CO_2 emissions from aviation associated with it.

However, Japanese airline companies have to mitigate their CO_2 emissions from international flights because the Japanese government decided to participate in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (MILT, 2016). Considering the increasing demands for aviation, a decrease in the total number of flights is not a practical policy (Figure 1). Importantly, in this study, we also found that an environmental and business strategy of introducing greener aircrafts such as the Boeing 787 with a better fuel efficiency was not enough for reducing CO_2 emissions.

The Japanese government has suggested improving aircraft and their greener operations, utilizing market mechanisms such as carbon emission trading, and introducing bio-jet fuel in order to mitigate CO_2 emissions from international flights (MLIT, 2016). Furthermore, the International Air Transport Association (IATA) has also emphasized the importance of bio-jet fuel for CO_2 emission reduction (IATA, 2018). Bio-jet fuel is actually commercialized in European countries and the U.S., and the EU established the EU-ETS framework, which offsets CO_2 emissions from the combustion of bio-jet fuel. According to NASA, bio-jet fuel enables CO_2 emissions from the aviation industry to be reduced by approximately 50 to 70%, which will accelerate the implementation of biofuel in the aviation industry. In the case of Japan, both JAL and ANA have invested in R&D for the utilization of bio-jet fuel and conducted test flights powered by bio-jet fuel (JAL, 2008; ANA, 2012). Thus, the utilization of bio-jet fuel would be crucial for reducing the aviation emissions with safety of passengers.

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Figures

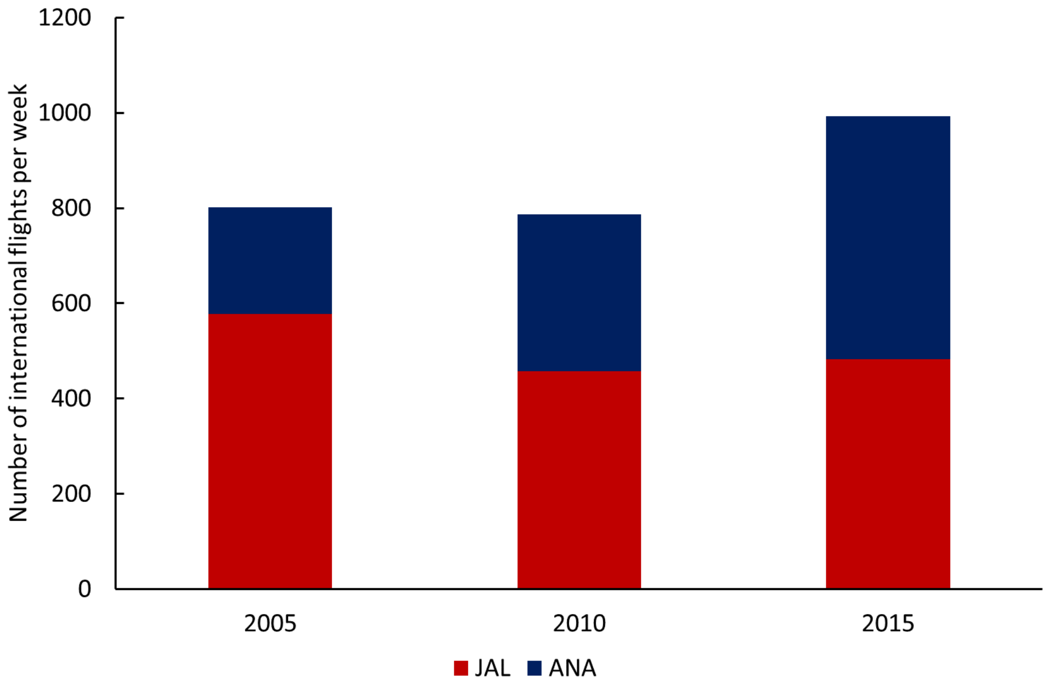

Figure 1. Total number of international flights per week

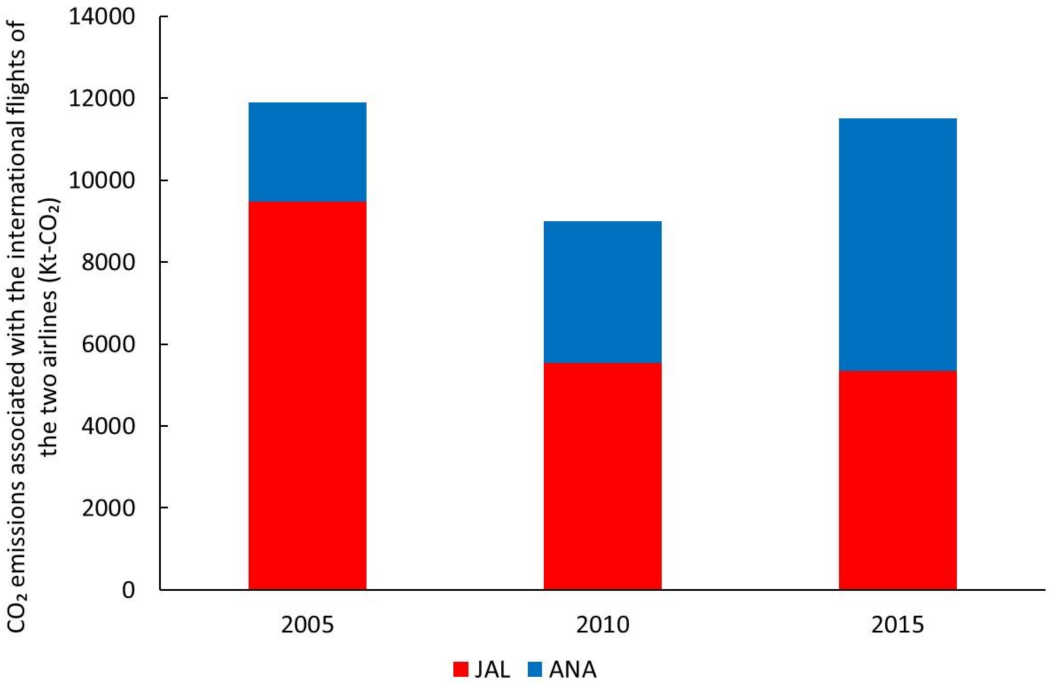

Figure 2. CO_2 emissions associated with the international flights of the two airlines

Figure 3. Decomposition effects of changes in CO_2 emissions associated with international flights of JAL between 2005 and 2010

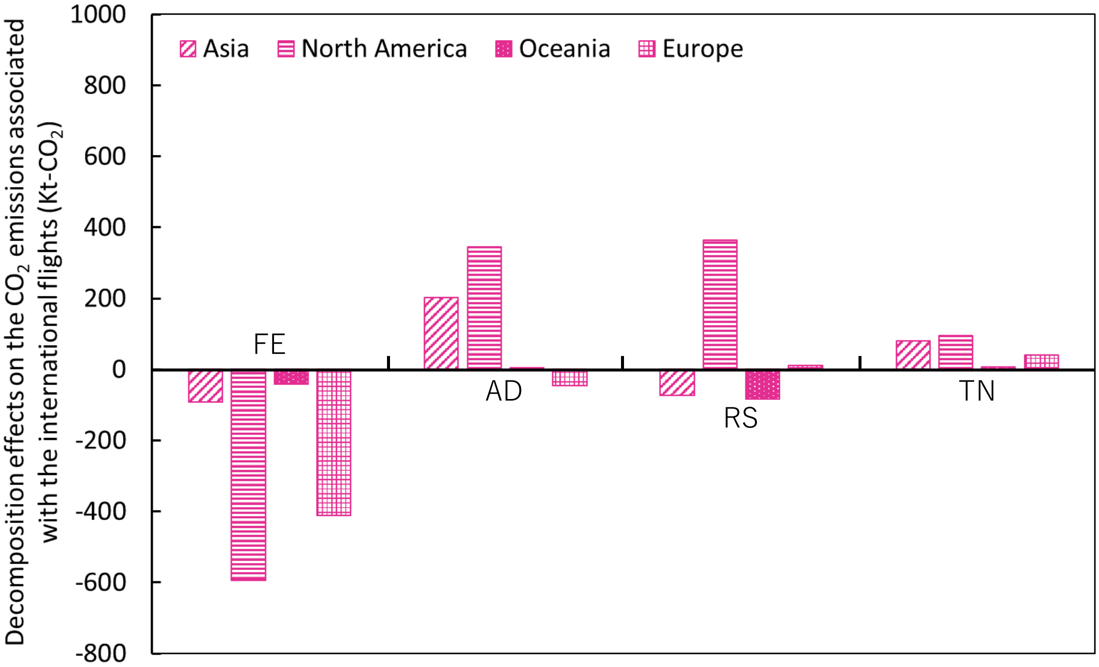

Figure 4. Decomposition effects of changes in CO_2 emissions associated with international flights of ANA between 2010 and 2015

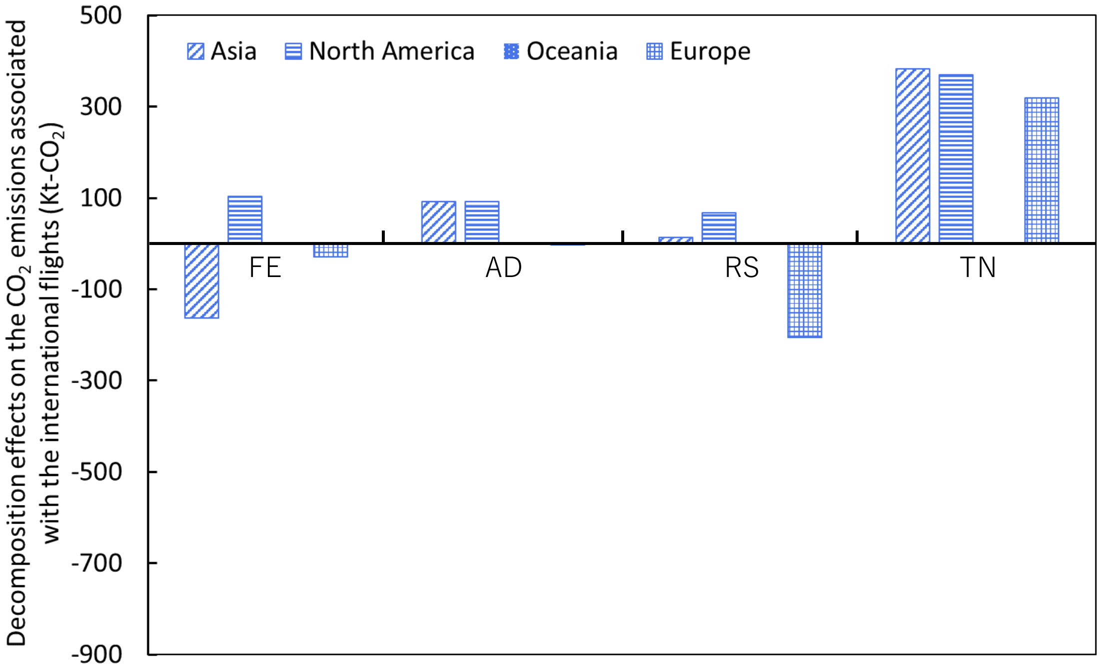

Figure 5. Decomposition effects of changes in CO_2 emissions associated with international flights of ANA between 2005 and 2010

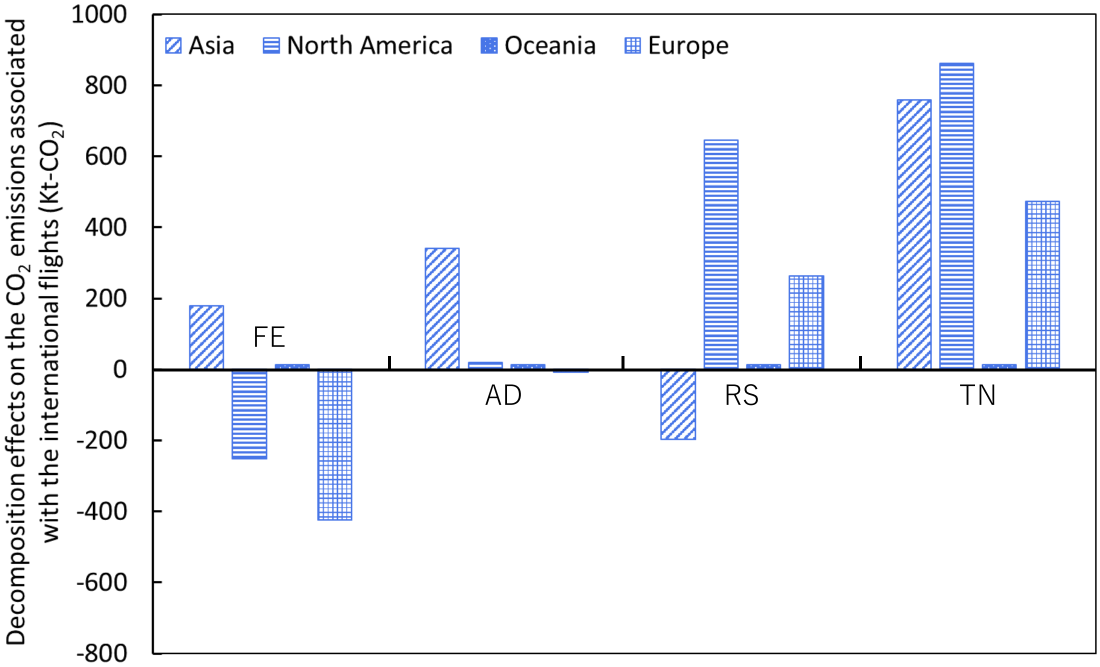

Figure 6. Decomposition effects of changes in CO_2 emissions associated with international flights of ANA between 2010 and 2015