Alternative Fuels and Biofuels for Aircraft Development

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Projection of the Fuel Market to the mid-term (2025)

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1 Introduction

Over the past thirty years, air traffic has been steadily increasing with growth rates dramatically superior to world's GDP growth rates, respectively 6.6% and 3.3%. According to the International Civil Aviation Organization (ICAO (2007)), the wedge between these growth rates has been even higher during 1960-1980. Thus, it is clearly established that air transport sector has encountered during the second half of the 20th century a growth strictly superior to most sectors in the economy. In a scarce energy resources context, this development may appear problematic during the 21st century (IPCC (1999, 2007), RCEP (2002), ECI (2006), IEA (2009)), leading to an increased interest for policy makers. The classical example is the integration of the aviation sector in the EU Emissions Trading Scheme (EU ETS) in January 2012[1].

Hence, forecasting and modeling demand for air traffic has become more and more a central issue for public policy, that this reports aims at pursuing. The major contribution of this study is to provide air traffic and then Jet-Fuel projections at the worldwide level until 2025. Several studies have already proposed aviation Jet-Fuel demand forecasts, either on a country/region basis or on a more global scale (BTE (1986), Gately (1988), Schafer (1998), Vedantham and Oppenheimer (1998), Graham (2000), Abed Seraj et al. (2001), Battersby and Oczkowski (2001), Lee et al. (2001), Olsthoorn (2001), Lim and McAleer (2002), Bhadra (2003), Wickrama et al. (2003), Lai and Lu (2005), Bhadra and Kee (2008), Mazraati and Faquih (2008), Dft (2009)).

The general methodology followed by these studies is usually the same. Since it is now well accepted, it will be also applied in this study. To synthesize, the general methodology may be summarized into two steps. First, total air traffic flows and their growth rates (per year) have to be forecast. Second, these traffic forecasts are converted into a quantity of Jet-Fuel.

To understand the past evolution of air traffic, and anticipate its evolution, it effectively appears necessary to examine the specific characteristics of demand in this sector. As any demand relative to a transportation means, air traffic demand is specific because it does not satisfy a need directly. Indeed, consumers rarely purchase plane tickets to satisfy their need to fly. They choose this transportation means in order to satisfy another need: going from point A to point B; whatever the reason (private or business) of their motivation. Thus, air traffic demand is driven by passengers' needs for other goods and services in the economy. Therefore, airline companies appear quite limited concerning their abil-

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[1] The amending Directive 2003/87/EC highlights that "'emissions from all flights arriving at and departing from Community aerodromes should be included"'. Compared to other sectors included in the EU ETS, this requirement introduces a major specificity when estimating aviation CO_2 emissions concerned by the EU ETS. Indeed, some CO_2 emissions from airlines that are not registered in one of the 27 Member States (MS) need also to be estimated.

ity to move the market. They can only react to the demand which is addressed to the aviation sector. This situation explains why the evolution of air traffic depends mainly on the drivers of demand, and not on the drivers of supply, in the aviation sector. That is why most studies model first the demand for mobility in air transportation, and second deduce Jet-Fuel demand from these estimates.

Concerning the first step (modeling of the demand for mobility in the aviation sector), traffic forecasts are estimated using econometric methods. Thus, these estimates are derived from the historical relationship between air traffic and its main drivers. According to Gately (1988), Vedantham and Oppenheimer (1998), Macintosh and Wallace (2008), Mazraati and Faquih (2008), air traffic drivers are mainly *i)* GDP growth rates – by far its most important driver; *ii)* ticket prices – which may be proxied by Jet-Fuel prices for instance; *iii)* alternative transport modes –such as train; and *iv)* some external shocks such as the September 11 terrorist attacks in 2001. The influence of these drivers depends on two criteria: on the one hand shorts/medium haul *vs.* long haul[2], on the other hand air transport market maturity[3]. Once estimated from historical data, the model is then used to generate air traffic forecasts. To take into account the two latter criteria, the modeling is realized for eight geographical zones[4], within each two sectors are estimated separately: domestic – as a proxy for shorts/medium hauls – and international – as a proxy for long hauls – traffic. It is thus possible to obtain different air traffic forecasts *scenarii*; depending on assumptions made on the evolution of air traffic drivers previously identified. These air traffic projections are required for estimating the demand for Jet-Fuel.

Regarding the second step (estimation of Jet-Fuel demand), the conversion of air traffic projections into quantities of Jet-Fuel is accomplished using the ‘Traffic Efficiency’ method developed previously by UK DTI to support the IPCC (1999). The intuition behind this method may be summarized as follows. An increase of 6% per year of air traffic does not imply a corresponding Jet-Fuel demand increase of 6%. Indeed, the rise of Jet-Fuel demand resulting from air traffic demand rise can be mitigated by energy efficiency improvements. Over the past twenty years for instance, the large increase in aviation in air traffic has been accompanied by dramatic improvements into the energy efficiency of the aviation task (Greene (1992), Greene (2004)). As a consequence, Jet-Fuel demand has widely increased during this period, but at average growth rates per year largely lower than those of air traffic demand. Thus, one of the major tasks of the second step of this methodology will consist in examining the expected rates, expressed per year, of energy efficiency improvements. To do so, different scenarios of both load factor (i.e. aircraft are using more of their capacity) and energy efficiency im-

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[2] Long hauls are less sensitive to both ticket prices and the existence of alternative transport modes.

[3] Growth rates of domestic air transport market of industrialized nations (USA and Europe) are lower than those of some emerging nations.

[4] Projections are thus estimated for the following regions: Central and North America, Latin America, Europe, Russia and CIS (Commonwealth of Independent States), Africa, the Middle East, Asian countries and Oceania. The eighth region is China, in order to have a specific focus on this rapidly developing country.

provements will be investigated. Concerning the potential source of energy efficiency improvements, Greene (2004) identifies likely improvements of *i)* Air Traffic Management (ATM); *ii)* existing aircrafts (such as upgrades); and *iii)* aircraft and airframe/engine design (which is linked to fleet renewal rates).

The report is organized as follows. The first section presents descriptive statistics for world's air traffic during 1980-2007. The second section introduces a new methodology to investigate energy efficiency improvements in the aviation sector. The third section contains projections of Jet-Fuel demand until 2025. The last section concludes.

2 Descriptive Statistics on Air Traffic

Air Traffic data for 1980 to 2007[5] have been obtained from the International Civil Aviation Organization (ICAO). This specialized agency of the United Nations provides the most complete air traffic database[6]: international and domestic, passenger and freight traffic (both for scheduled and non-scheduled flights).

The ICAO database used in this report is the ‘Commercial Air Carriers - Traffic’ database. As detailed on the ICAO website[7] it contains, on annual basis, operational, traffic and capacity statistics of both international and domestic scheduled airlines as well as non-scheduled operators. Where applicable, the data are for all services (passenger, freight and mail) with separate figures for domestic and international services, for scheduled and non-scheduled services, and for all-freight services[8]. One of the interest of this database consists in providing data by country, and not by pre-aggregated regions. Thus, it allows to recompose any kind of regions on any *scenarii*. Within the database by country, statistics are provided for airlines registered in a given country on a yearly basis[9]. Another advantage lies in the possibility to account for freight *vs*. passenger, and for domestic *vs*. international air traffic within each zone. There exists however one limit with the use of such data for international air traffic. When re-aggregating the data by zone, one considers that the airline which declared the flights as ‘international air traffic’ has not registered international flights outside the country within which it is registered, and thus outside of the region within which it has been re-aggregated.

When required, Jet-Fuel consumption statistics are also provided for each region. This information is drawn from the ‘World Energy Statistics and Balances’ database of the International Energy Agency (IEA), which provides Jet-Fuel consumptions during 1980–2006. Due to a one-year delay between the ICAO and IEA database, air traffic data are presented for the 1980–2006 period , when they are compared with Jet-Fuel consumption. Unless otherwise indicated, all descriptive statistics presented below are thus valid during 1980–2007. Also note that air traffic statistics are not available before 1983 for Russia and CIS (Commonwealth of Independent States). In order to account for this gap, we present the descriptive statistics only during 1983-2006.

Cargo traffic is measured in Revenue Ton Kilometers (RTK) whereas passenger traffic is expressed

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[5] Air traffic data for the year 2008 are already available, but only for a few months. Last accessed in June 2009.

[6] Note the International Air Transport Association (IATA), which represents about 230 airlines comprising 93% of scheduled international air traffic, also provides Air Traffic data, but this source is less detailed to our best knowledge.

[7] *http://www.icaodata.com*

[8] These data are not provided on air routes basis.

[9] With such statistics, air traffic data of a given airline cannot be provided in two different tables. Thus, it avoids the problem of double-counting.

both in Revenue Passenger Kilometers (RPK)[10] and RTK[11]. The decomposition in geographical zones follows a classical representation: thus we obtain air traffic for eight distinct regions (Central and North America, Latin America, Europe, Russia and CIS, Africa, the Middle East, China, Asian countries and Oceania), and on a worldwide basis (computed as the sum of the eight regions). The first part presents in great details the air traffic database from the ICAO, and the fuel consumption database from the International Energy Agency (IEA).

2.1 Evolution of Air Traffic during 1980–2007

Figure 1 shows the evolution of world air traffic from 1980 to 2007.

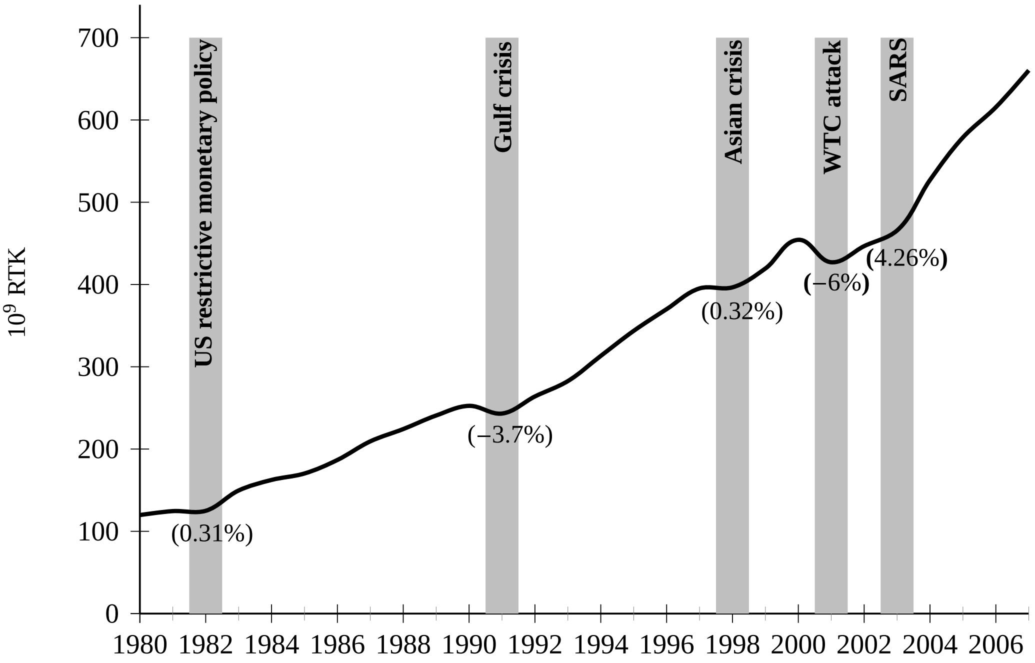

Figure 1: Evolution of World Air Traffic (1980-2007) expressed in RTK (billion). Source: ICAO.

Two major remarks may be inferred from this graph. First, it emphasizes the strong increase of this sector, with a variation growth of +340% during the period. Second, the aviation sector - cyclical in nature - has encountered some specific shocks (represented with gray solid bars) that all had downward impacts on the demand for air travel (Mason (2005)). Figures in brackets represent the variation of activity of the aviation sector during these events. The terrorist attacks in New York and Washington had a major impact on airline industry (Alderighi and Cento (2004), Ito and Lee (2005)). The attacks caused many travelers to reduce or avoid air travel and resulted in a transitory, negative

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[10] A passenger kilometer is equal to one passenger transported one kilometer.

[11] A ton kilometer is equal to one ton of load (passenger or cargo) transported one kilometer.

demand shock in addition to an ongoing negative demand shift (Inglada and Rey (2004), Guzhva and Pagiavlas (2004), Ito and Lee (2005)). The recovery patterns clearly vary across countries and regions (Gillen and Lall, 2003). Airlines were also affected by macro shocks such as the Asian financial crisis, SARS (Severe Acute Respiratory Syndrome) and Gulf War.

Table 1 describes air traffic statistics[12], along with Jet-Fuel consumption, expressed in levels, for each zone and the world. Data are presented within two sub-periods: 1983–1996 and 1996–2006 (1996-2007 when air traffic data is not compared with Jet-Fuel data). Note that air traffic data are expressed in two different units: RTK and ATK. RTK measures actual air traffic, whereas ATK is a unit to measure the capacity of an aircraft/airline. The link between these two units is the Weight Load Factor (WLF): $RTK = WLF * ATK$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight. Then, if airline companies fill their aircrafts at the maximum available load ($WLF = 100\%$), RTK is strictly equal to ATK. Because airlines never fully fill their aircrafts, ATK > RTK. Note that in this report air traffic is measured in ton kilometer (as opposed to passenger kilometer). This explains why there is typically a 10 percentage points difference between the WLF value presented in Table 1 and the usual WLF as read in the literature which are rather expressed in passenger kilometer (thereafter called Passenger Load Factors (PLF)).

As a stylized fact, Table 1 shows that during the whole period airline companies' WLF values have rather increased. For instance, at the world level, WLF mean yearly growth rates for the first sub-period is equal to 0.07% (last line, fourth column) – thus registering a constant WLF – and to 0.65% (last line, fifth column) during the second sub-period – thus registering a steady WLF increase of 0.6% per year. This evolution is common to the most part of regions, except in China and Asian countries and Oceania regions where the mean yearly growth rate of WLF is negative in the first sub-period. Globally, we still notice the stylized fact that on average aircrafts are less filled in the first sub-period compared to the second one).

Yearly mean growth rates are provided in the three last columns. According to this table, world air traffic (expressed in RTK) has registered a mean growth rate per year of 6.4% on the whole period. Note that this mean growth rate is higher during the first sub-period (7.28%) than during the second sub-period (5.34%). Various yearly means growth rates may be observed within each zone, which explains the evolution of each zone's weight in total air traffic as depicted in Table 2. Figure 2 offers an alternative view of this evolution.

Table 2 highlights a few stylized facts. The share of USA and Europe in total air traffic represents around two thirds. This share appears stable over the period (62.93% in 1983 compared to 62.61% in 2006). It is due to the fact that the share of USA has decreased (with a mean variation growth during

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[12] For the sake of clarity the tables and the majority of graphs are presented in the appendix.

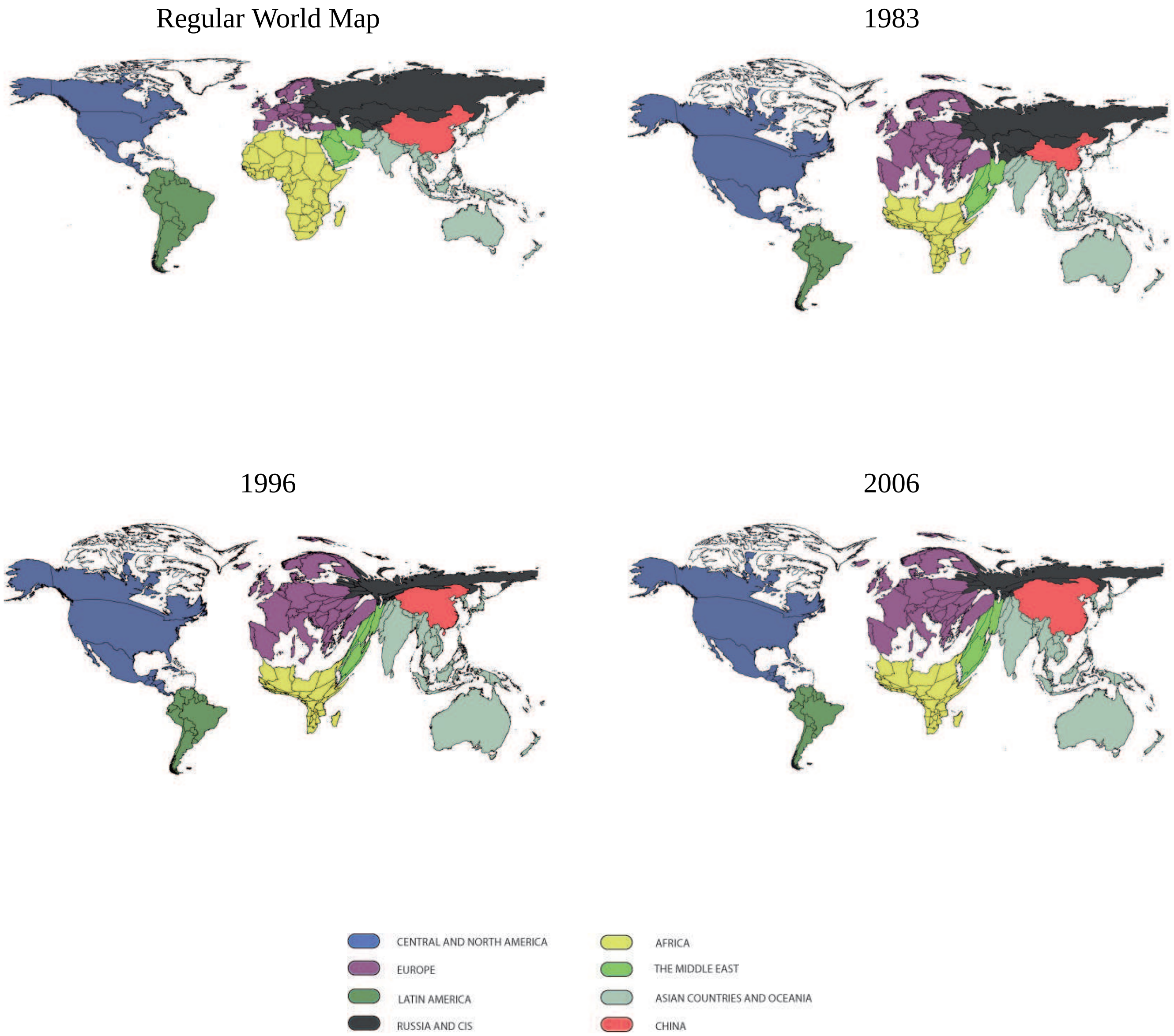

Figure 2: An alternative view of the air traffic (expressed in RTK) (Maps generated using ScapeToad)

Note: These cartograms size the zones according to their relative weight in world air traffic (expressed in RTK), offering an alternative world view to a regular map. Thus, for example, zones such as China (1983 and 1996) and Russia become smaller next to Central and North America and Europe.

the whole period of -11.90%), while the share of Europe has increased (with a mean variation growth during the whole period of +21.25%). With its strong economic growth and large population size, China is becoming a major player in air transportation (Shaw et al. (2009)). The share of China in total air traffic has skyrocketted during the second sub-period, going from 4.74% in 1996 to 8.57% in 2006. Its mean variation rate represents +80% for a yearly mean growth rate of +11.89% (Table 1). In order to diversify their traditionnally oil- and gas- dependent economies some Middle Eastern countries - such as the United Arab Emirates and Qatar - pursue substantial investments into their aviation sector (Vespermann et al. (2008)). The share of the Middle East in total air traffic represents 4.66% in 2006. Africa plays a minor role in the global air transport pattern (Mutambirwa and Turton (2000)).

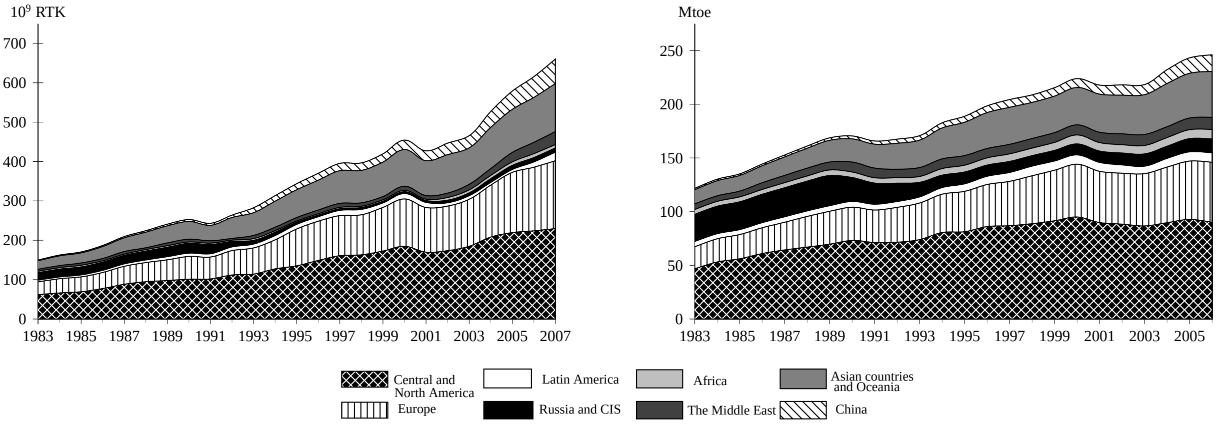

Figure 4: Evolution of air traffic (left panel, expressed in RTK (billion)) and Jet-Fuel Consumption (right panel, expressed in Mtoe) by zone during 1983-2007 and 1983-2006, respectively. Source: Authors, from ICAO data.

(Note that China starts declaring some of its air traffic data in 1993. Russia and CIS presents some inconsistency in the data until 1991. Thus, some statistics must be interpreted with great care.)

Figures 3, 4 and 5 present the same information as in Table 1 (Figure 3) and Table 2 (Figures 4 and 5) displayed in different ways. Actually, Figure 5 contains some additional information: in each panel, WLF values and evolution of each zone may be directly compared to the world's values and evolution. It then indicates how the zone performs compared to the world.

Again, ICAO provides highly detailed data for freight, passengers, domestic and international air traffic. It allows us to present the evolution of air traffic for each zone in different ways: freight *vs.* passengers, and domestic *vs.* international, presented respectively in Tables 3 and 4. This decomposition will be further studied.

Table 3 shows that passengers' traffic predominates freight traffic at the world level with a share of

91.93% in 1983 and 85.07% in 2007. Even if passengers' traffic represent the most part of air traffic, freight has widely increased during the period. Indeed, its share has almost doubled. This comment applies for most cases, except in Russia and CIS, Africa, Central and North America. The repartition is globally more in favor of passengers' traffic in the two former zones. In North America however, freight traffic has relatively more increased than in other zones, going from 9.12% in 1983 to 18.49% in 2007.

As shown in Table 4, at the world's level, the repartition of air traffic between international and domestic has always been more favorable to international air traffic. Moreover, this share has greatly increased, going from 55.33% in 1983 to 70.77% in 2006, meaning that globally international air traffic has more grown than domestic air traffic. Actually, at the regional level, this share is even more in favor of international air traffic (around 95% in 2006 in Europe for instance). In fact, the world's statistic appears biased by the repartition between international (43.84% in 2006) *vs* domestic (56.16% in 2006) air traffic in Central and North America. This region is the only one to feature a repartition more favorable to domestic air traffic, even if international air traffic has increased during the period (32.79% in 1983, 43.84% in 2006). This analysis confirms the role played by *(i)* the domestic market for air transport in the USA; and *(ii)* the weight of the North American zone in total air traffic (about 36% in 2006 according to Table 2).

Figures 6 and 7 illustrate, respectively, the results presented in Tables 3 and 4. By comparing these figures at the world level (bottom right panel), the evolution of the repartition between freight and passengers' traffic appears to be more stable than the repartition of domestic *vs.* international traffic during the period.

Tables 3 and 4 have shown in two different ways the evolution of air traffic: first, freight *vs.* passengers; second, domestic *vs.* international.

The next subsections explore in greater details these two decompositions between the evolution of air traffic. The first one focuses on domestic *vs.* international air traffic, while the second focuses on freight *vs.* passengers' air traffic.

2.2 Domestic *vs.* international air traffic

Compared to Table 2, Table 5 presents the share of each zone in air traffic but at a more disaggregated level. Indeed, the latter table presents the share of each zone in both domestic and international world air traffic. For instance, in Table 2, 36.38% (first line, third column) means that the Central and North American air traffic represents 36.38% of the world air traffic in 2006. In Table 5, 66.39% (first line, third column) means that the Central and North American domestic air traffic represents 66.39% of the world domestic air traffic. Similarly, in Table 5, 21.85% (second line, third column) means that the Central and North American international air traffic represents 21.85% of the world international air traffic[13].

As may be seen in Table 5, when compared to Table 2, the Central and North American domestic market predominates other domestic air traffic markets (by representing around two thirds). On the contrary, whereas this region represents 36.38% of the world air traffic, its share in world international air traffic is ‘only’ equal to 21.85% in 2007. Regarding the European region, it appears that its share in domestic world air traffic is dramatically low. This region indeed represents 26.23% of world aggregated (domestic+international) air traffic (Table 2), while it only represents 4.56% of world domestic air traffic. As a consequence, the share of the European region in world international air traffic is relatively more developed (34.92% in 2007). The relative sur-representation of the international air traffic market also applies for the Asian (without China) and Oceanian region.

Figure 8 presents the same information as in Table 5.

2.2.1 *Focus on domestic air traffic*

This section investigates air traffic data at the disaggregated domestic level.

Compared to Table 1, Table 6 describes domestic air traffic statistics expressed in levels for each zone and the world. Given the very detailed level of the descriptive statistics, each disaggregated table is not compared to its corresponding aggregated table (for instance here Tables 6 and 1), but comments only focus on the disaggregated table (Table 6 here). This comment applies in the remainder of this section.

At the world level, domestic air traffic has increased at the rate of 4% per year on average. Domestic air traffic has thus encountered a less dynamic development than the aggregated (domestic+international) air traffic (6.44%, Table 1). Because the domestic market in the Central and North American region represents around two thirds of the world domestic market (Table 5), its evolution dictates the world evolution. It appears that generally other regions have had higher growth rates than the world’s evolution. In asian countries, air transport, particularly within domestic markets, appeared to be booming in the first period. In most Asian countries except China, the financial crisis has affected people’s willingness to travel. Since 1997, air traffic grew more slowly than in other aviation regions (Rimmer (2000)). The most dynamic zone was China (+16.24% during the second sub-period, Table 6). Regarding WLF values, the evolution of mean yearly growth rates is similar to previous comments at the aggregated level (Table 1).

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[13] To summarize,

$$36.38\% = \frac{\text{Central and North American aggregated (domestic+international) air traffic}}{\text{World aggregated (domestic+international) air traffic}}$$

$$66.39\% = \frac{\text{Central and North American domestic air traffic}}{\text{World domestic air traffic}}$$

$$21.85\% = \frac{\text{Central and North American international air traffic}}{\text{World international air traffic}}$$

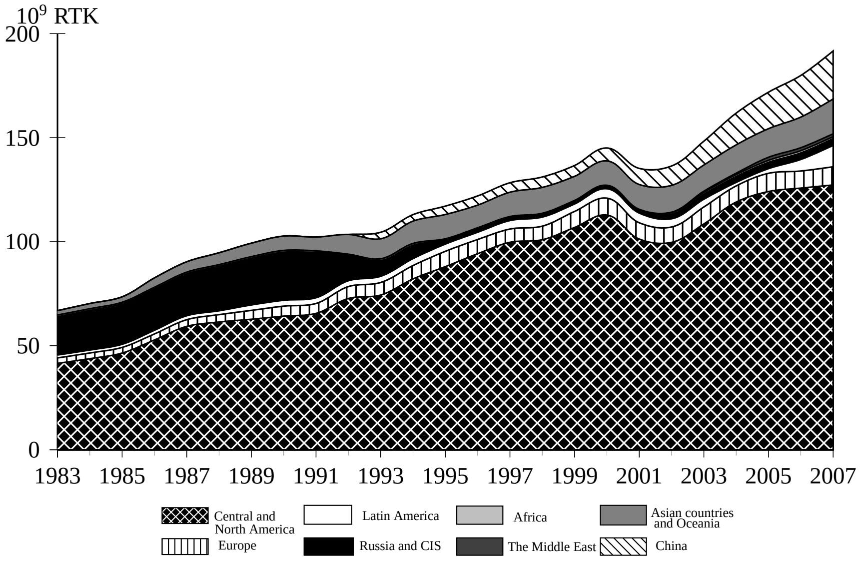

Figure 9: Evolution of Domestic Air Traffic (expressed in RTK (billion)) by zone during 1983-2007. Source: Authors, from ICAO data.

(Note that China starts declaring its domestic air traffic data in 1993. Russia and CIS presents some inconsistency in the data until 1991. Thus, some statistics must be interpreted with great care.)

Figures 9 and 10 present the same information as in Table 6.

Table 7 shows the repartition of domestic air traffic between passenger and freight. At the world level, passengers' (freight) air traffic represents 90.01% (9.99%) of domestic air traffic in 2007, to be compared with 85.07% (14.93%) of aggregated (domestic+international) air traffic (Table 3). Thus, the share of passengers is more important in domestic air traffic than in aggregated (domestic+international) air traffic. This stylized fact observed at the world level applies also at the regional level.

Next section focuses on international air traffic.

2.2.2 *Focus on international air traffic*

This section investigates air traffic data at the disaggregated international level. The same type of analysis as in the previous section is developed.

Compared to Tables 1 (aggregated) and 6 (domestic), Table 8 describes international air traffic statistics. At the world level, international air traffic has increased at the rate of 7.49% per year on average. International air traffic has thus encountered a more dynamic development than domestic – 4%, Table 6 – and aggregated (domestic+international) – 6.44%, Table 1 – air traffic. The most dynamic zones were China (+10.44% during the second sub-period) and the Middle East (8.84% during the whole period). The former Soviet bloc had relatively undeveloped international air transport prior to 1989 (Button (2008)). Regarding WLF values, the evolution of mean yearly growth rates

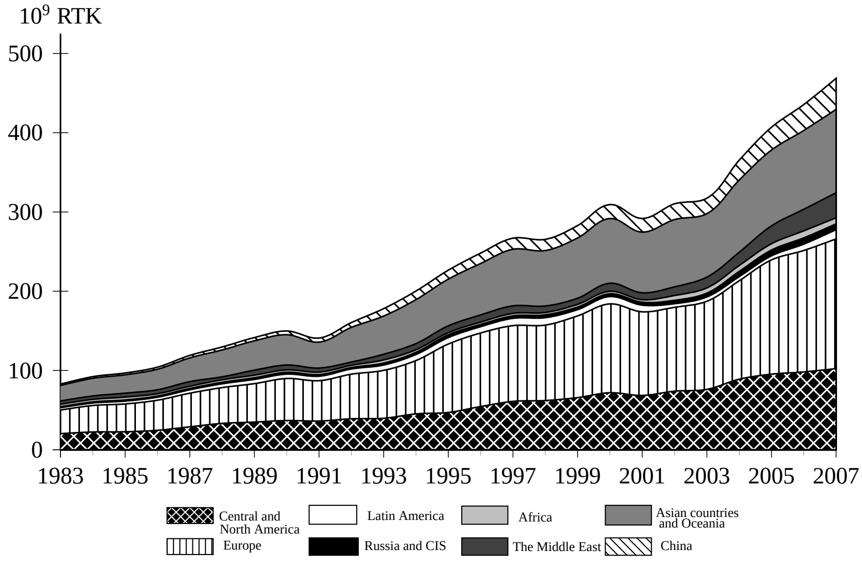

Figure 11: Evolution of International Air Traffic (expressed in RTK (billion)) by zone during 1983-2007. Source: Authors, from ICAO data.

(Note that China starts declaring some of its air traffic data in 1993. Russia and CIS presents some inconsistency in the data until 1991. Thus, some statistics must be interpreted with great care.)

is very different from the aggregated level (Table 1): the stylized fact previously identified at the aggregated (domestic+international) level is not valid at the world level and for three zones.

Figures 11 and 12 present the same information as in Table 8.

Table 9 shows the repartition of international air traffic between passenger and freight. At the world level, passengers' (freight) air traffic represents 83.05% (16.95%) of international air traffic in 2007, to be compared with 85.14% (14.93%) of aggregated (domestic+international) and 90.01% (9.99%) of domestic air traffic (Table 3). Thus, the share of passengers appears to be less important in international air traffic than in both aggregated (domestic+international) and domestic air traffic. This stylized fact observed at the world level applies also at the regional level. While for domestic air traffic the superiority of passengers has been observed at the world level and globally within each zone, another pattern is observable for international air traffic. Passengers (as opposed to freight) are indeed less represented in international air traffic, both at the world level and within each zone, than in aggregated (domestic+international) and domestic air traffic.

Next section focuses on passenger *vs.* freight air traffic.

2.3 Freight *vs.* passengers' air traffic

Similarly to Table 5, Table 10 presents the share of each zone in air traffic but at another disaggregated level: freight *vs.* passengers. As may be seen in Table 10, when compared to Table 2, two regions exhibit notable different patterns in their freight *vs.* passenger repartition. First, the Central and North American freight market predominates other freight markets (by representing 43.07%). On the contrary, whereas this region represents 36.38% of the world air traffic, its share in world passenger traffic is equal to 33.32% in 2007. Second, in the European region, it appears that its share in freight traffic is 6 percentage points lower than its share in world aggregated (freight+passenger) air traffic (26.23%, Table 2). It represents indeed 20.35% (Table 10) of world freight traffic. Compared to their repartition at the aggregated (freight+passenger) level (Table 2), other regions do not exhibit notable different patterns in their freight *vs.* passenger repartition.

Figure 13 presents the same information as in Table 10.

2.3.1 *Focus on freight air traffic*

This section investigates air traffic data at the disaggregated freight level.

Compared to Table 1, Table 11 describes freight traffic statistics expressed in levels for each zone and the world. At the world level, freight traffic has increased at the rate of 9.14% per year on average. The key influence on air freight demand is world economic and trade growth. The air cargo volume has grown at between 1.5 and 2 times the rate of worldwide GDP growth (Zhang and Zhang (2002)) during the nineties. Freight traffic has played a increasingly important role in world trade (Kasarda and Green (2005)) and has thus encountered a more dynamic development than the aggregated (freight+passenger) air traffic (6.44%, Table 1). Globally, other regions have a similar development, except China which registered the highest mean yearly growth rate (12.62% for the second sub-period). This spurt is mainly due to the China's rapid industrialization and the development of its manufacturing industries that export commodities and import components that are needed to keep factories working (Button (2008)). Regarding WLF values, the evolution of mean yearly growth rates is very different from the aggregated level (Table 1): the stylized fact previously identified at the aggregated (domestic+international) level is not valid at the world level (same negative values for both sub-periods: -0.13%) and for five zones.

Figures 14 and 15 present the same information as in Table 11.

Table 12 shows the repartition of freight between domestic and international air traffic. At the world level, domestic (international) air traffic represents 19.42% (80.58%) of freight traffic in 2007, to be compared with 29.23% (70.77%) of aggregated (freight+passenger) air traffic in 2006 (Table 4). Thus, the share of international air traffic is more important in freight than in aggregated (freight+passenger) air traffic. This stylized fact observed at the world level applies also at the regional level. This statistic is logical given the nature of freight transport, which is inherently international (Gardiner and Ison (2007)).

Next section focuses on passengers' air traffic.

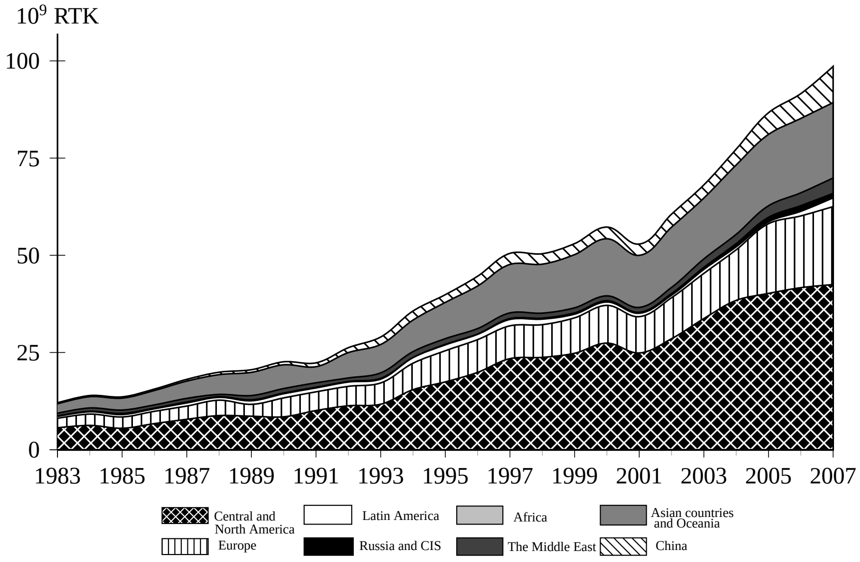

Figure 14: Evolution of Freight Traffic (expressed in RTK (billion)) by zone during 1983-2007. Source: Authors, from ICAO data.

(Note that China starts declaring some of its air traffic data in 1993. Russia and CIS presents some inconsistency in the data until 1991. Thus, some statistics must be interpreted with great care.)

2.3.2 *Focus on passengers' air traffic*

This section investigates air traffic data at the disaggregated passengers' level. This section provides tables labelled in both RTK and RPK. To conserve space, we only comment RTK values, as it is directly comparable with previous sections. However, because passengers' air traffic data are usually provided in RPK units, descriptive statistics expressed in RPK are also included in this report[14].

Compared to Tables 1 (aggregated) and 11 (freight), Table 13 describes passengers' air traffic statistics. At the world level, passengers' air traffic has increased at the rate of 6.04% per year on average. Passenger's air traffic has thus encountered a less dynamic development than freight – 9.14%, Table 11 – and roughly the same as aggregated (freight+passenger) – 6.44%, Table 1 – air traffic. The most dynamic zones are China (+12.13% during the second sub-period). Note that passengers' air traffic in the Central and North American zone has registered a lower growth rate than the world's average growth rate, both for the whole period and the corresponding sub-periods. In Asian countries (except China), as was the case with the freight market, passenger traffic dipped in 1998. Recall that to compare results throughout the report passengers' WLF values are given in RTK instead of RPK, which explains some difference with the values usually found in the literature. Besides, passengers' WLF values in RPK are given in the Appendix. Regarding WLF values, the evolution of mean yearly growth rates is slightly different from the aggregated level (Table 1): *(i)* passengers' WLF mean yearly

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[14] The comments of RPK figures is left to the reader.

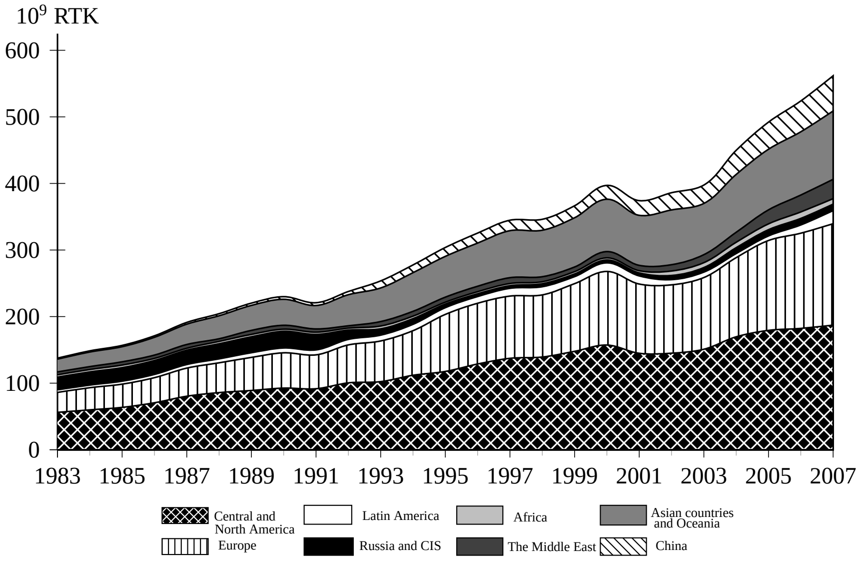

Figure 16: Evolution of passengers' air traffic (expressed in RTK (billion)) by zone during 1983-2007. Source: Authors, from ICAO data.

(Note that China starts declaring some of its air traffic data in 1993. Russia and CIS presents some inconsistency in the data until 1991. Thus, some statistics must be interpreted with great care.)

growth rates are positive within each sub-period; and *(ii)* these mean growth rates are higher during the second sub-period. Note that passengers' WLF stylized facts are not valid for two zones: Europe and the Middle East.

Figures 16 and 17 present the same information as in Table 13.

Table 14 shows the repartition of passengers' air traffic between domestic and international. At the world level, domestic (international) air traffic represents 30.71% (69.29%) of passengers' traffic in 2007, to be compared with 29.23% (70.77%) of aggregated (freight+passenger) air traffic in 2006 (Table 4). Contrary to freight (Table 9), the same pattern for domestic *vs.* international applies for both passengers' – Table 14 – and aggregated (freight+passenger) – Table 4 – air traffic.

Note that the same kind of descriptive statistics for passengers' air traffic are also provided in RPK units (instead of RTK) in the Appendix.

World air traffic grew by 6.44% per year according to ICAO data. Figures show that air traffic (expressed in RTK) has quadrupled between 1983 and 2007. Freight traffic showed 9.14% yearly average growth over the period 1983-2007 while passenger traffic grew at 6.04%.

Regional variations in traffic are pronounced. Between 1983 and 2007, air traffic in China grew at a much faster rate than the rest of the world, i.e. 17.13 %. In the same time, Central and North America, which is the only region with a huge domestic market, saw their passenger traffic increase per year by 5.14% with freight growing 8.78%. Europe followed the same trend with freight traffic up 9.18% while passenger lagged behind at 7.01%. In Asia, financial crisis slashed demand for business and leisure air travel. In this region, air traffic dipped in 1998 and then continued to grow at a slower pace than previously. Both domestic and international air traffic has increased in Russia and the CIS by 10 percent over the past 10 years. RTK of the airlines of the Middle East region increased at a rate of 13.02 percent over the 1996-2006 period, substantially higher than the world average (5.34%).

There are important links between economic growth and aviation. Thus, macroeconomic conditions and external shocks had a significant impact on the year-on-year growth rates of the air traffic. The 1991 Gulf War had a strong impact on international traffic. Moreover, the terrorist attacks on 11 september 2001 were followed in 2002-2003 by the invasion of Afghanistan, the Iraq War, the Severe Acute Respiratory Syndrome (SARS) epidemic in Asia. They had a dramatic effect on the demand for air travel.

Next section develops the methodology to compute Energy Efficiency (EE) coefficients.

3 Traffic Efficiency Improvements and Energy Efficiency Coefficients

Jet-Fuel is not consumed for itself but to power aircraft engines which depend on the demand for mobility in air transportation. Thus Jet-Fuel forecasts are not based directly on Jet-Fuel consumptions time-series but need to be computed from air traffic forecasts. As a consequence, Jet-Fuel demand forecasts are obtained following a two-step methodology. First, total air traffic flows and their growth rates have to be forecast. Second, these traffic forecasts are converted in a quantity of Jet-Fuel to obtain Jet-Fuel demand forecasts.

This section deals with converting air traffic projections into quantities of Jet-Fuel. That is to say, one of the major tasks of this report consists in linking the methodology first and second steps. To do so, **it relies on the 'Traffic Efficiency' method** developed previously by UK DTI to support the IPCC (1999) to deduce the amounts of Jet-Fuel demand projections from air traffic forecasts estimated during the first step.

Basically, **the 'Traffic Efficiency' methodology allows to obtain Energy Efficiency (EE) coefficients** (called 'EE coefficients' in the remainder of the report) **to convert one amount of air transport** – usually expressed in RTK or ATK (see above for more details) – **into one amount of Jet-Fuel** – usually expressed in billion ton of oil equivalent (Mtoe). In this report:

$$EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}} \tag{1}$$

with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t[15]. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK)[16].

The intuition behind this method may be summarized as follows. **The rise of jet-Fuel demand resulting from air traffic demand rise can be mitigated by energy efficiency improvements.** For instance, an increase of 6% per year of air traffic does not mean a strictly corresponding increase of 6% in Jet-Fuel demand. According to Greene (1992, 2004), the large increase in aviation traffic has

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[15] It would be natural to have RTK instead of ATK in this equation. However, before converting RTK into Jet-Fuel quantities, it is first necessary to convert RTK into ATK. The link between RTK and ATK is the Load Factor (LF), expressed in percentage. The latter may be defined as the percentage of an aircraft available ton effectively occupied during a flight. Thus for one flight, $RTK = LF \times ATK$. Once RTK converted into ATK, it becomes possible to deduce the total amount of Jet-Fuel demand projections from air traffic forecasts estimated during the first step by using the equation of EE coefficients.

[16] Jet-Fuel consumption is obtained from IEA, while ATK are given by ICAO. See below for more details.

been accompanied by dramatic improvements into the energy efficiency of the aviation task over the past 30 years.

Thus, one of the major tasks of the second step of the general methodology consists in examining the expected rates, expressed per year, of EE improvements; corresponding to the evolution of air traffic energy gains.

According to previous literature (Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Lee et al. (2001, 2004, 2009), Olsthoorn (2001), Eyers et al. (2004), Whitelegg and Cambridge (2004), Macintosh and Wallace (2008), Mazraati and Faquih (2008), Lee (2010)), **traffic efficiency improvements depend on: *(i)* load factors improvements** (aircraft are using more of their capacity); ***(ii)* energy efficiency improvements**. Note that in the former case (load factors improvements) no technological progress is achieved: airlines diminish their Jet-Fuel consumption by filling more their aircrafts. However, in the latter case (energy efficiency improvements) there may be some opportunities for technological progress to happen. Energy efficiency improvements depend on a wide variety of factors, some of which are not linked to technological progress (such as Air Traffic Management), while others do. In the latter category, which is most likely predominant in the evolution of energy efficiency, the factors concern first the upgrade of existing aircrafts, and second changes in aircraft and airframe/engine design which are conditioned to the fleet renewal rate.

As a consequence, and regarding the objective of this section, two pieces of information are required to convert air traffic projections into quantities of Jet-Fuel: first, value(s) of EE coefficients; second, a rule for the evolution of EE coefficients.

To obtain this information, previous literature uses a specific methodology called ‘bottom-up’ in the remainder of the report. **The major contribution of this section consists in proposing a new methodology to obtain EE coefficients based on modeling at the macro-level.**

The first subsection summarizes previous ‘bottom-up’ methodologies. It also explains why these methodologies have not been retained here. The second subsection introduces the new macro-level methodology. The third subsection contains the results from the new methodology.

3.1 Methodologies used in the literature: the ‘Bottom-up’ approaches

Previous literature features two ways of modeling air transport mobility. First, modeling by routes (gravity models), and second modeling without routes (simple time-series analysis). In the former modeling, air traffic is estimated for various routes. At a more aggregated level, it allows to forecast traffic flows between two regions, for instance between Europe and Asia. On the contrary, the latter modeling does not allow to forecast traffic flows, but the expansion of various regions. In other words, the latter methodology provides spheres instead of routes.

To convert air transport traffic into Jet-Fuel demand, researchers generally use a ‘bottom-up’ approach to *(i)* obtain EE coefficients, and *(ii)* deduce an evolution rule for EE coefficients (see for instance IPCC (1999), Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Eyers et al. (2004)). This ‘bottom-up’ approach is mostly used for modeling by routes. In his econometric estimation of demand for air travel in the US, Bhadra (2003) defines ‘top-down’ and ‘bottom-up’ approaches. When demand is determined econometrically by GDP, among other things, the estimated relationship is then allocated from the top down to the terminal areas, taking into consideration the historical shares of the airport, master plans, and expert opinion, to derive traffic forecasts. By contrast, when econometric relationships are estimated at a lower level (i.e., between origin and destination travel), they may be called a bottom-up approach. While traffic forecasts are primarily designed to serve as a terminal area planning tool, the latter approach focuses on market routes and flows (i.e., passengers and aircraft) within. Thus, ‘bottom-up’ approaches appear especially useful for network flow aspects. Several studies may be cited in this literature. Bhadra and Kee (2008) analyze the structure and dynamics of the origin and destination of core air travel market demand using 1995-2006 US quarterly time-series data. They show that passenger flows between origin and destination travel markets have exhibited strong growth in recent years. Macintosh and Wallace (2008) document international aviation emissions to 2025. They remark that the fuel efficiency gains associated with the latest generation of aircraft are unlikely to be sufficient to offset the increases in international demand, and conclude that the slow rate of turnover in the fleet will hinder progress on curbing emissions growth. Mazraati and Faquih (2008) model aviation fuel demand in the case of the US and China. By estimating Jet-Fuel demand in these two extremes of a mature sector versus a fast growing one, they confirm that mature sectors tend to be more sensitive to fluctuations in fuel prices and economic growth, as opposed to the fast growing regions where the price effect is less pronounced[17].

The so-called ’bottom-up’ approach starts with the observation of aircrafts’ energy efficiency (expressed in Mtoe/ASK, liter/ASK or Mjoule/ASK). Aircrafts’ energy efficiencies are published by manufacturers. By replacing aircrafts’ models by their vintage year, one can obtain *(i)* approximations of the values of Jet-Fuel consumption for a typical aircraft, and *(ii)* an idea of the evolution rule of EE coefficients overtime (IPCC (1999), Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Eyers et al. (2004)).

Such a representation is given in Figure 18. The first point represents the average Jet-Fuel consumption of the Comet 4 aircraft model issued in 1958. The last point represents the average Jet-Fuel

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[17] Besides, they show that the Chinese aviation sector and Jet-Fuel consumption will continue to outpace that of the United States, but growth in both regions will reach a steady state as the Chinese economy cools down and approaches maturity.

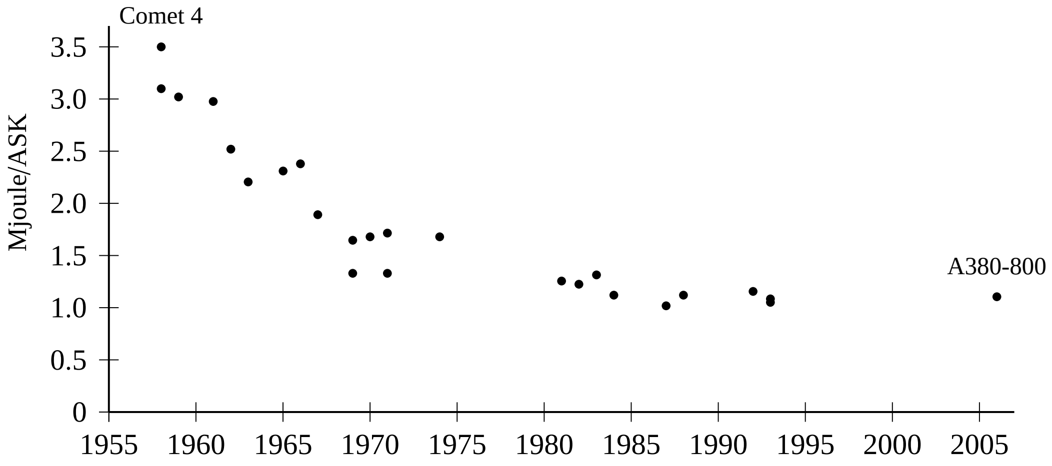

Figure 18: Evolution of average Jet-Fuel Consumption by aircraft vintage expressed in Mjoule/ASK (1955-2007) (based on manufacturers' data)

consumption of the A380-800 aircraft model issued in 2007. In Figure 18, notice that due to technological innovations aircrafts' energy efficiency has been improved by a factor nearly equal to 3.50 between 1958 and 2007.

Having detailed the 'bottom-up' methodology, one understands why it is usually used in the literature due to its intuitive appeal. However, this approach encounters several important empirical limits.

First, it relies on a few assumptions which may be seen as too restrictive. Indeed, once the 'bottom' step has been realized (as illustrated by Figure 18), some assumptions need to be made in order to obtain EE coefficients at the aggregated level. These assumptions include basically: *i)* the composition of the aircrafts' fleet, and *ii)* an evolution rule for this fleet concerning the renewal/upgrade policy of existing aircrafts. This underlying information about fleet characteristics and their evolution appears hard to investigate in practice, since researchers lack the access to detailed and reliable databases on this topic. The need for such data is all the more complicated that it is required by routes. Based on these restrictive assumptions, average aircrafts' Jet-Fuel consumption are used to obtain aggregated EE coefficients and their evolution rule.

Second, besides relying on restrictive assumptions, this approach is very time-consuming in terms of data management. Modeling by routes adds another layer of complexity, since this approach necessitates to obtain aggregated EE coefficients for each route.

Third, recall that there exist two main factors to increase traffic efficiency: load factors improvements on the one hand, and energy efficiency improvements on the other hand. The latter factor contains three possible sources of improvements: ATM, aircrafts' upgrades, and fleet renewal. Regarding energy efficiency improvements, the 'bottom-up' approach relies only on the last two sources. No improvements stemming from ATM can thus be accounted for when using this methodology.

Fourth, the last drawback concerns data availability. Recall that *(i)* $EE_{i,t} = Tjet_{i,t}/ATK_{i,t}$, and *(ii)* 'bottom-up' approaches are mostly used with modeling by routes. ICAO provides air traffic by routes only for international scheduled air traffic (not for domestic air traffic)[18]. IEA does not provide Jet-Fuel consumption by routes, but by countries. Whereas the 'bottom-up' approach leads to obtain Jet-Fuel consumption by routes, results cannot be confronted to actual data. Even if the 'bottom-up' approach is not used for modeling by route, it supposes to infer Jet-Fuel consumption data which is then adjusted to match historical data, as provided by IEA.

Given these various limits, an alternative methodology to compute directly aggregated EE coefficients is presented in the next section based on deductions from empirical data.

3.2 Macro-level methodology proposal used in this report

This section proposes another approach to reconstruct EE coefficients values and their evolution rule. It departs from the previous one by *1)* providing directly aggregated EE coefficients; and *2)* deducing them directly from empirical data.

As defined in eq(1):

$$EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$$

The new methodology proposed to obtain EE coefficients is to directly compare the Jet-Fuel consumption and the evolution of air traffic (see Figure 19). As straightforward as it may look like, this methodology has not been implemented before to our best knowledge.

Again, Jet-Fuel consumption is obtained from IEA, while air traffic is given by ICAO. More precisely the 'World Energy Statistics and Balances' database of the International Energy Agency (IEA) provides Jet-Fuel consumption (expressed in ktoe) for the 1980–2006 period, while the 'Commercial Air Carriers - Traffic' database of the ICAO provides Air traffic (expressed in ATK) data during 1980–2007. Both databases provide these data by country. It is thus readily possible to re-aggregate these

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[18] When forecasting Jet-Fuel demand at the worldwide level, this data limitation generates some incoherence in the methodology used: international air traffic may be modelled by route, while domestic air transport cannot. This limitation involves to use another type of dataset.

two data time-series for each of the eight geographical regions preliminary defined.

This macro-level methodology allows then to obtain the 'aggregated' EE coefficients – as opposed to 'bottom-up' EE coefficients – and their growth rates from 1980 to 2006. This idea is summarized for a typical region in Figure 19.

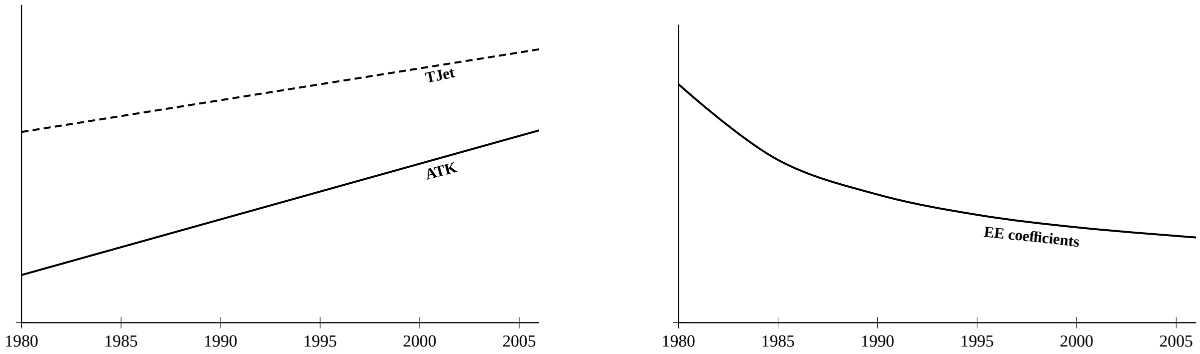

Figure 19: Illustration of the macro-level methodology to compute 'aggregrated' EE coefficients and their yearly growth rates: ATK and Tjet (left panel) and EE coefficients (right panel). Source: Authors, based on manufacturers' data.

In Figure 19 (left panel), the solid black line represents air traffic (expressed in ATK) and the dotted black line represents Jet-Fuel consumption (expressed in ktoe) for a given region. As defined in eq(1), EE coefficients for each year may be obtained by dividing ktoe/ATK (right panel).

Thus defined, EE correspond to the quantity of Jet-Fuel required to power the transportation of one ton over one kilometer. **For a given region $EE_{t+1} < EE_t$ means that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased. Thus, a negative growth rate of EE coefficients, as it is expected, indicates the realization of energy efficiency improvements in air traffic for the region under consideration.** As it may be deduced from the illustrative Figure 19, EE coefficients negative growth rates arise when, in a given year, Jet-Fuel consumption growth rates are slower than air traffic ones.

By following this methodology, first for each zone the value of the EE coefficients until 2006 is obtained. Second, an evolution rule for these EE coefficients in the future may be derived for each zone by observing the evolution of their growth rates between 1980 and 2006. Actually, both datasets are available at an even more disaggregated level for each zone, *i.e.* domestic *vs.* international. Following the same methodology for each region, it becomes thus possible to obtain not only the 'aggregated' EE coefficients, but also EE coefficients corresponding to both international and domestic air travels.

This methodology allows to investigate three issues. First, by comparing the evolution of EE coefficients overtime, one may observe the realization (or not) of energy efficiency improvements over the last 30 years. Second, by comparing the values found for aggregated EE coefficients, one may deduce which zone is more energy efficient compared to others. Third, by comparing 'domestic' and 'international' EE coefficients within each zone, one may observe if domestic air travel is effectively less efficient than international air travel[19]. These questions are investigated in-depth in the next sub-section.

The new methodology proposed seems promising. However, it is also characterized by some limitations.

First, EE coefficients obtained cannot be used in a modeling by routes. This restriction supposes a modeling without routes, as done in this report. This corresponds to an output loss compared to the 'bottom-up' approach, which does not prevent from using either of the two modeling types of air transport mobility.

Second, even if all potential sources of energy efficiency improvements are covered by the macro-level methodology, it is not possible to disentangle the effects from which improvements in energy efficiency are obtained. Recall that it could come from ATM, aircrafts' upgrades, aircraft and airframe/engine design (which is linked to fleet renewal rates). However, this drawback is relatively less important than the corresponding limitations of the 'bottom-up' approach, which cannot account for the ATM source of possible energy efficiency improvements.

Overall, each methodology ('bottom-up' *vs.* macro-level) involves numerous assumptions. For various reasons presented above, it has been chosen to use the macro-level methodology in this report. Results of this methodology are given in the next section.

3.3 Results of the Macro-level methodology

As already explained, the macro-level approach to recover EE coefficients is summarized in eq(1):

$$EE_{i,t} = \frac{T\,jet_{i,t}}{ATK_{i,t}}$$

where EE coefficients for the *i*-th region and date *t* correspond to the ratio of Jet-Fuel consumption ($T\,jet_{i,t}$) over air traffic ($ATK_{i,t}$). Again, the 'World Energy Statistics and Balances' database of the International Energy Agency (IEA) provides Jet-Fuel consumption (expressed in ktoe) for the 1983–

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[19] As highlighted in the literature (Gately (1988), Vedantham and Oppenheimer (1998)), domestic air traffic is supposed to be more energy intensive than international air traffic due to more frequent take-off and landing of aircrafts, the most energy-intensive component of a flight.

2006 period, while the ‘Commercial Air Carriers - Traffic’ database of the ICAO provides Air traffic (expressed in ATK) data during 1983–2007. Both databases are given by country. Thus, for each zone, EE coefficients are computed over the period going from 1983 to 2006.
These mean values are presented for two sub-periods (1983-1996 and 1996-2006) and the whole period. Databases are first re-aggregated by region. Then, EE coefficients are computed for each region. Countries do not necessarily start declaring their data simultaneously. For instance, China has started to declare its air traffic data to ICAO since 1993. As a consequence, exogenous shocks in the evolution of EE coefficients values may be wrongly interpreted, as they only reflect the entrance of a new data source (*e.g.* a country starts declaring either its Jet-Fuel consumption or its air traffic data). Thus, to smooth these potential biases in the data, EE coefficients are presented in mean values during two sub-periods: 1983-1996 and 1996-2006, besides the whole period.
Despite the fact that data are globally available since 1983, USSR started to declare its air traffic data in 1983 only. Besides USSR, some other countries did not declare either air traffic data or Jet-Fuel consumption during the first years of the 1980’s. Thus, it has been chosen to start the first sub-period in 1983, in particular to allow comparisons of the Russia and CIS region with other regions.
EE mean values during the first sub-period are not provided for two regions: China, and Russia and CIS. Again, China starts declaring its air traffic data in 1993. Russia and CIS presents some inconsistencies in the data during 1991-1992, since this region had to be re-aggregated.

This section presents results from the macro-level methodology. A three-step analysis is conducted here.
First, EE coefficients values for each zone and the world and their respective growth rates are presented and analyzed. By comparing the evolution of EE coefficients overtime, one may observe the realization (or not) of energy efficiency improvements over the last 30 years. Thus, both research questions are answered, *i.e.* what the level of the EE coefficients values for each zone, and what is their respective evolution rule. These coefficients are given for international and domestic travels, and at the aggregated (domestic + international) level.
Second, EE coefficients values are compared in order to assess which region is more energy efficient compared to the world’s average.
Third, within each zone, domestic EE coefficients are compared with international EE coefficients. This is done in order to test if domestic air travel is less efficient than international air travel, as underlined in the literature.

Note that to our best knowledge this report provides for the first time EE coefficients at such a detailed level: *(i)* by region; and *(ii)* by type of travel (domestic *vs.* international).

3.3.1 *How do EE coefficients evolve overtime? An analysis for each zone and worldwide*

EE coefficients mean values, their yearly mean growth rates for sub-periods and the whole period, and the rate of change during the whole period are provided in Table 15. These coefficients are presented for domestic travel, international travel, and aggregated (domestic+international) travel, and for each region and the world.

Comments are not provided for the mean value of each zone, as the actual figures obtained are not meaningful. However, the comparison of these coefficients between and within regions yields significant economic insights. These comments are presented in the two next subsections (respectively in Tables 16 and 17).

In what follows, only yearly mean growth rates are commented upon. As explained above, one may observe the realization (or not) of energy efficiency improvements over the last 30 years by comparing the evolution of EE coefficients overtime. EE coefficients indicate the quantities of Jet-Fuel required to power the transportation of one ton over one kilometer (recall eq(1)). Hence computed, a decrease in EE coefficients indicates that less Jet-Fuel is needed to power the same unit of air transport. Thus, negative growth rates of EE coefficients shall be interpreted as energy efficiency improvements.

All regions have registered energy efficiency improvements during the whole period at the aggregated (domestic+international) level. Effectively, all yearly mean growth rates are negative (Table 15, sixth column), ranging from -0.80% (Africa) to -3.86% (the Middle East)[20]. **At the world level, energy efficiency improvements have been equal to 2.88% per year during the whole period** (Table 15, sixth column, last lines). These values rank dramatically higher than usual estimates obtained by the 'bottom-up' approach, which are around 2% at the higher end (Greene (1992, 1996, 2004), Eyers et al. (2004)). What comes to mind immediately to interpret this difference between the macro-level and 'bottom-up' approaches may be explained as follows. Recall that macro-level estimates integrate potential improvements from ATM, which cannot be done with the 'bottom-up' approach. This argument may indicate that ATM has a real potential in explaining energy efficiency improvements.

The next sections present the comparison between and within regions of these EE coefficients values.

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[20] Note the presence of two outliers at the domestic *vs.* international level: Africa registers a yearly mean growth rate of +3.50% at the domestic level during the whole period (this region records however negative yearly mean growth rates during the second sub-period); and Latin America registers a positive growth rate of +0.14% at the international level during the whole period.

3.3.2 *Which region is more energy efficient?*

To compare EE coefficients between regions, three kinds of ratios between EE coefficients are computed. Results are presented in Table 16.

In Table 16, aggregated (domestic + international), domestic and international EE coefficients mean values of each region are compared to the world ones for the whole and the corresponding sub-periods. To do so, ratios presented in the first (respectively second and third) line of the *i*-th region correspond to, for the period under consideration, the aggregated (respectively domestic and international) EE coefficient mean value of the *i*-th region over the aggregated (respectively domestic and international) EE coefficient mean value of the world. In other words, these ratios are computed as follows:

$$\frac{EE_{i,t,k}}{EE_{w,t,k}} \tag{2}$$

where $EE_{i,t,k}$ represents the EE coefficient mean value of region *i*, at time *t={1983-1996;1996-2006;1983-2006}*, and for kind of travel *k={aggregated; domestic; international}* and $EE_{w,t,k}$ represents the EE coefficient mean value of the world, at time *t={1983-1996;1996-2006;1983-2006}*, and for kind of travel *k={aggregated; domestic; international}*.

For instance the value in the first line of the first column (0.95) represents the relative energy efficiency mean value of the Central and North American region during 1983-1996, when compared to the world's energy efficiency. It corresponds to the ratio of $3.93E-0.7/4.17E-0.7$, where 3.93E-0.7 is equal to the Central and North American region EE coefficient value during 1983-1996 (Table 15, first line, first column), and 4.17E-0.7 is equal to the World's EE coefficient value during 1983-1996 (Table 15, third to last line, first column).

Again, according to eq(1), EE coefficients mean values shall be interpreted as the quantity of Jet-Fuel required to transport a given quantity (ton) over a given distance (kilometer). A ratio superior to one means that one needs more quantity of Jet-Fuel to transport one ton kilometer in a given region compared to the world's average. Thus constructed, a ratio >(<) 1 means that the region's energy efficiency is inferior (superior) to the world's energy efficiency.

During the whole period[21] (Table 16, column 3), aggregated (domestic + international) EE ratios are less than one for four regions (Central and North America, Europe, China, Asia and Oceania), and greater than one for the four others (Latin America, Africa, Russia and CIS, the Middle East). This result means that, for aggregated (domestic + international) travel, **the former regions are in average**

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[21] Comments apply only for the second sub-period for Russia and CIS, and China. See above in Section 3.3 for more details.

more energy efficient during the whole period than the world's benchmark. In the contrary, **the four latter regions are less energy efficient than the world's average during 1983-2006.** According to previous literature (Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Eyers et al. (2004)), these results appear quite intuitive except for the Middle East region. Indeed, according to the results, the Middle East seems to be 1.66 more energy-intensive than the world's benchmark (Table 16, sixteenth line, third column). This particular case is further investigated below by a visual inspection of the data. Comments are no further developed at the domestic *vs.* international level, since they follow the trends observed at the aggregated (domestic + international) level.

Figure 20 provides a visual representation of the evolution of EE coefficients. It compares each region's aggregated EE coefficients against the world's benchmark (left panel).

EE coefficients correspond to the ratio of two time-series: Jet-Fuel consumption over Air traffic. To understand EE coefficients evolution (Figure 20, left panel), one needs thus to know the evolution of the two time-series. That is why they are also represented in middle and right panels.

By looking at Figure 20, one may observe the results commented in Table 16. EE coefficients (solid black curve) of Central and North America (first line, left panel), Europe (second line, left panel), Asia and Oceania (seventh line, left panel) and China (eighth line, left panel) are globally below the EE world's benchmark (dashed black curve). One retrieves indeed the result that these regions are the less energy-intensive in the world. Similarly, the same patterns as in Table 16 are observable for the four more energy-intensive regions.

Figure 20 provides an additional information compared to Table 16: all EE trends are decreasing globally. These globally decreasing trends illustrate that **each region has achieved energy efficiency improvements**, as it has been already highlighted in Table 16.

As explained above, the middle and right panels of Figure 20 allow to understand the evolution of EE coefficients by representing the evolution of its constituent aggregates: Jet-Fuel consumption (expressed in Mtoe, middle panel) and air traffic (expressed in ATK, right panel).

This representation is convenient, since it may explain the *a priori* counter-intuitive results observed in the Middle East. Indeed, Table 16 indicated that this region is less energy efficient than the world's benchmark. It is common knowledge that the Middle East airline companies are currently purchasing a lot of new aircrafts. Thus, they have a higher fleet renewal rate than other airlines. One may deduce that in this region the performance in terms of energy efficiency should be relatively better than the world's benchmark. By looking at the left panel of Figure 20, EE coefficients are effectively always above the world's benchmark during the period, but they have dramatically decreased since 2001 to be below this benchmark in 2006. When looking at the right panel of Figure 20, a strong increase of the traffic registered in this region may be noted since 2001. However, one cannot notice an equivalent increase in the consumption of Jet-Fuel during the same period in the middle panel of Figure 20, which means that energy efficiency improvements must have occurred through the use of newer aircrafts.

To summarize, it has been identified that **some regions appear effectively more energy efficient than others.** This result is not neutral when realizing Jet-Fuel demand forecasts. *Ceteris paribus*, a relatively less energy efficient region which encounters a dramatic increase of its air traffic will lead to corresponding higher Jet-Fuel demand forecasts than a relatively more energy efficient region.

3.3.3 *Are domestic air travels less energy efficient than international ones?*

To reply to this question, one proposes to compare EE coefficients within regions. To do so, three kinds of ratios between EE coefficients are computed. Results are presented in Table 17.

In Table 17, within each zone, domestic and international EE coefficients mean values are compared to respectively aggregated (domestic + international) and international ones for the whole and the corresponding sub-periods. To do so, ratios presented in the first (respectively second and third) line of the *i*-th region correspond to, for the period under consideration, the domestic (respectively international and domestic) EE coefficient mean value of the *i*-th region over the aggregated (respectively aggregated and international) EE coefficient mean value of the same region. In other words, these ratios are computed as follows:

$$\begin{aligned} First\ Ratio &= \frac{EE_{i,t,dom}}{EE_{i,t,agg}} \\ Second\ Ratio &= \frac{EE_{i,t,int}}{EE_{i,t,agg}} \qquad (3) \\ Third\ Ratio &= \frac{EE_{i,t,dom}}{EE_{i,t,int}} \end{aligned}$$

where:

$EE_{i,t,dom}$ represents the EE coefficient mean value of region *i*, at time *t={1983-1996;1996-2006;1983-*

2006} for domestic air travel;

$EE_{i,t,agg}$ represents the EE coefficient mean value of region i, at time *t={1983-1996;1996-2006;1983-2006}* for aggregated (domestic + international) air travel;

$EE_{i,t,int}$ represents the EE coefficient mean value of region i, at time *t={1983-1996;1996-2006;1983-2006}* for international air travel.

For instance the value in the last line of the third column (1.33) represents the domestic relative energy efficiency mean value of the world during the whole period, when compared to its international energy efficiency. It corresponds to the ratio of $4.36E-0.7/3.28E-0.7$, where 4.36E-0.7 is equal to the world's domestic EE coefficient value during the whole period (Table 15, second-to-last line, third column), and 3.28E-0.7 is equal to the World's international EE coefficient value during the whole period (Table 15, last line, third column).

Again, according to eq(1), EE coefficients mean values shall be interpreted as the quantity of Jet-Fuel required to transport a given quantity (ton) over a given distance (kilometer). Thus constructed, a ratio >(<) 1 means that the energy efficiency of the kind of travel in numerator is inferior (superior) to the kind of travel in denominator. These ratios aim at comparing, within each region, *(i)* the domestic vs. aggregated (domestic+international) EE coefficients mean values, *(ii)* the international vs. aggregated (domestic+international) EE coefficients mean values, and *(iii)* the domestic *vs*. international EE coefficients mean values.

Hence, the value 1.33 indicates that there is a ratio of 1.33 to one between world's international and domestic energy efficiencies for the whole period. Thus, at the world level, domestic energy efficiency appears to be lower than the international one. This comment applies in all regions: domestic energy efficiency appears to be inferior to international energy efficiency whatever the region considered (third line for each zone). **This result confirms the intuition that domestic air travels are more energy intensive than international air traffic.** One of the main reasons advanced in previous literature is that domestic flights are more energy intensive due to more frequent take-off and landing.

Figure 21 clearly illustrates this stylized fact. At the world level, international air travels (black dashed line) are more energy efficient than domestic air travels (gray dashed line), over the last twenty years. Indeed, the domestic EE coefficients curve is above the one for international EE coefficients[22]. Thus, this figure illustrates previous results presented in Table 17. Moreover, the decreasing trend of the three curves illustrates the results presented in Table 15: **both international and domestic air**

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[22] As a consequence the aggregated (domestic + international) EE coefficients curve (solid black line) is between the two other ones.

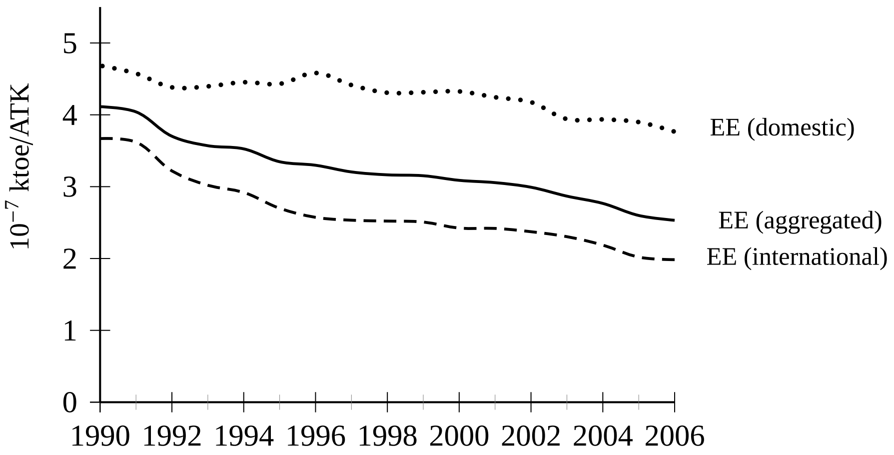

Figure 21: Comparison of the evolution of (i) aggregated (domestic + international), (ii) domestic and (iii) international EE coefficients at the world level from 1990 to 2006. Source: Authors, from ICAO and IEA data.

travels – and as a consequence aggregated (domestic + international) air travel too – **have encountered energy efficiency improvements during 1983-2006 at the world level.**

The same kind of figures may be obtained at the regional level. They are not provided here as they would exhibit exactly the same kind of pattern and stylized fact[23].

The two precedent remarks lead then to the following **stylized fact: even if both international and domestic air travels have encountered energy efficiency improvements from 1983 to 2006, international air travels appear to be less energy intensive than domestic air travels.** The macro-level approach proposed in this report conducts then to same conclusions drawn from previous literature, but obtained with ‘bottom-up’ approaches. Applied to air traffic at the world level, the macro-level approach allows to quantify this stylized fact: air traffic efficiency gains have been equal to +4.08% per year and +1.00% per year during the whole period, respectively for international and domestic air travels (see Table 15, last lines, sixth column). Still at the world level, **domestic air travels are 1.33 less energy efficient than international ones during the whole period** (see Table 17, last line, third column).

Compared to previous literature (Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Lee et al. (2001, 2004, 2009), Olsthoorn (2001), Eyers et al. (2004), Whitelegg and Cambridge (2004), Macintosh and Wallace (2008), Mazraati and Faquih (2008)), energy efficiency

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[23] These figure may be obtained upon request.

gains drawn from the macro-level approach are relatively higher.

To conclude, this section allows us to obtain ’aggregated’ EE coefficients and their growth rates from 1980 to 2006. **Central and North America, Europe, China, Asia and Oceania are in average more energy efficient than the world’s benchmark.** At the world level, **domestic energy efficiency appears to be lower than the international one.** This comment applies in all regions. One of the main reasons advanced in previous literature is that domestic flights are more energy intensive due to more frequent take-off and landing. Thus, **international air travels appear to be less energy intensive than domestic air travels.** Regarding energy policy issues, these results indicate that a higher development of international air traffic compared to domestic air traffic yields, *ceteris paribus*, to a less important increase of Jet-Fuel demand.

In the next section EE coefficients obtained by our ’macro-level’ methodology are used to convert air traffic projections into quantities of Jet-Fuel.

4 Econometric Analysis of Air Traffic Determinants and Jet-Fuel Demand Forecasts

This section presents first the econometric analysis of air traffic determinants. Combined with those of the previous section, these results are then used to project Jet-Fuel demand in the mid-term (2025).

As explained in the introduction, Jet-Fuel demand cannot be modelled directly. A preliminary step is required by modelling air traffic mobility. Indeed, Jet-Fuel is not purchased for itself, but for the services that it provides: flying for leisure or business and transportation of goods and services. Thus it appears necessary to first examine the specific characteristics of demand in the aviation sector to understand the past evolution of air traffic[24], and second anticipate its evolution before deducing Jet-Fuel demands. That is why most studies model first the demand for mobility in air transportation, and second deduce Jet-Fuel demand from these estimates (BTE (1986), Gately (1988), Schafer (1998), Vedantham and Oppenheimer (1998), Graham (2000), Abed Seraj et al. (2001), Battersby and Oczkowski (2001), Lee et al. (2001), Olsthoorn (2001), Lim and McAleer (2002), Bhadra (2003), Wickrama et al. (2003), Lai and Lu (2005), Bhadra and Kee (2008), Mazraati and Faquih (2008), Dft (2009)).

In a first step, the influence of air traffic determinants is estimated using econometric analysis. This analysis supports an interpretation of world air traffic growth in which GDP and Jet-Fuel price play a central role. The former has a positive influence on air traffic whereas the influence of the latter is negative.

Depending on assumptions made on the evolution of air traffic drivers we obtain different air traffic projections. According to our '*business as usual*' scenario, at the world level, air traffic (expressed in RTK) should increase with a yearly average growth rate of about 4.7%. These air traffic forecasts differ from region to region. At the regional level yearly average growth rate range from 3 % in North America to about 8.2 % in China.

In a second step, EE coefficients and their growth rates (corresponding to the evolution of energy gains) obtained in Section 3 **are applied to these air traffic projections to deduce the evolution of Jet-Fuel demand until 2025.** As traffic (and energy) efficiency differ among regions, **Jet-Fuel demand projections are given at a regional level** too.

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[24] Recall that the evolution of air traffic depends mainly on the drivers of demand in the aviation sector.

The section is organized as follows. The first subsection reports and discusses the econometrical results. It also presents different air traffic *scenarii*. In the second subsection these traffic forecasts are converted into a quantity of Jet-Fuel to obtain Jet-Fuel demand projections.

4.1 First step: Econometric analysis and forecasts of air traffic

First, the econometric analysis is conducted, and second the forecasts of air traffic are performed.

4.1.1 *Air Traffic Econometric Analysis*

Gravity models appear to be the most intuitive modeling, since it represents a way to model journeys by following specific routes (Jorge-Calderon (1997), Graham (1999), Wojahn (2001), Becken (2002), Swan (2002), Bhadra (2003), Jovicic and Hansen (2003), Njegovan (2006), Wei and Hansen (2006), Grosche et al. (2007), Bhadra and Kee (2008), DfT (2009)). However, this approach is not adopted here for different reasons. The first reason is linked to data access limitations. Recall that ICAO provides air traffic by routes only for international scheduled air traffic (not for domestic air traffic)[25]. Second, even if all routes data could be accessed, there would remain the problem of re-aggregating journeys by route which can be extremely time consuming. Thus, if gravity models appear to be more appropriate at first glance, they do not necessarily fit well when one wants to model jet-Fuel demand at the worldwide level.

For all these reasons, a more parsimonious approach is adopted here by modeling air traffic demand based on panel-data econometric techniques. Before presenting the estimates, the potential explanatory variables of air traffic are detailed (Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Lee et al. (2001, 2004, 2009), Eyers et al. (2004)).

4.1.1.1 Analysis of potential determinants

This section presents the main drivers of air traffic demand. As recalled in the introduction, the literature identifies broadly three categories of air traffic drivers. The first type is represented by GDP growth rates, the second deals with ticket price, and the third concerns exogenous shocks. Besides, the magnitude of the influence of these air traffic determinants depend on Regions' market maturity.

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[25] When forecasting Jet-Fuel demand at the worldwide level, this data limitation generates some incoherence in the methodology used: international air traffic may be modeled by route, while domestic air transport cannot. This limitation involves to use another type of dataset.

GDP

Figure 22 presents the respective growth rates of world GDP *vs.* world air traffic (measured in RTK).

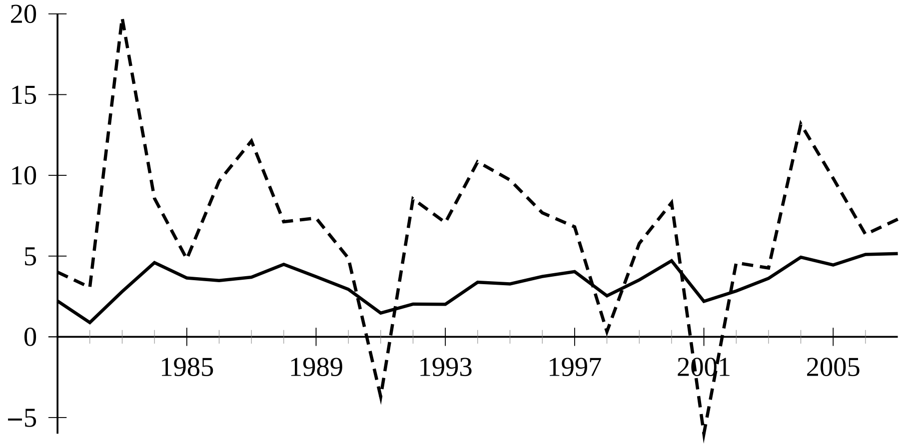

Figure 22: Comparison of GDP (solide line) and world air traffic (dashed line) growth rates during 1981-2007. Source: Authors, from ICAO and Thomson Financial Datastream Data.

Figure 22 confirms that world air traffic has been increasing at 6.4% on average during 1980-2006 (see Table 1), while world's GDP growth rates with a mean value of 3.3%. When comparing GDP growth rates and the rate of growth of the variation sector, one may conclude that the aviation sector is characterized by a dynamic growth compared to other sectors in the economy. GDP constitutes by far the most important determinant of air traffic (Gately (1988), Greene (1992, 1996, 2004), Vedantham and Oppenheimer (1998), Lee et al. (2001, 2004, 2009), Eyers et al. (2004)). Moreover, we notice a high variability in the range of world's air traffic growth rates, going from +20% in 1983 to -6% in 2001.

Ticket Prices

Dresner (2006) and Graham and Shaw (2008) show that there exists a negative elasticity between ticket prices and air traffic: the higher ticket prices, the lower the demand for flights. More particularly, Dresner (2006) indicates that leisure passengers display higher elasticities of demand and lower valuations for travel time compared to business travelers[26]. According to Graham and Shaw (2008), the escalating desire and propensity to fly is driven by the growing affordability of air travel, which stems from increased disposable income and the growth of low-cost airlines. Low fares allow customers to fulfill derived demand in a much wider variety of ways and more often while also stimulating latent

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[26] Thus, the percentage of leisure to total passengers is likely to increase as low-cost air carriers increase their market share.

demand at regional airports. This is satisfied with relatively small aircraft flying short sectors[27].

Besides taxes, the two other main components of plane tickets are first wage costs and second Jet-Fuel prices. Prices variation of these two inputs influence unitary costs, and thus ticket prices fixed by airline companies. Apart from wage costs, the strong increase in Jet-Fuel prices between 2002 and July 2008[28] has fostered numerous debates, more especially about the extra-charge to be paid in order to cope with Jet-Fuel prices increases. Airline companies have introduced an extra-charge for Jet-Fuel since its strong increase was impacting negatively their operating costs. Thus, the share of Jet-Fuel in airline companies' operating costs has risen from 13% in 2002 to 36% in 2008, according to the ICAO. When crude oil brent prices have been remarkably high, the (positive) impact of Jet-Fuel prices on airline companies' ticket prices has become quite large[29].

At least in the short term and for relatively modest prices variation, it seems that ticket prices has a limited impact on demand in the aviation sector. This fact may be illustrated as follows. Figure 1 shows that air traffic has increased dramatically between 2002 and 2007. In the meantime, average ticket prices have been increasing due to crude oil brent price increases (see Figure 23 for a representation of the Jet-Fuel Price evolution between 1980 and 2007). These arguments lead to minimize (not eliminate) the negative impact of tickets' price levels on demand in the aviation sector. Indeed, *ceteris paribus*, other drivers seem to have a stronger impact on demand in the aviation sector. However, when ticket prices reach a given threshold (top or bottom) or when they are characterized by significant (positive or negative) variation levels, demand reacts quite rapidly. The introduction of low-cost airlines in Europe since the middle of the 1990s, and the structural changes that it caused on demand, is a good example of such phenomena[30].

Exogenous Shocks

With respect to Figure 1, one may observe a strong increase of activity in the aviation sector, which corresponds to the evolution of GDP analyzed above. The evolution of air traffic seems to over-react to exogenous shocks[31]. It is important to distinguish between two types of exogenous shocks. The first type corresponds to a slow-down in economic activity, such as the influences of the restrictive

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[27] Note however that this industry has changed the social structure of air travel, but has also accelerated the growth rates of a mode that is the fastest-growing cause of transport's contribution to atmospheric emissions.

[28] Jet-Fuel prices appear to be strongly correlated with brent crude oil prices.

[29] This impact may be captured with a delay to airline companies' 'fuel hedging' behavior, which aims at avoiding the negative impacts due to rapid increases in crude oil brent prices.

[30] Note, to our best knowledge, there is no study that attempts to quantify the impact of low cost airline companies on increased air traffic.

[31] See for instance Gately (1988), Alperovich and Machnes (1994), Witt and Witt (1995), Oppermann and Cooper (1999), Hätty and Hollmeier (2003), Lai and Lu (2005), Koetse and Rietveld (2009) for specific analysis of different shocks on air traffic.

monetary policy led by the U.S. in 1982 (with corresponding GDP and air traffic growth rates respectively equal to 0.88% and 0.3%), the first Gulf-War in 1991 (with corresponding GDP and air traffic growth rates respectively equal to 1.47% and -3.7%), and the Asian financial crisis in 1997 (with corresponding GDP and air traffic growth rates respectively equal to 2.5% and 0.3%). The second type corresponds to exogenous shocks specific to the aviation sector, such as the 9/11 World Trade Center Attack (with a corresponding air traffic growth rate equal to -5.99%), and the epidemic of SARS in 2003 (with a corresponding air traffic growth rate equal to 4.26%).

Influence of regions' market maturity and short/medium hauls *vs.* long hauls

The main drivers of demand in the aviation sector have been detailed. While not exhaustive, this description shows that the number of these drivers is quite limited. Their influence varies depending on two criteria. Indeed, demand in the aviation sector - and the influence of its drivers - is not the same depending on *(i)* short/medium hauls *vs.* long hauls, and *(ii)* the maturity of the market in the region considered.

Short/medium hauls vs. *long hauls*

Compared to short/medium hauls, long hauls are less sensitive to competition from alternative transportation means. This situation explains why the (negative) effect of ticket prices on demand in the aviation sector is less important for long hauls. To synthesize, Long hauls are less sensitive to ticket prices because of the lack of alternative transport modes for these kind of travels.

Air transport market maturity of geographical regions

The degree of maturity of the aviation sector, and thus the growth rate of the traffic, is linked to the level of economic development of a given regional zone (see for instance Vedantham and Oppenheimer (1998)). Globally, the growth rate of air traffic is higher in developing countries like India and China than in OECD countries. At a certain point in time, the market seems to reach maturity and its growth rate decreases towards the GDP growth rate. Regarding the eight geographical regions exhibited in this report, the air transport market of both Europe and Central and North America appear to be the more mature. Following the typology proposed by Vedantham and Oppenheimer (1994, p.17) Africa seems to remain in the '*Transition*' stage of '*[Aviation] Market Life Cycle*' whereas the five other regions are in its 'Growth' Stage. According to the authors, the latter stage corresponds to the period of the aviation market life cycle in which air traffic growth rates are likely to be the highest. Besides, the most part of countries composing 'China' and the 'Asian countries and Oceania' regions are rapidly developing economies. Thus, the perspectives of growth in the aviation sector are more in Asia than in Europe or the U.S.

We turn now to the presentation of the econometric specifications. To take into account the latter criteria (*air transport market maturity of geographical regions*), the modeling is realized for the following eight regions: Central and North America, Latin America, Europe, Russia and CIS (Commonwealth of Independent States), Africa, the Middle East, Asian countries and Oceania. As already explained, the eighth region is China, in order to have a specific focus on this rapidly developing country.

4.1.1.2 Data and econometric specification

This section presents first the data used, and second the econometric specifications.

Data

Air Traffic data are the same as used in Section 2. It spans the time period going from 1980 to 2007, and has been obtained from the International Civil Aviation Organization (ICAO)[32].

As explained above, one of the interest of this database consists in providing data by country, and not by pre-aggregated regions. Thus, it allows to recompose any kind of regions on any *scenarii*. Within the database by country, statistics are provided for airlines registered in a given country on a yearly basis. Another advantage lies in the possibility to account for freight *vs*. passenger, and for domestic *vs*. international air traffic within each zone.

Air traffic data have been re-aggregated for each of the eight geographical regions. These data correspond to the total amount of air traffic of these regions[33] (such as those presented in Table 1 for instance), and are expressed in RTK. Indeed, as explained above, cargo traffic is measured in RTK whereas passenger traffic is expressed both in RPK and RTK.

Data for GDP time-series (expressed in 2000 constant USD) are taken from Thomson Financial Datastream. Series have been obtained for all countries and then re-aggregated by region. Thus, 9 series of GDP are computed: one for the world and one for each zone.

Jet-Fuel price is expressed in 2000 constant USD per ton. The original series, expressed in current terms, have been obtained from Platts. Figure 23 displays the evolution of Jet-Fuel prices during 1980-2007, which may be used as a proxy of ticket prices. Indeed, according to the literature (Abed Seraj et al. (2001), Battersby and Oczkowski(2001), Bhadra (2003), Lai and Lu (2005), Bhadra and Kee (2008)), the time-series of tickets prices is unobservable, or at least hard to investigate empirically.

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[32] The ICAO database used in this report is the ‘Commercial Air Carriers - Traffic’ database.

[33] One do not discriminate anymore neither between domestic and international travels nor between freight and passenger air traffic.

The time-series of Jet-Fuel prices exhibits a wide variability during the period, going from 143$/ton in 1998 to 730$/ton in 1980. During 1980-1986, the price of Jet-Fuel has been rapidly decreasing as a rebound effect of the second oil crisis. Until 2003, the time-series fluctuated in the range of 150-300$/ton. Due to its strong correlation with the brent crude oil market, Jet-Fuel prices have been rapidly increasing since 2004 (up to 600$/ton), mainly due to dramatic increases in worldwide energy demand.

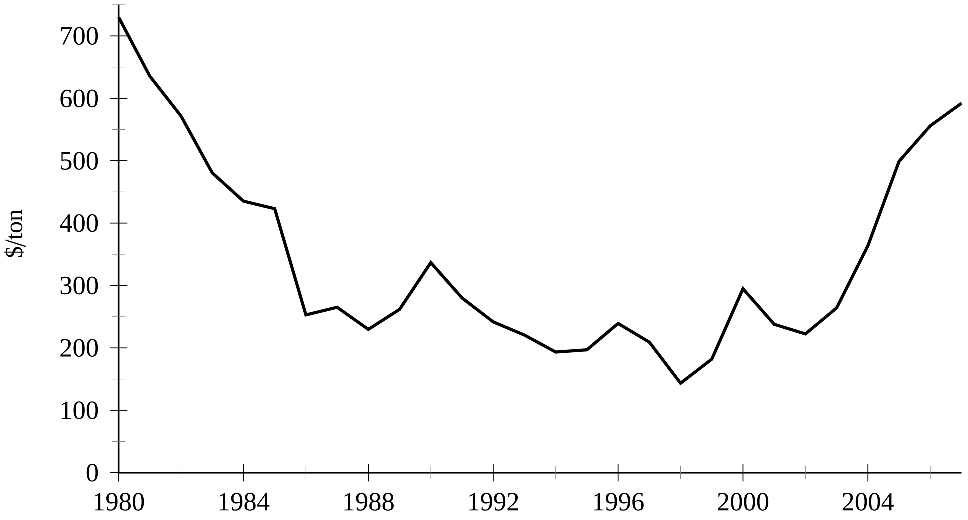

Figure 23: Evolution of Jet-Fuel prices during 1980-2007. Expressed in 2000 constant USD per ton. Source: Authors, from Platts.

Econometric specifications

According to the discussion presented in Section 4.1.1.1, **GDP, Jet-Fuel prices (used as a proxy of ticket prices) and some exogenous shocks should have an influence on air traffic. But the magnitude of the influence of these air traffic determinants seems also to depend on air transport market maturity which vary widely among the eight geographical regions previously identified**[34].

Following this discussion, and to take into account the different regional air transport market maturities, the role played by these variables on air traffic is estimated using **panel-data modeling**. As detailed below, cross-sectional units of the panel-data sample correspond to the eight zones. Moreover, our panel-data sample is closer to time-series data than cross-sectional data as it contains, in particular, Jet-Fuel price and the eight geographical regions' air traffic and GDP time-series. It appears thus suitable to include the lagged dependent variable among regressors.

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[34] These arguments have already been presented in Section 4.1.1.1. See this section for more details.

Then it comes that the **econometric specification** retained in this report to test the influence of previously identified air traffic determinants is the following dynamic panel-data model:

$$lrtk_{i,t} = \gamma lrtk_{i,t-1} + \mathbf{x}'_{i,t}\beta + \alpha_{i,t} + \epsilon_{i,t} \tag{4}$$

with t={1980, . . . , 2007} the period on which air traffic data have been obtained and i={ *Central and North America, Europe, Latin America, Russia and CIS, Africa, the Middle East, Asian countries and Oceania, China*} the eight regions considered.

$lrtk_{i,t}$ is the log of the i-th region's air traffic (expressed in RTK) at time t and, as usual, $(\alpha_{i,t} + \epsilon_{i,t})$ is the composite error term.

$\mathbf{x}'_{i,t}$ is the vector of explanatory variables.

$\mathbf{x}'_{i,t} = \{lgdp_{i,t}, sgrowth, csgrowth, sair, csair, ljetprice\}$ where $lgdp_{i,t}$ is the log of the i-th **region's GDP** at time t, *sgrowth* is a dummy variable for slow-downs in GDP activity, *csgrowth* is a dummy variable for counter GDP activity shocks, *sair* is a dummy variable for shocks specific to the aviation sector, *csair* is a dummy variable for counter-shocks specific to the aviation sector, and $ljetprice$ corresponds – to simplify – to the log of the Jet-Fuel price (see below for a more detailed description regarding the latter variable specifications).

Regarding **exogenous shocks**, as explained above, two kinds of variables may be computed: *(i)* slow-down activity shocks, and *(ii)* aerial-specific shocks. For each category, two kinds of dummy variables have been computed. The first ones (*sgrowth* and *sair*) are equal to 1 the year the shock occur, and 0 otherwise. According to previous literature (Lai and Lu (2005)), air traffic may over-react after these shocks. To test this hypothesis, a second category of dummy variables is used (*csgrowth* and *csair*) which are equal to 1 the two years following the shock, and 0 otherwise. Following what have been explained in Section 4.1.1.1, *sgrowth* is equal to one for the years 1982, 1991 and 1997 and *sair* is equal to one for the years 2001 and 2003.

Regarding the **Jet-Fuel price** variable, $ljetprice$, **two different specifications** are investigated to uncover the influence of Jet-Fuel price on air traffic demand. As a consequence, the $ljetprice$ variable can be decomposed in two ways: either $ljetprice = \{ljetp_t\}$, or $ljetprice = \{ljetpup_{t-1}, ljetpdown_t\}$. $ljetp_t$ is simply the log of the Jet-Fuel price at time t. $ljetpup_{t-1}$ is the log of the upward Jet-Fuel price lagged one period and $lpjetdown_t$ is the log of the downward Jet-Fuel price at time t. The former specification ($ljetprice = \{ljetp_t\}$) is the most straightforward approach, while the latter specification ($ljetprice = \{ljetpup_{t-1}, ljetpdown_t\}$) takes into account threshold effect of Jet-Fuel price changes (respectively above and below 300 US$).

This leads us to express – and estimate, see below – **eq.(4) in two different ways, depending the way Jet-Fuel price is modeling.**
The first specification of eq.(4) is:

$$\begin{aligned} lrtk_{i,t} =& \gamma lrtk_{i,t-1} + \beta_1 lgdp_{i,t} + \eta_1 ljetp_t \\ & + \beta_2 sgrowth + \beta_3 csgrowth + \beta_4 sair + \beta_5 csair + \alpha_{i,t} + \epsilon_{i,t} \end{aligned} \tag{5}$$

The second specification of eq.(4) is:

$$\begin{aligned} lrtk_{i,t} =& \gamma lrtk_{i,t-1} + \beta_1 lgdp_{i,t} + \eta_2 ljetpup_{t-1} + \eta_3 ljetpdown_t \\ & + \beta_2 sgrowth + \beta_3 csgrowth + \beta_4 sair + \beta_5 csair + \alpha_{i,t} + \epsilon_{i,t} \end{aligned} \tag{6}$$

Concerning the second specification of the Jet-Fuel price variable (eq.(6)), two kinds of variables have been computed: $ljetpup_{t-1}$ and $ljetpdown_t$.
As explained in Section 4.1.1.1, above a given threshold (such as 300$/ton), Jet-Fuel prices constitute a significant part of airline companies' operating costs[35]. Thus, **Jet-Fuel prices may have a non-linear effect on air traffic: this variable may have effectively a negative impact on air traffic, but only above a given price threshold.** To test this hypothesis, one variable is computed as a cross-product of a dummy variable – equal to 1 when Jet-Fuel prices' value is above 300$/ton[36] and zero otherwise – and of the Jet-Fuel price series. Hence computed, the cross-product variable is equal to the Jet-Fuel price, but only when the latter is above 300$/ton. To be clear, this cross-product variable takes the value of 0 whenever Jet-Fuel prices are below the threshold of 300$/ton.

Moreover, previous literature indicates that **this non-linear effect may differs depending on the existence of an upward – or downward Jet-Fuel price trend.** Indeed, on an upward (downward) Jet-Fuel price trend, airline companies anticipate increasing (decreasing) Jet-Fuel prices. As a consequence, on an upward price trend (above 300$/ton), airline companies purchase Jet-Fuel through forward contracts to limit the anticipated increase in the price of Jet-Fuel. This does not hold necessarily however on a downward price trend.

To test for this potential asymmetric non-linear effect, and similarly to the methodology used for the cross-product variable described above, two cross-product variables are computed.
First, $ljetpup_{t-1}$ is computed as a cross-product of a dummy variable – equal to 1 when Jet-Fuel prices'

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[35] According to ICAO (2007), the share of Jet-Fuel price in airline companies' operating costs has skyrocketed from about 13 % in 2002 to 36 % in 2008. Whereas in the meantime, the price of a ton of Jet-Fuel has risen from about 200 (2000 constant) USD to more than 600 (2000 constant) USD, see Figure 23.

[36] This threshold has been fixed considering the average level of Jet-Fuel prices variation over the whole period (see Figure 23). After experimenting for other thresholds, cross-product variables were only found to be significant as such.

value is above 300$/ton *on an upward trend* (see Figure 23) and zero otherwise – and of the Jet-Fuel price series. Hence computed, the cross-product variable is equal to the Jet-Fuel price, but only when the latter is above 300$/ton *on an upward trend*. Note that this variable is lagged one period to take into account the airline companies' forward contracting behavior.

Second, $ljetpdown_t$ is computed as a cross-product of a dummy variable – equal to 1 when Jet-Fuel prices' value is above 300$/ton *on an downward trend* (see Figure 23) and zero otherwise – and of the Jet-Fuel price series. Hence computed, the cross-product variable is equal to the Jet-Fuel price, but only when the latter is above 300$/ton *on an downward trend*. Contrary to $ljetpup_{t-1}$, $ljetpdown_t$ is not lagged because airline companies do not purchase forward contracts in a context of downward Jet-Fuel prices.

Note that the first letter – *'l'* – figuring at the beginning of $ljetpup_{t-1}$ and $ljetpdown_t$ indicates that one have taken the log of these two variables when introducing them in eq. (6), as it is usual in panel-data models.

The econometric specification has been explained in detail. The next section presents estimates of these two specifications.

4.1.1.3 Estimation results and interpretation

The panel-data sample used in this report to estimate eq. (5) and eq. (6) is a long-panel dataset[37]. Moreover, the econometric specifications of eq.(5) and eq.(6) is characterized by a dynamic structure that specify the dependent variable for an individual ($lrtk_{i,t}$) to depend in part on its values in previous periods. As a consequence, **traditional panel-data estimation approaches (fixed and random effects models) are not appropriate** and then not presented here. Indeed, if the lagged dependent variable is included among regressors, the fixed effects needs to be eliminated by first-differencing rather than mean-differencing[38].

Our generic econometric specification (Eq. (4)) becomes then:

$$\Delta lrtk_{i,t} = \gamma \Delta lrtk_{i,t-1} + \Delta \mathbf{x}'_{i,t}\beta + \Delta\epsilon_{i,t} \qquad (7)$$

where $\epsilon_{i,t}$ is now supposed to be serially uncorrelated (this assumption is testable, see below).

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[37] Long-panel dataset are characterized by a relatively small number of individuals and a relatively long time period (N is small and $T \to \infty$).

[38] For a general presentation of dynamic panel-data models, see Cameron and Trivedi (2005).

The descriptive statistics of variables used in eq. (7) are given in Table 18[39].

Estimates results are presented in Table 19. **Eq. (5) and eq. (6)**, in first-differences, **are estimated using the Anderson–Hsiao (Anderson and Hsiao (1981)** – column (1), Table 19 – **and the GMM (Arellano and Bond (1991))** – columns (2) and (3), Table 19 – **estimators**. Note that these estimates results are only presented in reduced form.

As explained in Cameron and Trivedi (2005), Anderson and Hsiao (1981) proposed IV estimation using $lrtk_{i,t-2}$[40], which is uncorrelated with $\Delta\epsilon_{i,t}$, as an instrument for $\Delta lrtk_{i,t-1}$ in eq. (7). The regressors $\mathbf{x}_{i,t}$ are used as instruments for themselves as they are strictly exogeneous.

As explained in the previous paragraph, the first column of Table 19 reports the Anderson–Hsiao estimator for eq. (5) and eq. (6) in first-differences. The null hypothesis of the endogeneity test is '*variables are exogenous*'. According to the $P-value$ of this test ($P-value = 0.03 < 0.05$), one can not accept this hypothesis when using this estimator.

According to column (1), no explicative variables, except $lrtk_{i,t-1}$, are statistically significants: $lrtk_{i,t}$ seems thus to follow an AR(1) process when the model is estimating using the Anderson–Hsiao estimator. This result holds whatever the econometric specification of the Jet-Fuel price variable (estimates of either eq. (5) or eq. (6) lead to the same reduced form estimate presented in column (1)). Unsurprisingly, the coefficient of $lrtk_{i,t-1}$ is positive, indicating a positive influence of previous air traffic level of the $i-$th region ($lrtk_{i,t-1}$) on its current air traffic level ($lrtk_{i,t}$).

The two last columns of Table 19 report the estimates results of respectively eq. (5) – column (2), Table 19 – and eq. (6) – column (3), Table 19 – from the (one-step) GMM estimator.

This estimator is also called the Arellano–Bond estimator after Arellano and Bond (1991), who detailed implementation of the estimator and proposed tests of the assumption that $\epsilon_{i,t}$ are serially uncorrelated (Cameron and Trivedi (2005)). This estimator can be thought as an extension to the Anderson–Hsiao estimator. Indeed, the approach of Arellano and Bond (1991) is based on the notion that the estimator proposed by Anderson and Hsiao (1981) does not exploit all the information available in the sample. Compared to the former estimator, the GMM estimator proposes to make a more efficient use of the information in the dataset by using additional lags of the dependent variable as an instrument. By using additional instrument variables, the GMM estimator proposed by Arellano and Bond (1991) leads to more efficient estimates[41].

For a large T (relatively to cross-sectional units), the Arellano–Bond method generates many in-

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[39] The first-difference of a variable expressed in logarithm may be approximated by its growth rate. This reason explains why Table 18 summarizes descriptive statistics of the growth rates of the explanatory variables of air traffic.

[40] As indicated in the last line of Table 19. This line indicates, for both estimators, which instruments have been used for $\Delta lrtk_{i,t-1}$.

[41] This may explained why the Anderson–Hsiao estimator do not pass the endogeneity test.

Variable	Mean (%)	Std. Dev. (%)	Min. (%)	Max. (%)
Air traffic growth rates (RTK)				
Central and North America	5.22	4.89	-8.06	14.13
Europe	6.83	6.43	-5.74	27.04
Latin America	7.90	22.91	-34.92	84.80
Russia and CIS	-0.64	18.39	-39.82	39.99
Africa	5.81	23.38	-22.68	99.46
The Middle East	9.94	25.22	-31.76	85.08
Asian countries and Oceania	8.17	9.20	-12.81	35.23
China	12.30	6.91	3.02	30,00
World	6.64	5.09	-5.99	19.75
GDP growth rates (2000 constant USD)				
Central and North America	3.02	1.65	-1.95	6.89
Europe	2.17	1.13	-0.69	4.26
Latin America	2.54	2.34	-2.55	6.21
Russia and CIS	-2,08	16.05	-72.83	9.54
Africa	3.19	1.53	0.06	5.78
The Middle East	2.85	2.91	-2.03	9.60
Asian countries and Oceania	8.21	2.07	2.25	11.33
China	9.89	1.58	7.60	13.10
World	3.33	1.12	0.88	5.15
Jet-Fuel Price growth rate (2000 constant USD/ton)				
	1.66	22.98	-40.23	62.00

Table 18: Descriptive statistics

struments, leading to potential poor performance of asymptotic results[42]. This argument explains why the number of instruments have been restricted to $lrtk_{i,t-2}$ and $lrtk_{i,t-3}$, as shown in the last line of Table 19.

The quality of regressions presented in column (2) and (3) of Table 19 is verified through two specification tests: the serial correlation tests $m1$ and $m2$ and a test of overidentifying restrictions (the *Sargan Test*).

$m1$ and $m2$ are tests for respectively first-order and second-order serial correlation, asymptotically $N(0,1)$. The null hypothesis of these tests is that $Cov(\Delta\epsilon_{i,t}, \Delta\epsilon_{i,t-k}) = 0$ for $k = 1, 2$ is rejected at a level of 0.05 if $P - value < 0.05$. If $\epsilon_{i,t}$ are serially uncorrelated, we expect to reject at order 1 but not at order 2 (or higher orders). According to $P - values$ of $m1$ and $m2$ tests, this is indeed the case for both column (2) and (3) of Table 19. In each case, the $P - value$ of $m1$ is equal (or very closed) to 0.05. Thus we reject at order 1 at the level of 0.05. At order 2, $\Delta\epsilon_{i,t}$ and $\Delta\epsilon_{i,t-2}$ are serially uncorrelated because $P - values$ are both superior to 0.05 ($P - values$ of the $m2$ test are equal to 0.78 and 0.90).

Regarding the second specification test, the Sargan statistic is used to test the validity of the overidentifying restrictions. The null hypothesis of the Sargan Test is ‘overidentifying restrictions are valid’. The $P - values$ of this test are equal to 0.19 for column (2) and 0.09 for column (3). Thus the null hypothesis that the population moment conditions are correct is not rejected because $P - values > 0.05$. Thus, there is no evidence either from the serial correlation tests or from the Sargan test that reduced forms estimates results presented in columns (2) and (3) of Table 19 are misspecified.

We turn now to the interpretation of these estimates.

Column (2) – Table 19 – presents the reduced form estimate of eq. (5) in first-differences from the (one-step) GMM estimator. As in column (1), $lrtk_{i,t-1}$ is statistically significant and its coefficient is positive. Again, this indicates that the **current air traffic level of the $i-$th region ($lrtk_{i,t}$) depends positively on its previous level ($lrtk_{i,t-1}$).** Compared to column (1), the $lgdp_{i,t}$ variable is now statistically significant. Its coefficient is positive: **the more the GDP of the $i-$th region is growing, the more its air traffic is growing too.** The *growth shocks* and *sectorial shocks* variables are both statistically significant and their coefficients are negative. This indicates that **air traffic ($lrtk_{i,t}$) effectively overreacts to *(i)* slow-down activity shocks (the *growth shocks* variable) and *(ii)* (negative) aerial-specific shocks (*sectorial shocks*).** The $P - value$ of the test for equality of these two latter variables (see Table 19, third-to-last line, column (2)) is equal to 0.001. Thus, one can not group these two dummy variables in a single one. Both slow-down activity shocks and aerial-specific shocks have a negative influence on air traffic but one should not confound these two kind of shocks. Finally, the price of Jet-Fuel, lagged or not (respectively $ljetp_{t-1}$ and $ljetp_t$), seems to have no influence on air traffic as the coefficients of these two variables are not statistically significant. Contrary to Dresner (2006) and Graham and Shaw (2008), our eq. (5) estimate result does not indicate a negative elasticity

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[42] See Cameron and Trivedi (2005) for more details on this subject.

	Anderson-Hsiao First-Differenced 2SLS estimator	**Arellano & Bond First-Differenced GMM estimator**	
	Reduced Form	Reduced Form First kind of modeling of Jet-Fuel Price	Reduced Form Second kind of modeling of Jet-Fuel Price
	(1)	(2)	(3)
$lrtk_{i,t-1}$	1.019*** (0.065)	0.868*** (0.112)	0.666*** (0.135)
$lgdp_{i,t}$		0.276** (0.132)	0.363* (0.209)
$ljetp_t$			-
$ljetp_{t-1}$			-
$ljetpup_{t-1}$		-	0.014* (0.008)
$ljetpdown_t$		-	-0.015*** (0.002)
growth shocks		-0.059* (0.035)	-
growth counter-shocks			-
sectorial shocks		-0.116*** (0.030)	-
sectorial counter-shocks			-
shocks (growth or sectorial)		-	-0.152*** (0.039)
counter-shocks (growth or sectorial)		-	
constant	-	-4.518** (1.979)	-2.162 (3.392)
Endogeneity Test (P-value)	6.52 (0.03)	-	-
m1 (P-value) m2 (P-value)	- -	-1.8393 (0.06) -0.27987 (0.78)	-1.8997 (0.05) -0.1219 (0.90)
Sargan Test (P-value)	-	58.68 (0.19)	63.2889 (0.09)
Test for growth shocks coeff. = sectorial shocks coeff. (P-value)	-	14.56 (0.001)	0.68 (0.41)
Test for ljetpup(t-1) coeff. = ljetpdown coeff. (P-value)	-	-	10.34 (0.001)
Instruments	$lrtk_{i,t-2}$	$lrtk_{i,t-2}$, $lrtk_{i,t-3}$	$lrtk_{i,t-2}$, $lrtk_{i,t-3}$

Notes:
Sample: 8 geographical regions; 1980-2007.
Dependent variable: $lrtk_{i,t}$, the log of the i-th region's air traffic (expressed in RTK) at time t. The variables used in the regressions are built with the logarithms of the data described in Section 4.1.1.2.
The standard errors (reported into brackets, unless otherwise indicated) are robust standard errors that permit the underlying error $\epsilon_{i,t}$ to be heteroskedastic but do not allow for any serial correlation in $\epsilon_{i,t}$, because then the estimator is inconsistent.
***, ** and * indicate 1%, 5% and 10% significance levels, respectively.
The null hypothesis of the endogeneity test is '*variables are exogenous*'.
$m1$ and $m2$ are tests for first-order and second-order serial correlation, asymptotically $N(0,1)$. These test the first-differenced residuals.
Sargan test is a test of the overidentifying restrictions for the GMM estimator, asymptotically χ^2.

Table 19: Reduced form estimates results of eq. (5) and eq. (6) in first-differences from the Anderson–Hsiao (column (1)) and the Arellano–Bond (column (2) and (3)) estimators.

between ticket prices (proxied by the Jet-Fuel price) and air traffic.

Before concluding to the non-existence of such an elasticity, one may wonder if this latter result is not due to a wrong specification of the influence of the Jet-Fuel price variable on air traffic. Eq. (6) proposes another way to specify the influence of the Jet-Fuel price variable by taking into account price thresholds effects (see Section 4.1.1.2 for more details). Column (3) – Table 19 – presents the reduced form estimate of eq. (6) in first-differences from the (one-step) GMM estimator. Coefficients of $lrtk_{i,t-1}$, $lgdp_{i,t}$ and '*shocks*' variables are not commented as the same comments than those presented in the previous paragraph apply[43]. Regarding the new way to specify the influence of Jet-Fuel prices on air traffic, $ljetpup_{t-1}$ and $ljetpdown_t$ are both statistically significants. This result tends to prove that **Jet-Fuel prices have a non-linear effect on air traffic**[44]. Moreover the negative coefficient of $ljetpdown_t$ indicates that, **above a given price threshold, Jet-Fuel prices have effectively a negative impact on air traffic.** The positive sign of $ljetpup_{t-1}$ seems then counter-intuitive, indicating a positive elasticity between ticket prices (proxied by the Jet-Fuel price) and air traffic. The following reason may explain this seemingly counter-intuitive result. Recall that the $ljetpup_{t-1}$ variable is the log of the upward Jet-Fuel price lagged one period. $ljetpup_{t-1}$ is computed as a cross-product of a dummy variable – equal to 1 when Jet-Fuel prices' value is above 300$/ton *on an upward trend* and zero otherwise – and of the Jet-Fuel price series. Thus, according to Figure 23, $ljetpup_{t-1}$ was equal to the Jet-Fuel price serie (lagged one) during the period going from 2003 to 2008. This particular period is characterized by an important increase of energy demand causing a rapidly increase of all energy prices. Thus, the positive sign of $ljetpup_{t-1}$ may actually just reflects this very particular period.

Econometric results of eq. (5) and eq. (6) and their interpretations have been presented in this section. As detailed in the next section, these results are then used to build different air traffic forecasts *scenarii*. We turn now to the presentation of these air traffic forecasts.

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[43] Note however the relatively stability of these coefficients between column (2) and column (3), which tends to prove the robustness of our results.

[44] This statement is also confirmed by the $P-value$ of the test for equality of the coefficients of $ljetpup_{t-1}$ and $ljetpdown_t$ (see Table 19, second last line, column (3)). This $P-value$ is equal to 0.001, indicating that one can not accept the null hypothesis that these two coefficients are equals.

4.1.2 *In-sample prediction and air traffic forecasts*

Following the discussion developed in Section 4.1.1.3, **the reduced form estimate of eq. (6) in first-differences from the (one-step) GMM estimator (Column (3), Table 19) is used to generate air traffic forecasts until 2025.** The modeling presented in previous sections has been realized for eight geographical zones. **Air traffic projections are thus estimated for the following regions: Central and North America, Latin America, Europe, Russia and CIS, Africa, the Middle East, Asian countries and Oceania, and China.** Before presenting these forecasts, in-sample predictions are first presented in order to assess how well our model fit historical data.

4.1.2.1 In-sample predictions

After estimating eq. (6) by a dynamic panel-data estimator, one can compute the predicted values of this model. Computing predicted values allows us to generate in-sample predictions: the values of the response variable generated by the fitted model using historical data. Because cross-sectional units of our panel-data sample correspond to the eight geographical regions already presented, the modeling has been realized for each of these eight zones. The response variable of our model is $lrtk_{i,t}$, the log of the i-th region's air traffic (expressed in RTK) at time t[45] (recall eq. (6)). It is thus readily possible to compute our model' s predicted values of (the log of) air traffic (expressed in RTK) for each of these eight regions during the period 1981-2007.

Predicted values estimate average values of the dependent variable for given value of the regressors. The precision of these estimates depends on the 'quality' of the model used and is measured by the variances of the predicted values. Thus, in order to assess how well our model fits historical data, we provide interval predictions to complement point predictions by obtaining their bounds. An interval prediction is simply a confidence interval for the predicted values. Thus, using the variance of predicted values yields to obtain a prediction interval for these predicted values. One then obtains an upper and lower bounds that contain predicted values with a given probability[46].

Figure 24 (see Appendix) provides 95 % interval predictions for predicted values of (the log of) air traffic (expressed in RTK) for each of the eight regions during the period 1981-2007. By comparing these interval predictions with (the log of) each region's air traffic '*true values*', it is possible to judge the 'quality' of our model. A well-specified model should generate reasonable in-sample predictions, that is predicted values relatively close to historical data. A simple visual inspection of

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[45] With, as already explained, $t=\{1980, \ldots, 2007\}$ the period on which air traffic data have been obtained and $i=\{$ *Central and North America, Europe, Latin America, Russia and CIS, Africa, the Middle East, Asian countries and Oceania, China*$\}$ the eight regions considered.

[46] See Wooldridge (2006) for more about forming and interpreting interval predictions.

Figure 24 yields to conclude that, globally, in-sample predicted values of our model fits historical data rather well. Indeed, '*true values*' are, in most cases, inside interval predictions. Note however that our model seems to over-estimate the 'Latin America' region's air traffics and to under-estimate the 'Asian countries and Oceania' region's air traffics.

Once computed each region's predicted values of air traffic, it becomes readily possible to re-aggregate these values at the world level. One then obtain predicted values of air traffic (expressed in RTK) at the world level and its 95 % interval prediction.
Figure 25 compares in-sample predicted values of air traffic at the world level (bold line) with '*true values*' of world air traffic (grey line) during the 1981-2007 period.

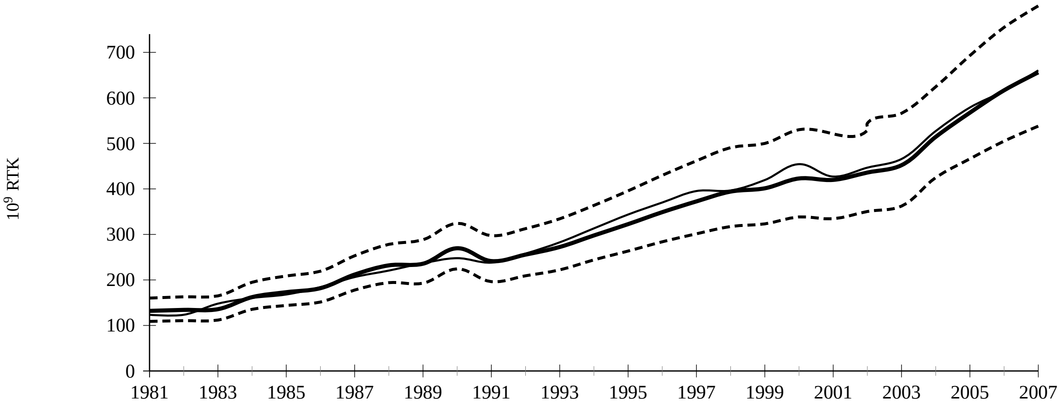

Figure 25: In-sample predictions and evolution of world air traffic (10^9 RTK) between 1981 and 2007.
Grey line: ICAO data, bold line: in-sample predicted values, dashed lines: 95 % Interval Prediction.

Figure 25 shows how well our model fits historical data at the world level. **In-sample predicted values are very closed to historical data.** The 95 % Interval Predictions (dashed lines) indicates the precision of these estimates.

The 'quality' of our model has been assessed. We can now present air traffic forecasts based on this model.

4.1.2.2 Air traffic forecasts until 2025

Air traffic forecasts presented in this report are obtained by computing out-of-sample predictions. These out-of-sample predictions are generated by applying the estimated regression function of eq. (6) (column (3), Table 19) to observations that were not used to generate the estimates.

It is thus possible to obtain different air traffic forecasts *scenarii*; depending on assumptions made on the evolution of air traffic drivers previously identified[47]. One needs then to use hypothetical values of the regressors to generate air traffic forecasts. In particular, it has been already underlined that GDP growth rate is, by far, the most important air traffic determinant. Thus, air traffic forecasts presented below rely on a crucial assumption: the future evolution of the eight geographical regions' GDP growth rates. The International Monetary Fund (IMF) provides previsions of these GDP growth rates until 2014.

Three 'air traffic forecasts' *scenarii* are build from these previsions:

- The '*IMF GDP growth rates*' air traffic forecasts scenario:
  This is **the main air traffic forecasts scenario**. GDP growth rates previsions are obtained from the IMF World Economic Outlook (WEO) Database[48].
  Two other air traffic forecasts *scenarii* are defined:

- The '*Low GDP growth rates*' air traffic forecasts scenario:
  In this second air traffic forecasts scenario, IMF GDP growth rates previsions are decreased by 10 %.

- The '*High GDP growth rates*' air traffic forecasts scenario:
  Finally, in this last air traffic forecasts scenario, IMF GDP growth rates previsions are increased by 10 %.

The two latter alternative *scenarii* are such defined in order to measure the sensibility of air traffic to GDP growth rates variations.

As already explained in the previous section, air traffic forecasts are computed for each of the eight regions. By re-aggregating these forecasts, one then obtains air traffic forecasts at the world level.
Figure 26 provides a visual representation of our '*IMF GDP growth rates*' air traffic forecasts scenario – expressed in RTK – at the world level until 2025 (bold line, from 2008 to 2025) and its 95 % Interval Predictions[49] (dashed lines, from 2008 to 2025).

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[47] See Section 4.1.1.2, in particular eq. (6), for a complete description of these determinants.

[48] The IMF regularly revises previsions presented in this data base. Last access to the IMF WEO Database was on November, 2009.

[49] Variances of in-sample predicted values and forecasts are different. As is intuitive, the variances of the forecasts are higher than the variances of the predicted values. This explains the progressively increasing gap between the lower bound and the upper bound of the 95 % Interval Predictions.

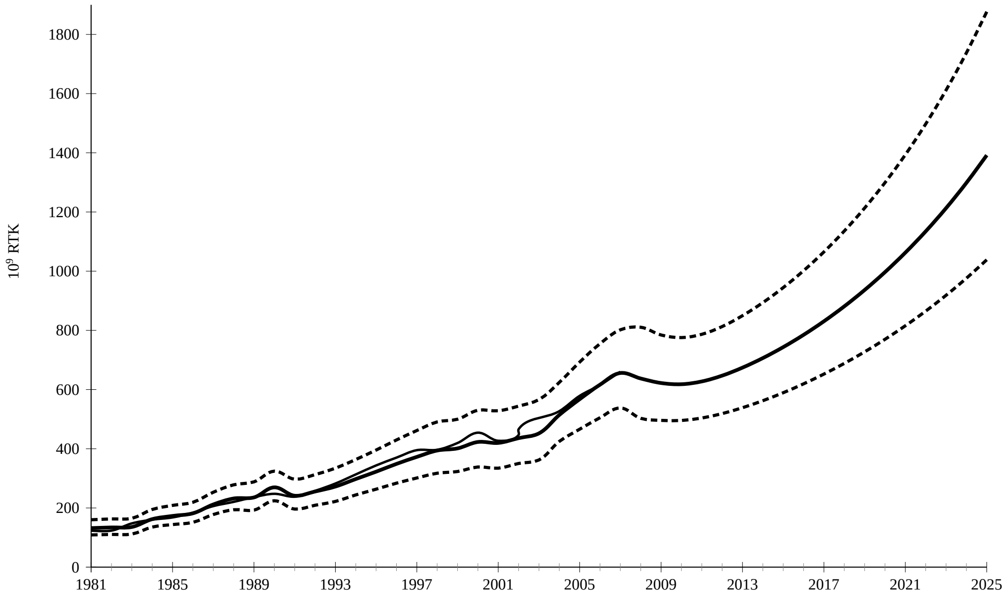

Figure 26: World Air Traffic Forecasts (10^9 RTK) until 2025.
Grey line: ICAO data, bold line: in-sample predicted values (from 1981 to 2007) and air traffic forecasts (from 2008 to 2025), dashed lines: 95 % Interval Prediction.
‘*IMF GDP growth rates*’ air traffic forecasts scenario.

According to Figure 26, our **model predicts first a relatively high decrease of air traffic in 2008 and 2009 (- 3.47 % between 2007 and 2008) followed by the recover of its positive evolution from 2010 to 2025.** Negative GDP growth rates in 2008 and 2009 – as specified in our '*IMF GDP growth rates*' air traffic forecasts scenario (according to IMF GDP previsions) – explain the predicted decrease of air traffic during this period.

According to our '*IMF GDP growth rates*' air traffic forecasts scenario, **world air traffic** (expressed in RTK (10^9)) **should, overall, increase at a yearly mean growth rate of 4.7%**, rising from 637.4 to 1391.8 between 2008 and 2025 (see next section, Table 20, first column, two last lines).
By comparison, the '*Low GDP growth rates*' and '*High GDP growth rates*' air traffic forecasts *scenarii* predict a yearly mean growth rate of world air traffic – expressed in RTK – of 4.2% (Table 22, first column, last line, figure into bracket) and 5.3% (Table 23, first column, last line, figure into bracket), respectively. Thus, **a decrease (an increase) by 10% of regions' GDP growth rates previsions yields to a decrease (an increase) of the world air traffic yearly mean growth rate by about 10.6% (12.8%).**

Air traffic forecasts are no further commented here as it will be done in the next section. As already explained, these air traffic forecasts are necessary to deduce Jet-Fuel demand projections from these estimates. The latter are presented in the next section.

4.2 Second step: Jet-Fuel demand projections

This section presents Jet-Fuel demand projections until 2025 for each of the eight geographical regions and at the world level. Jet-Fuel is not consumed for itself but to power aircraft engines. Jet-Fuel demand depends on the demand for mobility in air transportation. Thus, the general methodology proposed in this report to project Jet-Fuel demands consists first in forecasting air traffic and second converting these forecasts into a quantity of Jet-Fuel.

The previous section has defined (and presented) air traffic forecasts *scenarii*. The current section deals then with the second step of our methodology. As already explained, **the conversion of air traffic projections into quantities of Jet-Fuel is accomplished using the 'Traffic Efficiency' method** developed previously by UK DTI to support the IPCC (1999). The intuition behind this method is that the rise of jet-Fuel demand resulting from air traffic demand rise can be mitigated by energy efficiency improvements. For instance, an increase of 6% per year of air traffic does not mean a strictly corresponding increase of 6% in Jet-Fuel demand.

Thus, one of the major tasks of this section consists in defining different *scenarii* of the expected rates, expressed per year, of EE improvements; corresponding to the evolution of air traffic energy gains. To do so, results presented in previous sections will be used.

As developed in Section 3, traffic efficiency improvements depend on: *(i)* load factors improvements (aircraft are using more of their capacity); *(ii)* energy efficiency improvements.
Load factors improvements are defined according to results on WLF presented in Section 2.
Regarding energy efficiency improvements, two pieces of information are required to convert air traffic projections into quantities of Jet-Fuel: first, value(s) of EE coefficients; second, a rule for the evolution of EE coefficients until 2025. As it will be explained below, three 'energy efficiency improvements' *scenarii* will be defined according to results presented in Section 3.

The next section presents the methodology used in this report to convert air traffic forecasts into Jet-Fuel projections. Then, the last section presents these projections.

4.2.1 *From air traffic forecasts to Jet-Fuel demand projections: Traffic Efficiency improvements scenarii*

As explained in the introduction of this section, **traffic efficiency improvements depend on: *(i)* load factors improvements ; *(ii)* energy efficiency improvements. One need then to define both 'load factor' and 'energy efficiency' improvements *scenarii* to convert air traffic forecasts into Jet-Fuel demand projections.** Note that in the former case (load factors improvements), no technological progress is achieved: airlines diminish their Jet-Fuel consumption by filling more their aircrafts.

By improving their load factors, airlines hold a relatively easy way to diminish their Jet-Fuel consumption without achieving any technological progress: they 'just' have to fill more their aircrafts. Section 2 has greatly presented geographical regions' Weight Load Factors (WLF) values and their evolution during the 1980-2006 period (see in particular Tables 1, 6, 8, 11, 13, 29 and Figures 5, 10, 12, 15, 17, 30). Each region's WLF value presented in Table 1 (third column, third line for each zone) is used to convert regions' air traffic forecasts expressed in RTK[50] into corresponding air traffic forecasts expressed in ATK. ATK are computed from RTK forecasts using the following equations: $RTK = WLF * ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight[51].
Regarding the evolution of each region's WLF until 2025, it has been chosen to adopt the following strong hypothesis. Each region's WLF is assumed to tend to 75%. Thus for each region, we apply the WLF yearly mean growth rate of the second sub-period (Table 1, fifth column, third line for each

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[50] Again these forecasts has been presented in the previous section.

[51] As already explained, because airlines never fully fill their aircrafts one have $ATK > RTK$.

zone) until the region's WLF reaches the 75% value.

The conversion of air traffic forecasts *expressed in RTK* into corresponding air traffic forecasts *expressed in ATK* yields to estimate how much more filling aircrafts (until 75 % of their capacity, which is, again, a strong hypothesis) will curb the air traffic increase.

Once air traffic forecasts expressed in RTK have been converted into air traffic forecasts expressed in ATK, one can use the 'Traffic Efficiency' method previously explained to convert air traffic forecasts into Jet-Fuel demand projections (expressed in Ton (10^3**).**

First, each region's EE coefficient value for the year 2006 (Table 15 provides mean values of each regions' EE coefficients for two sub-periods (1983-1996 and 1996-2006) and the whole period (1983-2006)) is used to convert regions' air traffic forecasts expressed in ATK into Jet-Fuel demand projections for the year 2006.

Then, one need to define the evolution of regions' EE coefficients until 2025. **Making assumptions on the evolution of air traffic Energy Efficiency (EE) is barely a difficult task.** In this report, it has been chosen to assume that the evolution of EE in a near future has very chance to be like what happened in the last ten years (see below). This choice may appears as being arbitrary. Yet, it may also be considered as rather intuitive. At least, other assumptions on the evolution of air traffic Energy Efficiency could not be considered as more legitimate than this one.

Three 'traffic efficiency improvements' *scenarii* are defined according to results obtained in Section 3. Section 3 highlighted that *i)* some regions are more energy efficient than others (EE coefficients are not the same among regions, see Tables 15, 16, 17 and Figure 20) and *ii)* regions do not encounter same energy gains (EE coefficients yearly average growth rates are not the same among regions, see Table 15 and Figure 20).

According to these results, the following **three 'traffic efficiency improvements' *scenarii* are defined:**

- The '*Heterogeneous energy gains*' traffic efficiency improvements scenario:

  This scenario aims at reflecting the heterogeneity of energy gains observed among regions during the past (see Table 15, last columns). **Globally, this scenario defines region's future energy gains as corresponding to their energy gains recorded in the second sub-period**

1996-2006.

Hence, this scenario assumes that EE coefficients of the ‘Central and North America’, the ‘Europe’, the ‘Russia and CIS’, the ‘Asian countries and Oceania’ and the ‘China’ regions will decrease at a yearly mean growth rate of respectively 3.18%, 1.20%, 5.79%, 1.54% and 1.65% until 2025. According to Table 15 (fifth column), these figures correspond to energy gains recorded in these regions during the second sub-period 1996-2006 (see also Section 3 for more details).

The yearly mean growth rate of the ‘Latin America’ region during the second sub-period 1996-2006 is positive and equal to 1.18%. Because a positive EE coefficient growth rate means energy losses[52], we chose not to apply this figure to the ‘Latin America’ region. Instead, we chose to suppose that the EE coefficient of the ‘Latin America’ region will decrease at a yearly mean growth rate of 1.63% until 2025. The latter figure corresponds to energy gains recorded in this region during the whole period 1983-2006 (see Table 15, sixth column).

Finally, EE coefficients of the ‘Africa’ and the ‘Middle East’ regions are supposed to decrease at a yearly mean growth rate of 4.2% until 2025. Contrary to other regions, this figure does not correspond to energy gains recorded in these regions during the second sub-period 1996-2006 (which are respectively equal to -7.22% and -8.68% per year; see Table 15, fifth column). The latter figures are effectively judged as being too high to be used as an energy gain hypothesis until 2025. -4.20% is the international travels EE coefficient yearly mean growth rate of the ‘Middle East’ region during the whole period 1983-2006 (see Table 15, sixth column). Except for the second sub-period 1996-2006, -4.20% corresponds to the highest energy gains recorded in the ‘Africa’ and the ‘Middle East’ regions.

- The ‘*Homogeneous energy gains*’ traffic efficiency improvements scenario:

This alternative scenario is drawn to conduct sensitive analysis. It **aims at testing the interest of having defined heterogeneous energy gains among the eight geographical regions** such as defined in the ‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario.

This scenario assumes homogeneous energy gains among regions. More precisely, it assumes that each region’s EE coefficient will decrease at a yearly mean growth rate of 2.61% until 2025.

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[52] A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.

According to Table 15 (fifth column), this figure corresponds to energy gains recorded at the world level during the second sub-period 1996-2006.

- The '*Green energy gains*' traffic efficiency improvements scenario:

  Finally, a third scenario is defined in which regions' energy gains improvements are supposed to be widely important. This scenario defines effectively region's future energy gains as being equal to their highest energy gains improvements recorded during either the first sub-period 1983-1996, or the second sub-period 1996-2006, or the whole period 1983-2006.

  Hence, this scenario assumes that EE coefficients of the 'Central and North America', the 'Europe', the 'Latin America', the 'Russia and CIS', the 'Africa', the 'Middle East', the 'Asian countries and Oceania' and the 'China' regions will decrease at a yearly mean growth rate of respectively 3.18%, 2.97%, 2.73%, 5.79%, 7.22%, 8.68%, 2.88% and 1.65% until 2025.

The methodology used in this report to convert air traffic forecasts into Jet-Fuel projections has been precisely detailed.
Converting first RTK forecasts into corresponding ATK forecasts and second ATK forecasts into Jet-Fuel demand projections, allows to disentangle the effect of both load factor and energy efficiency improvements on mitigating the rise of Jet-Fuel demand[53].
Moreover, this section defined one load factor improvements (strong) hypothesis and three 'traffic efficiency improvements' *scenarii*. Combined with 'air traffic forecasts' *scenarii*, it allows us to obtain various Jet-Fuel demand projections. Next section presents these results.

4.2.2 *Jet-Fuel demand previsions: results*

This section presents Jet-Fuel demand previsions both at the world level and at the regional ones. Previous sections have presented *i)* three air traffic forecasts *scenarii* (presented in Section 4.1.2.2) and *ii)* three traffic efficiency improvements *scenarii* (presented in Section 4.2.1). Combining these *scenarii* allows us to generate **nine 'Jet-Fuel demand projection' *scenarii***. As summarized in **Figure 27**, these nine *scenarii* are synthesized in **Tables going from 20 to 28.**

Instead of commenting in great details each of these nine Jet-Fuel demand projections *scenarii*, it appears more attractive first to focus our analysis on the most likely Jet-Fuel demand projections scenario (thereafter called the '*Business As Usual*' Jet-Fuel demand projection scenario, see below)

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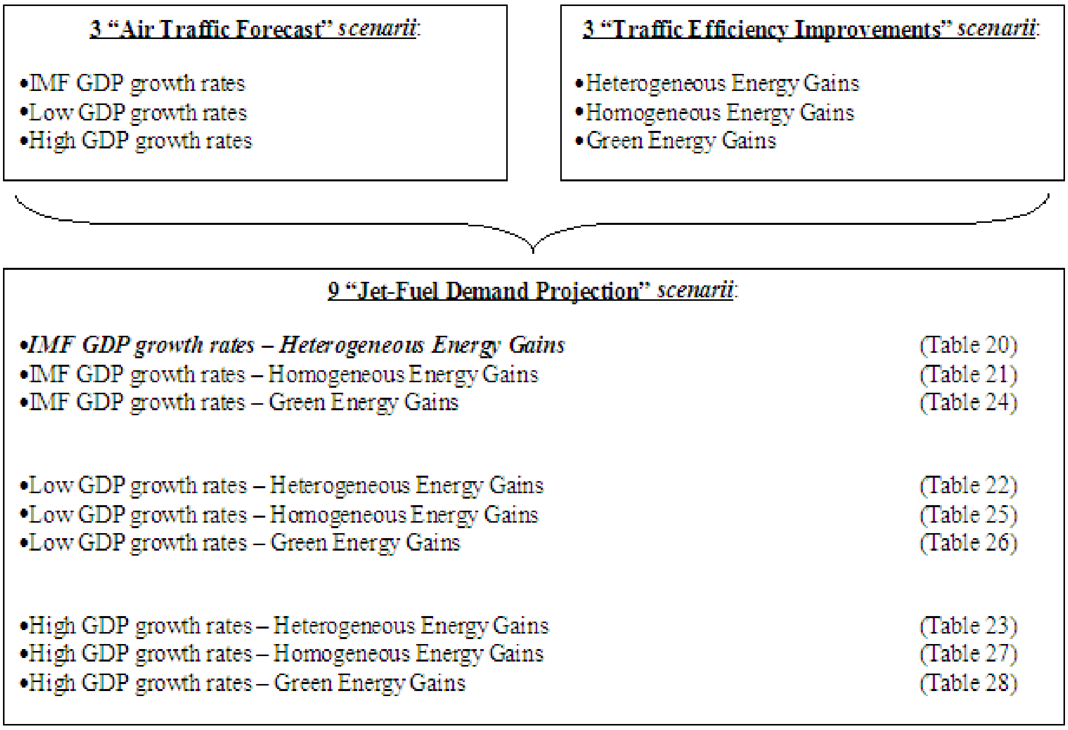
[53] See also Section 3 for more details.



3 "Air Traffic Forecast" ***scenarii*:**

- IMF GDP growth rates
- Low GDP growth rates
- High GDP growth rates

3 "Traffic Efficiency Improvements" ***scenarii*:**

- Heterogeneous Energy Gains
- Homogeneous Energy Gains
- Green Energy Gains

9 "Jet-Fuel Demand Projection" ***scenarii*:**

- ***IMF GDP growth rates – Heterogeneous Energy Gains*** (Table 20)
- IMF GDP growth rates – Homogeneous Energy Gains (Table 21)
- IMF GDP growth rates – Green Energy Gains (Table 24)

- Low GDP growth rates – Heterogeneous Energy Gains (Table 22)
- Low GDP growth rates – Homogeneous Energy Gains (Table 25)
- Low GDP growth rates – Green Energy Gains (Table 26)

- High GDP growth rates – Heterogeneous Energy Gains (Table 23)
- High GDP growth rates – Homogeneous Energy Gains (Table 27)
- High GDP growth rates – Green Energy Gains (Table 28)

Figure 27: The nine 'Jet-Fuel Demand Projection' *scenarii*.

and second to lead a sensitive analysis of this scenario by using some of others Jet-Fuel demand projection *scenarii* results.

4.2.2.1 Analysis of the '*Business As Usual*' Jet-Fuel demand projection scenario

Combining the '*IMF GDP growth rates*' air traffic forecasts scenario with the '*Heterogeneous energy gains*' traffic efficiency improvements scenario yields to our '*Business As Usual*' Jet-Fuel demand projection scenario. Results of this scenario are summarized in Table 20. As explained in the notes of this Table, the first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column). The other three columns concern Jet-Fuel projections.

Air traffic forecasts and Jet-Fuel demand projections first are analyzed at the world level. Second, results for each of the eight geographical regions are detailed.

Analysis at the worldwide level

According to Table 20 (first column, two last lines), world air traffic (expressed in RTK (10^9)) will, overall, increase at a yearly mean growth rate of **4.7%**, rising from 637.4 to 1391.8 RTK (10^9) between 2008 and 2025. Air transport sector should then remain one of the fast growing sector in the

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet Fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-3.18%)	246.2	405.9 (3.0%)	403.9	627.5 (2.6%)	86.96 37.9%	77.98 24.6%	-10%	-0.6%
Europe (-1.20%)	163.5	310.0 (3.9%)	235.2	413.1 (3.5%)	51.61 22.5%	73.83 23.3%	43%	2.2%
Latin America (-1.63%)	28.5	64.7 (5.0%)	47.1	89.3 (3.9%)	17.42 7.6%	24.97 7.9%	43%	2.2%
Russia and CIS (-5.79%)	9.6	21.1 (4.9%)	15.4	28.1 (3.8%)	9.03 3.9%	6.00 1.9%	-34%	-2.2%
Africa (-4.20%)	9.9	30.0 (6.7%)	17.3	47.6 (6.2%)	7.73 3.4%	10.27 3.2%	33%	1.7%
The Middle East (-4.20%)	24.1	48.7 (4.5%)	39.9	74.3 (4.0%)	7.91 3.5%	7.11 2.2%	-10%	-0.3%
Asian countries and Oceania (-1.54%)	98.6	296.4 (6.9%)	158.2	465.2 (6.8%)	33.62 14.7%	75.92 24.0%	126%	5.2%
China (-1.65%)	56.9	215.0 (8.2%)	82.8	296.7 (7.9%)	15.10 6.6%	40.77 12.9%	170%	6.1%
World (-2.22%)*	637.4	1391.8 (4.7%)	999.8	2041.9 (4.3%)	229.37 100%	316.87 100%	38%	1.9%

‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft’s available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region’s name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region’s Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.
* This figure corresponds to the world level energy gains (per year until 2025) resulting from regional energy gains hypothesis as defined in the ‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario.

Table 20: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
‘*IMF GDP growth rates*’ air traffic forecasts scenario.

near future.

Corresponding ATK (10^9)[54] are projected to go from 999.8 ATK (10^9) in 2008 to 2041.9 ATK (10^9) in

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[54] As already explained, ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft’s available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details).

2025 (Table 20, second column, second to last line). This increase corresponds to a mean growth rate of about **4.3%** per year (Table 20, second column, last line, figure into brackets). Hence, **using more aircraft capacities will curb world air traffic growth rates by about 8.5%** [55].

The third column (Table 20) presents 2008 and 2025 Jet-Fuel projections expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from air traffic forecasts *expressed in ATK* (Table 20, second column) using *i)* Energy Efficiency (EE) coefficients[56] and *ii)* regional energy gains hypothesis as defined in the 'Heterogeneous energy gains' traffic efficiency improvements scenario. Energy gains hypothesis corresponding to this scenario are indicated into brackets under each geographical region's name. Each figure corresponds to the EE coefficient yearly mean growth rate hypothesis of the region under consideration. As already explained, a negative sign means an energy efficiency improvement hypothesis[57].
These regional energy gains hypothesis yield, **at the world level**, to **energy gains of about 2.2% per year until 2025** (Table 20, figure into brackets under the 'World' region). **World Jet-Fuel demand is projected to grow by about 38% between 2008 and 2025** (Table 20, fourth column, last line), **rising from 229.37 Ton (**10^3**) in 2008 to 316.87 Ton (**10^3**) in 2025** (Table 20, third column, second to last lines) **at a mean growth rate of about 1.9% per year** (Table 20, last column, last line).

Analysis at the regional levels

We turn now to the analysis of air traffic and Jet-Fuel demand projections at the regional level. **Results show a wide heterogeneity among regions.**

Regarding air traffic forecasts, **RTK growth rates range from 3% per year for Central and North America to 8.2% per year for China** (Table 20, first column, figures into brackets). Regions having the highest degree of air transport market maturity (Central and North America and Europe) are also those recording the lowest air traffic growth rates. These results confirm the sensibility of air traffic drivers to the region's aviation sector maturity. Note that the two highest yearly mean growth rates are expected to arise in the two Asians regions[58], confirming the important growth perspectives of the aviation sector in Asia.

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[55] According to load factor improvement hypothesis defined in Section 4.2.1.

[56] Energy Efficiency (EE) coefficients are presented in Section 3. See also, Appendix, Table 15.

[57] Indeed, $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.

[58] Air traffic (expressed in RTK) mean growth rates of China and Asian countries & Oceania are equal to 8.2% per year and 6.9% per year, respectively.

Air traffic is expected to rise whatever the region under consideration. This is not the case anymore when analyzing Jet-Fuel demand projections.

Indeed, **three of the eight regions are expected to encounter a decrease of their Jet-Fuel demand between 2008 and 2025.** These regions are Central and North America, Russia & CIS and The Middle East where Jet-Fuel demand is expected to decrease by, respectively, 10% (going from 86.96 Ton (10^3) to 77.98 Ton (10^3)), 34% (going from 9.03 Ton (10^3) to 6 Ton (10^3)) and 10% (going from 7.91 Ton (10^3) to 7.11 Ton (10^3)) between 2008 and 2025 (Table 20, third and fourth columns).

As in the case of air traffic, the two fastest Jet-Fuel demand growing regions are China and Asian countries & Oceania. The former Jet-Fuel demand is expected to grow by about 170 % whereas the latter Jet-Fuel demand will increase by 126 % between 2008 and 2025 (Table 20, third and fourth columns).

Some regions' Jet-Fuel demands are expected to decrease whereas some others are projected to increase. These opposite developments have **important consequences on the evolution of each region's weight in total Jet-Fuel consumption between 2008 and 2025.** In the third column of Table 20, figures expressed in % terms indicate the share of each region's Jet-Fuel consumption in 2008 and 2025[59]. According to these figures, the Jet-Fuel consumption share of Europe, Latin America and Africa should remain relatively stable between 2008 and to 2025 with a share, respectively, equals to 23.3%, 7.9%, and 3.2%. Three regions are expected to record a decrease of their Jet-Fuel's share during the period: Central and North America (going from 37.9% to 24.6%), Russia & CIS (going from 3.9% to 1.9%) and the Middle East (going from 3.5% to 2.2%). The most notable decrease is, of course the Central and North America decrease, corresponding to a fall of more than 35%. On the contrary, the weight of China and Asian countries & Oceania should increase, going from 6.6% to 12.9% and from 14.7% to 24.0%, respectively. Overall, the Asian region's share (Asian countries & Oceania + China), is expected to go from 21.3% in 2008 to about 37% in 2025, and thus to surpass the 'Central and North America' region for the first time ever.

Figure 28 illustrates these comments by proposing an alternative view of the share of each region's Jet-Fuel consumption in 2008 and 2025.

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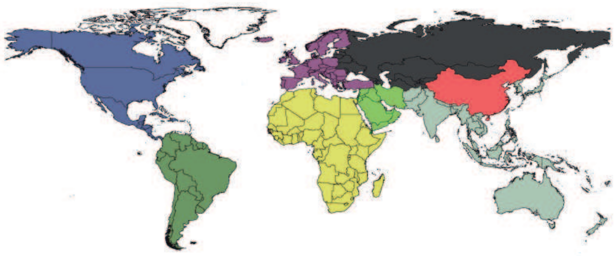
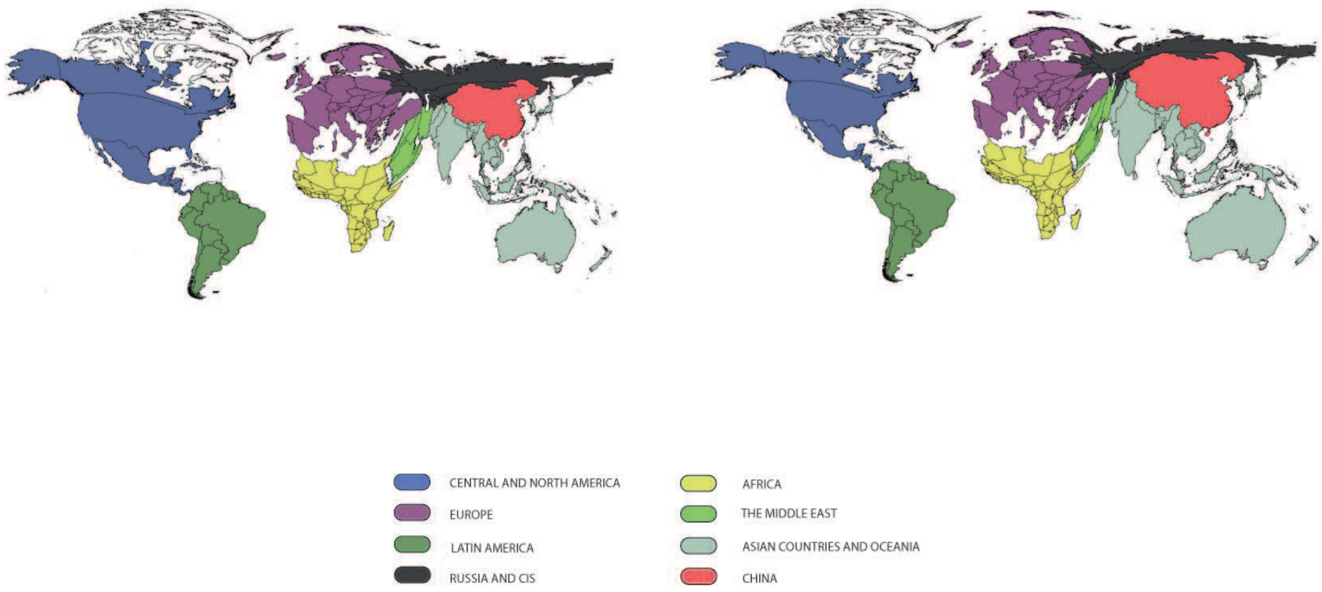
[59] For instance, in 2008, the 'Central and North America' region's Jet-Fuel consumption corresponds to 37.9% of the world Jet-Fuel consumption (Table 20, third column, second line).

Regular World Map



2008

2025 ’*Business as usual*’ scenario



Note: These cartograms size the zones according to their relative weight in world Jet-Fuel consumption (expressed in Ton (10^3)), offering an alternative world view to a regular map.

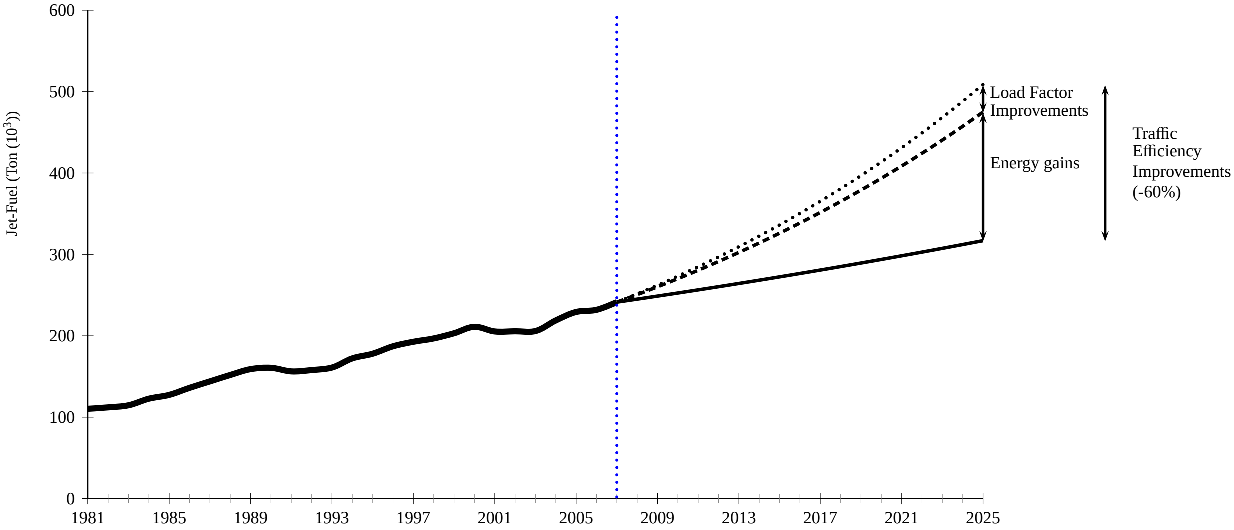
Figure 28: An alternative view of the share of each region’s Jet-Fuel consumption in 2008 and 2025 (expressed in Ton (10^3)).(Maps generated using ScapeToad)

4.2.2.2 Traffic efficiency improvements yield to reduce the effect of air traffic rise on the Jet-Fuel demand increase

It has been already explained how the rise of jet-Fuel demand resulting from air traffic demand rise can be mitigated by traffic efficiency improvements.

The comparison of yearly mean growth rates of both world air traffic expressed in RTK, + 4.7% per year until 2025, and world Jet-Fuel consumption, + 1.9% per year until 2025 (see Table 20, first and third columns, last line), effectively highlights the role played by traffic efficiency improvements on reducing the effect of air traffic rise on the Jet-Fuel demand increase.
According to our ‘Heterogeneous energy gains’ traffic efficiency improvements scenario, **Jet-Fuel demand projections are hence mitigated by about 60% thanks to traffic efficiency improvements.**

Figure 29 illustrates this argument:



***‘IMF GDP growth rates’* air traffic forecasts scenario** combined with ***‘Heterogeneous energy gains’* traffic efficiency improvements scenario**.
Bold line: Jet-Fuel demand from 1981 to 2007 (IEA data).
From 2007 to 2025:
black line: Jet-Fuel demand projections with traffic efficiency improvements (+1.9% per year);
dashed line: Jet-Fuel demand projections with load factor improvements but no energy gains (+ 4.3% per year);
dotted line: Jet-Fuel demand projections with no traffic efficiency improvements (+ 4.7% per year).

Figure 29: Illustration of the evolution of world Jet-Fuel demand forecasts (Ton (10^3)) with and without traffic efficiency improvements.

Moreover, converting first RTK forecasts into corresponding ATK forecasts and second ATK forecasts into Jet-Fuel demand projections allows us to disentangle the effect of both load factor and energy efficiency improvements on mitigating the rise of Jet-Fuel demand.

Indeed, by comparing yearly mean growth rates of world air traffic expressed in both RTK (+ 4.7% per year until 2025) and corresponding ATK (+ 4.3% per year until 2025), it has been already highlighted that load factor improvements should be able to curb world air traffic yearly mean growth rates by about 8.5%. It comes then that load factor improvements and energy gains correspond to, respectively, about 14% and 86% of traffic efficiency improvements[60].

4.2.2.3 Sensitive Analysis

Results of the '*Business As Usual*' Jet-Fuel demand projection scenario have just been analyzed in great details. Recall that these results have been obtained by combining the '*IMF GDP growth rates*' air traffic forecasts scenario with the '*Heterogeneous energy gains*' traffic efficiency improvements scenario. It is important to assess how sensitive are our results to these *scenarii*.

To do so, this section investigates two other Jet-Fuel demand projection *scenarii*.

The first one combines the '*IMF GDP growth rates*' air traffic forecasts scenario with the '*Homogeneous energy gains*' traffic efficiency improvements scenario. The second one combines the '*Low GDP growt rates*' air traffic forecasts scenario with the '*Heterogeneous energy gains*' traffic efficiency improvements scenario.

Results of these two alternative Jet-Fuel demand projections *scenarii* are briefly commented below.

Traffic efficiency heterogeneity among regions has to be taken into account

According to the '*Business As Usual*' Jet-Fuel demand projection scenario analyzed in the previous sections (and summarized in Table 20), Latin America and Russi & CIS are projected to record the same yearly mean growth rate of air traffic (about 5% per year, see Table 20, first column). When regarding their projected Jet-Fuel demand however, Latin America is expected to record a rise of 43% whereas the Jet-Fuel demand of the 'Russia and CIS' region should decrease by about 34%. These opposite results are explained by regional traffic efficiency improvements hypothesis: Latin America is expected to be less energy efficient than the 'Russia and CIS' region from 2008 to 2025[61]. This result highlights the importance of taking into account Traffic efficiency heterogeneity among regions.

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[60] This repartition holds as long as traffic efficiency improvements hypothesis are defined such as in the '*Heterogeneous energy gains*' traffic efficiency improvements scenario.

[61] Indeed, the yearly mean growth rate of EE coefficients is supposed to be equal to -1.63% per year in Latin America and to -5.79% per year in Russia and CIS.

To illustrate more in depth this statement, it has been chosen to combine the '*IMF GDP growth rates*' air traffic forecasts scenario with the '*Homogeneous energy gains*' traffic efficiency improvements scenario. Compared to the '*Business As Usual*' Jet-Fuel demand projection scenario, only the traffic efficiency improvements hypothesis have been shifted. Recall that the '*Homogeneous energy gains*' traffic efficiency improvements scenario assumes homogeneous energy gains among regions. More precisely, it assumes that each region's EE coefficient will decrease at a yearly mean growth rate of 2.61% until 2025. According to Table 15 (fifth column), this figure corresponds to energy gains recorded at the world level during the second sub-period 1996-2006.

This second Jet-Fuel demand projection scenario aims at testing the interest of having defined heterogeneous energy gains among the eight geographical regions such as defined in the '*Heterogeneous energy gains*' traffic efficiency improvements scenario (and thus the '*Business As Usual*' Jet-Fuel demand projection scenario). Indeed, if the analysis of EE coefficients had not been conducted at the regional level but only at the world level, the '*Homogeneous energy gains*' traffic efficiency improvements scenario would have been our reference scenario for the evolution of traffic efficiency improvements.

Table 21 shows the results. Results are just briefly commented.
At the regional level, all regions are now expected to record a rise of Jet-Fuel demand between 2008 and 2025 (Table 21, fourth column).
However, the homogeneous traffic efficiency hypothesis among regions yields to 'over-estimate' the role played by traffic efficiency improvements on mitigating the world Jet-Fuel demand increase. Indeed, world Jet-Fuel demand is now expected to grow by about 29% between 2008 and 2025 (Table 21, fourth column, last line), rising from 228.71 Ton (10^3) in 2008 to 294.59 Ton (10^3) in 2025 (Table 21, third column, second to last lines) at a mean growth rate of about 1.5% per year (Table 21, last column, last line).

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-2.61%)	246.2	405.9 (3.0%)	403.9	627.5 (2.6%)	87.98 38.5%	87.18 29.6%	-1%	-0.1%
Europe (-2.61%)	163.5	310.0 (3.9%)	235.2	413.1 (3.5%)	50.15 21.9%	56.19 19.1%	12%	0.8%
Latin America (-2.61%)	28.5	64.7 (5.0%)	47.1	89.3 (3.9%)	17.07 7.5%	20.65 7.0%	21%	1.2%
Russia and CIS (-2.61%)	9.6	21.1 (4.9%)	15.4	28.1 (3.8%)	9.65 4.2%	11.28 3.8%	17%	1.1%
Africa (-2.61%)	9.9	30.0 (6.7%)	17.3	47.6 (6.2%)	7.98 3.5%	14.04 4.8%	76%	3.4%
The Middle East (-2.61%)	24.1	48.7 (4.5%)	39.9	74.3 (4.0%)	8.18 3.6%	9.72 3.3%	19%	1.3%
Asian countries and Oceania (-2.61%)	98.6	296.4 6.9%	158.2	465.2 6.8%	32.89 14.4%	61.69 20.9%	88%	4.0%
China (-2.61%)	56.9	215.0 (8.2%)	82.8	296.7 (7.9%)	14.80 6.5%	33.84 11.5%	129%	5.1%
World (-2.61%)	637.4	1391.8 (4.7%)	999.8	2041.9 (4.3%)	228.71 100%	294.59 100%	29%	1.5%

'*Homogeneous energy gains*' traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region's name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region's Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.

Table 21: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
***'IMF GDP growth rates'* air traffic forecasts scenario**.

Analyzing the sensitivity of Jet-Fuel demand projections to the rise of air traffic

Tables 22 and 23 summarize the following two Jet-Fuel demand projections *scenarii*.
The first one combines the '*Low GDP growth rates*' air traffic forecasts scenario with the '*Heterogeneous energy gains*' traffic efficiency improvements scenario (Table 22).
The second one combines the '*High GDP growth rates*' air traffic forecasts scenario with the '*Heterogeneous energy gains*' traffic efficiency improvements scenario (Table 23).

Compared with the '*Business As Usual*' Jet-Fuel demand projection scenario, traffic efficiency improvements hypothesis remain the same. On the other hand, GDP growth rates previsions hypothesis are now different[62]. These two alternative Jet-Fuel demand projections *scenarii* are then compared with the '*Business As Usual*' Jet-Fuel demand projection scenario in order to analyze the sensitivity of Jet-Fuel demand projections to the rise of air traffic. Comments are focus at the world level.

As already developed in Section 4.1.2.2, the '*IMF GDP growth rates*' air traffic forecasts scenario yields to an increase of world air traffic projections (expressed in RTK (10^9)) at a yearly mean growth rate of 4.7%, rising from 637.4 to 1391.8 between 2008 and 2025 (Table 20, first column, two last lines). By comparison, the '*Low GDP growth rates*' and '*High GDP growth rates*' air traffic *scenarii* predict a yearly mean growth rate of world air traffic – expressed in RTK – of 4.2% (Table 22, first column, last line, figure into bracket) and 5.3% (Table 23, first column, last line, figure into bracket), respectively.
Regarding Jet-Fuel demand projections, the '*Business As Usual*' Jet-Fuel demand projection scenario predicts a yearly mean growth rate of 1.9% per year until 2025 (Table 20, last column, last line) at the world level. By comparison, Tables 22 and 23 predict a yearly mean growth rate of world Jet-Fuel demand of 1.4% and 2.5%, respectively (last column, last line).

Thus, a decrease (an increase) by 10% of regions' GDP growth rates previsions yields to a decrease (an increase) of the world air traffic yearly mean growth rate by about 10.6% (12.8%).
Variations in GDP growth rates prevision hypothesis (and thus variation of air traffic forecasts) have even a greater impact on Jet-Fuel demand projections. Indeed, by comparing the different yearly mean growth rates of world Jet-Fuel demand projections presented in Tables 20, 22 and 23, one conclude that **a decrease (an increase) by 10% of regions' GDP growth rates previsions yields to a decrease (an increase) of the world air traffic yearly mean growth rate by about 26% (32%), *ceteris paribus*. These results highlight the high sensitivity of Jet-Fuel demand projections to variations of both economic activity previsions and air traffic forecasts.**

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[62] As explained in Section 4.1.2.2, IMF GDP growth rates previsions are decreased (increased) by 10 % in the '*Low GDP growth rates*' ('*High GDP growth rates*') air traffic forecasts scenario.

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-3.18%)	246.1	391.2 (2.8%)	403.8	604.8 (2.4%)	86.92 37.9%	75.17 26.0%	-14%	-0.9%
Europe (-1.20%)	163.3	287.7 (3.5%)	235.0	383.5 (3.0%)	51.56 22.5%	68.53 23.7%	33%	1.8%
Latin America (-1.63%)	28.5	62.7 (4.8%)	47.1	86.5 (3.7%)	17.40 7.6%	24.20 8.4%	39%	2.0%
Russia and CIS (-5.79%)	9.6	19.1 (4.2%)	15.3	25.4 (3.2%)	9.01 3.9%	5.42 1.9%	-40%	-2.8%
Africa (-4.20%)	9.9	27.6 (6.2%)	17.2	43.8 (5.6%)	7.71 3.4%	9.45 3.3%	23%	1.2%
The Middle East (-4.20%)	24.0	42.3 (3.7%)	39.7	64.6 (3.2%)	7.88 3.4%	6.18 2.1%	-22%	-1.1%
Asian countries and Oceania (-1.54%)	98.3	253.8 (6.0%)	157.7	398.4 (5.8%)	33.51 14.6%	65.01 22.5%	94%	4.2%
China (-1.65%)	56.7	184.4 (7.3%)	82.5	254.5 (6.9%)	15.05 6.6%	34.97 12.1%	132%	5.2%
World (-2.22%)*	636.5	1268.9 (4.2%)	998.4	1861.5 (3.8%)	229.05 100%	288.92 100%	26%	1.4%

‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region's name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region's Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.
* This figure corresponds to the world level energy gains (per year until 2025) resulting from regional energy gains hypothesis as defined in the ‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario.

Table 22: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
‘*Low GDP growth rates*’ Air traffic forecasts scenario.

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-3.18%)	246.3	421.0 (3.2%)	404.1	650.9 (2.8%)	86.99 37.9%	80.89 23.2%	-7%	-0.4%
Europe (-1.20%)	163.7	333.7 (4.4%)	235.4	444.8 (3.9%)	51.66 22.5%	79.49 22.8%	54%	2.7%
Latin America (-1.63%)	28.6	66.8 (5.2%)	47.1	92.2 (4.1%)	17.43 7.6%	25.77 7.4%	48%	2.4%
Russia and CIS (-5.79%)	9.6	23.4 (5.5%)	15.4	31.1 (4.4%)	9.06 3.9%	6.65 1.9%	-27%	-1.6%
Africa (-4.20%)	10.0	32.7 (7.2%)	17.3	51.8 (6.7%)	7.74 3.4%	11.16 3.2%	44%	2.2%
The Middle East (-4.20%)	24.2	56.0 (5.4%)	40.1	85.4 (4.9%)	7.94 3.5%	8.17 2.3%	3%	0.5%
Asian countries and Oceania (-1.54%)	98.9	345.7 (7.9%)	158.7	542.6 (7.8%)	33.72 14.7%	88.55 25.4%	163%	6.1%
China (-1.65%)	57.1	250.3 (9.2%)	83.0	345.4 (8.8%)	15.14 6.6%	47.47 13.6%	214%	7.0%
World (-2.22%)*	638.3	1529.5 (5.3%)	1001.2	2244.2 (4.9%)	229.68 100%	348.15 100%	52%	2.5%

‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft’s available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region’s name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region’s Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.
* This figure corresponds to the world level energy gains (per year until 2025) resulting from regional energy gains hypothesis as defined in the ‘*Heterogeneous energy gains*’ traffic efficiency improvements scenario.

Table 23: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
‘High GDP growth rates’ **Air traffic forecasts scenario**.

5 Conclusion

This report examines air traffic and Jet-Fuel demand forecasts until 2025. This assessment appears central in a scarce energy resources context, as air traffic are expected to rise strongly in the near future.

Our results may be summarized as follows. First, we provide detailed descriptive statistics on air traffic, using air traffic data from the International Civil Aviation Organization during 1980-2007. This section highlights the strongly rising trends in the evolution of worldwide air traffic, along with changes in the composition of air traffic by zone. Our analysis reveals that, while the share of Europe and in the U.S. in international air traffic remained relatively stable over the period, China is becoming a major player in air transportation. Indeed, its share in total air traffic has skyrocketed, going from 4.74% in 1996 to 8.57% in 2006. This trend is expected to be even stronger. We provide also detailed descriptive statistics on domestic vs. international air traffic and freight vs. passengers' air traffic. We show that at the world level, domestic air traffic has increased at the rate of 4% per year on average, which corresponds to a less dynamic development than the aggregated (domestic+ international) air traffic (6.44%). Besides, we document that at the world level, freight traffic has increased at the rate of 9.14% per year on average, fostered by world economic and trade growth. This development is stronger than passengers' air traffic, which increased at the rate of 6.04% per year on average.

Second, we propose a new methodology in order to measure energy efficiency coefficients and energy efficiency improvements. Since Jet-Fuel is not consumed for itself but to power aircraft engines, our forecasts are not based directly on Jet-Fuel consumption, but need to be computed using a preliminary step. The methodology adopted here relies on the 'Traffic Efficiency' method developed previously by UK DTI to support the IPCC (1999) to deduce the amounts of Jet-Fuel demand projections from air traffic forecasts. The 'Traffic Efficiency' methodology allows to obtain coefficients to convert one amount of air transport into one amount of Jet-Fuel. Traffic Efficiency improvements typically depend on *i)* Load Factors improvements (aircraft are using more of their capacity) and *ii)* energy efficiency improvements. Our major contribution of this section consists in proposing a new methodology to obtain Energy Efficiency (EE) coefficients based on modeling at the macro-level. We obtain EE coefficients by directly comparing Jet-Fuel consumption and the evolution of air traffic. As straightforward as it may look like, this methodology has not been implemented before to our best knowledge.

Our macro-level methodology allows to obtain 'aggregated' EE coefficients and their growth rates from 1980 to 2006. We notice that all regions have registered energy efficiency improvements during the whole period at the aggregated (domestic+international) level. At the world level, energy efficiency improvements have been equal to 2.88% per year during the whole period. Aggregated (domestic + international) EE ratios are less than one for four regions (Central and North America, Europe, China, Asian countries and Oceania), and greater than one for the four others (Latin America, Africa, Russia and CIS, the Middle East). This result means that, for aggregated (domestic+international) travel, the former regions are in average more energy efficient during the whole period than the world's benchmark. On the contrary, the four latter regions are less energy efficient than the world's average during 1983-2006. At the world level, domestic energy efficiency appears to be lower than the international one. This comment applies in all regions: domestic energy efficiency appears to be inferior to international energy efficiency whatever the region considered. This result confirms the intuition that domestic air travels are more energy intensive than international air traffic. One of the main reasons advanced in previous literature is that domestic flights are more energy intensive due to more frequent take-off and landing. These remarks lead to the following stylized fact: even if both international and domestic air travels have encountered energy efficiency improvements from 1983 to 2006, international air travels appear to be less energy intensive than domestic air travels.

Third, we provide an econometric analysis of air traffic determinants and Jet-Fuel demand forecasts. Previous literature identified broadly three categories of air traffic drivers. The first type is represented by GDP growth rates, the second deals with ticket price, and the third concerns exogenous shocks. Regarding the first driver, world air traffic has been increasing at 6.4% on average during 1980-2006, while world's GDP growth rates with a mean value of 3.3%. Thus, the aviation sector is characterized by a dynamic growth compared to other sectors in the economy. Regarding the second driver, there exists a negative elasticity between ticket prices and air traffic: the higher ticket prices, the lower the demand for flights. Besides taxes, the two other main components of plane tickets are first wage costs and second Jet-Fuel prices. Prices variation of these two inputs influence unitary costs, and thus ticket prices fixed by airline companies. At least in the short term and for relatively modest prices variation, previous literature has shown that ticket prices have a limited impact on demand in the aviation sector. However, when ticket prices reach a given threshold (top or bottom) or when they are characterized by significant (positive or negative) variation levels, demand reacts quite rapidly (the development of "low cost" airlines illustrates this fact). Concerning the third type of drivers, the evolution of air traffic seems to over-react to exogenous shocks: slow-down in economic activity, the first Gulf-War in 1991, the Asian financial crisis, the 9/11 World Trade Center Attack, the epidemic of SARS in 2003, etc. Besides, demand in the aviation sector - and the influence of its drivers - is not the same depending on *(i)* the maturity of the market in the region considered, and *(ii)* short/medium hauls (mainly domestic air traffic) *vs.* long hauls (international traffic).

In the first step of our econometric analysis, the influence of air traffic determinants previously presented is estimated using the Arellano-Bond estimator (1991). GDP appears to have a positive influence on air traffic whereas the influence of Jet-Fuel price - above a given threshold - is negative. Exogenous shocks can also have a (negative) impact on air traffic growth rates. The magnitude of the influence of these air traffic determinants depends on region's market maturity. Thus, air traffic forecasts differ between regions. Various air traffic forecasts *scenarii* are developed. According to our '*Business As Usual*' scenario, air traffic is set to experience rapid growth until 2025. Our results suggest that the revenue ton kilometer (RTK) will grow at an average rate of 4.7 per annum between 2008 and 2025 at the worldwide level (ranging from 3% /yr (Central and North America) to 8.2 % /yr (China), at the regional level). The '*Low GDP growth rate*' air traffic forecasts scenario projects that air traffic will grow, during same period, at an average rate of 4.2% per year. The '*High GDP growth rate*' air traffic forecasts scenario indicates that air traffic will be 140 per cent above 2008 level by 2025 (i.e. 5.3%/yr).

In the second step of our econometric specification, we focus on Jet-Fuel demand projections. Because of the improvements of energy efficiency and/or load factors, Jet-Fuel demand and air traffic growths are not strictly correlated. Thus, energy efficiency and load factors improvements hypothesis have a critical impact on Jet-Fuel demand projections. According to our '*Business As Usual*' scenario, world Jet-Fuel demand is expected to increase by about 38% between 2008 and 2025 at the world level – corresponding to a yearly average growth rate of about 1,9% per year –, ranging from -10% in Central and North America to +170% in China. According to a stronger energy gains hypothesis scenario, Jet-Fuel demand is expected to grow at an average growth rate of 1.5% per year until 2025. Thus, Jet-Fuel demand is unlikely to diminish unless there is a radical shift in technology or air travel demand is restricted.

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APPENDIX

Note to the reader

Note that China starts declaring some of its air traffic data in 1993. Russia and CIS presents some inconsistency in the data until 1991. Thus, some statistics must be interpreted with great care.

List of Figures

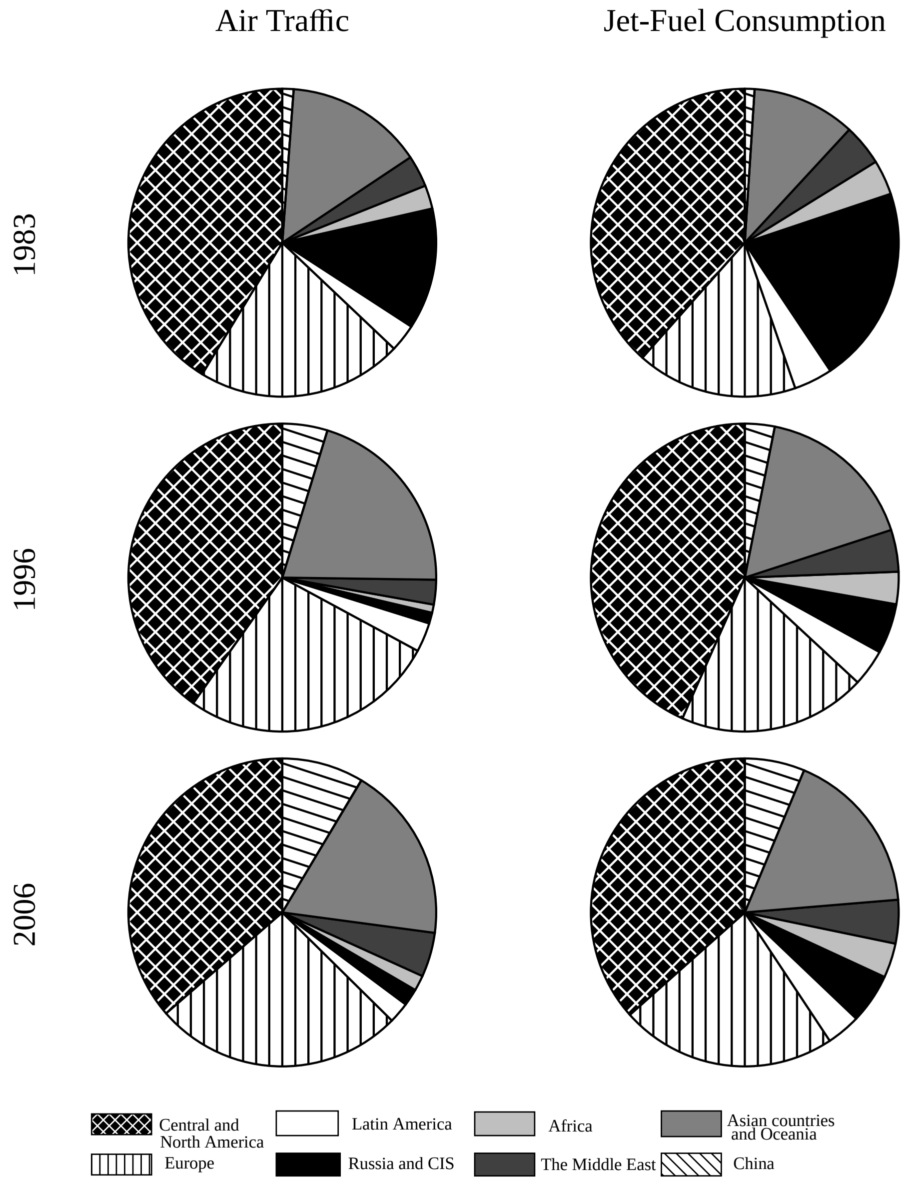
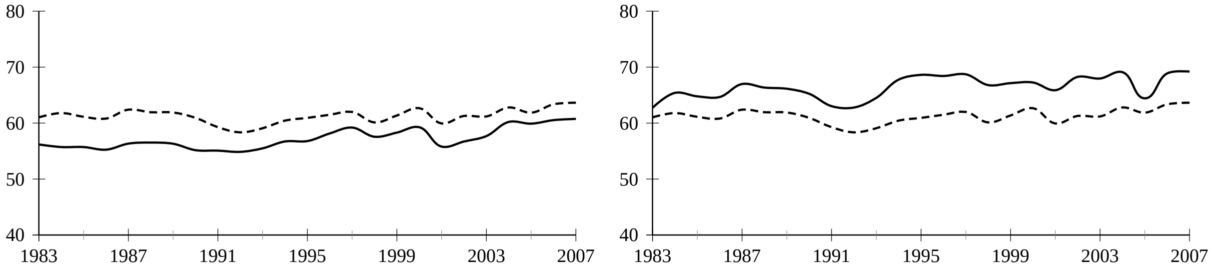
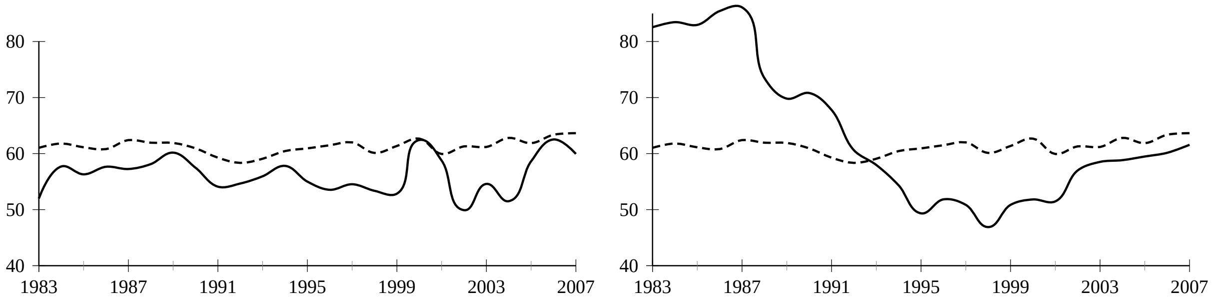


Figure 3: World Repartition by zone in 1983 (top), 1996 (middle) and 2006 (bottom) of Air Traffic (left panel, expressed in RTK) and Jet-Fuel Consumption (right panel, expressed in Mtoe). Source: Authors, from ICAO data.



Central and North America

Europe



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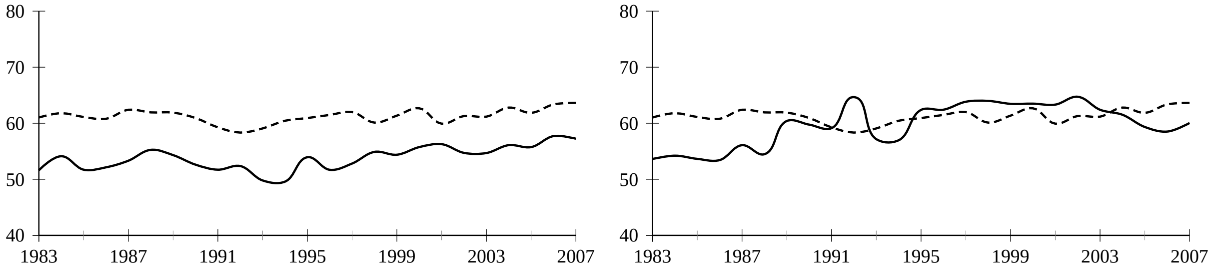
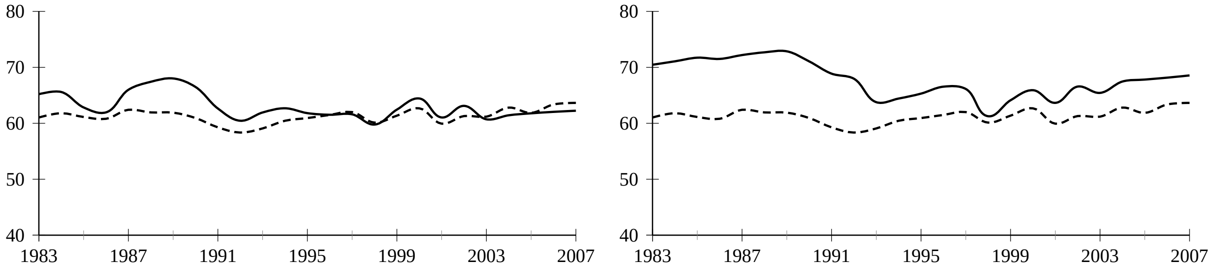
Russia and CIS



Africa

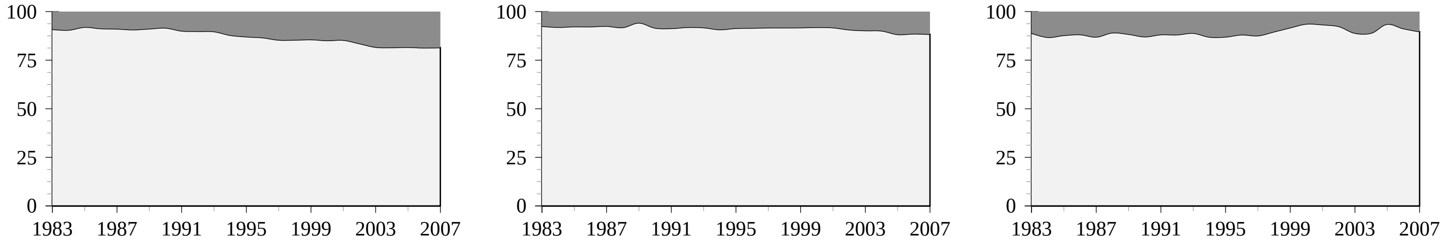
The Middle East



Asian countries and Oceania

China

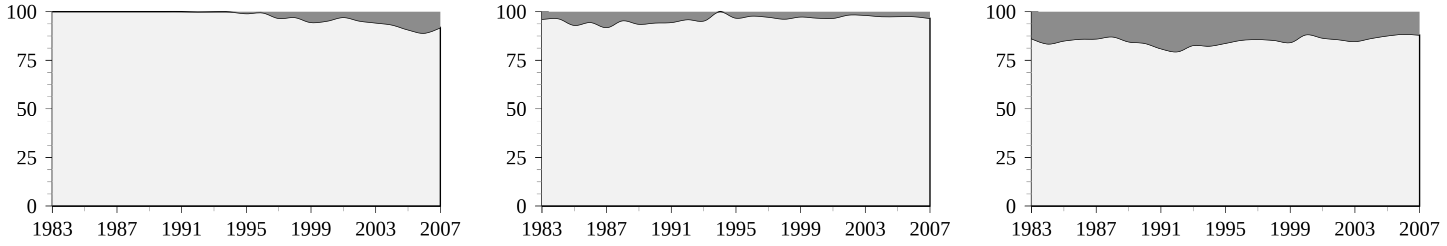
Figure 5: Evolution of each zone’s Weight Load Factors (solid line) compared to World’s Weight Load Factors (dashed line) (1980-2007). Source: Authors, from ICAO data.



Central and North America

Europe

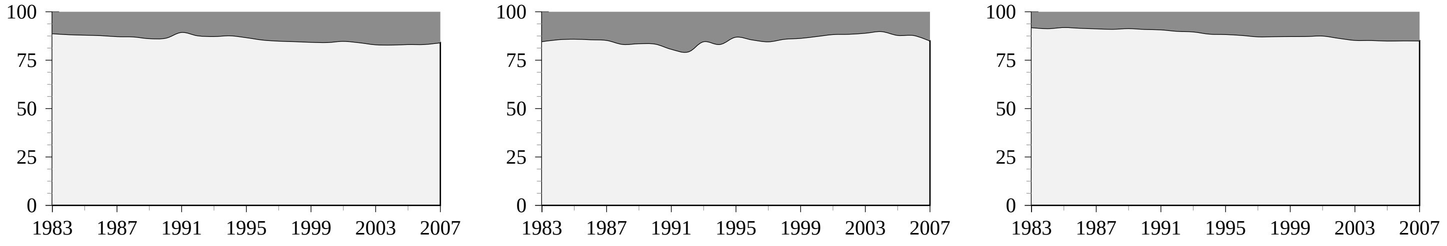
Latin America



Russia and CIS

Africa

The Middle East



Asian countries and Oceania

China

World

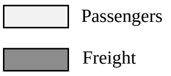
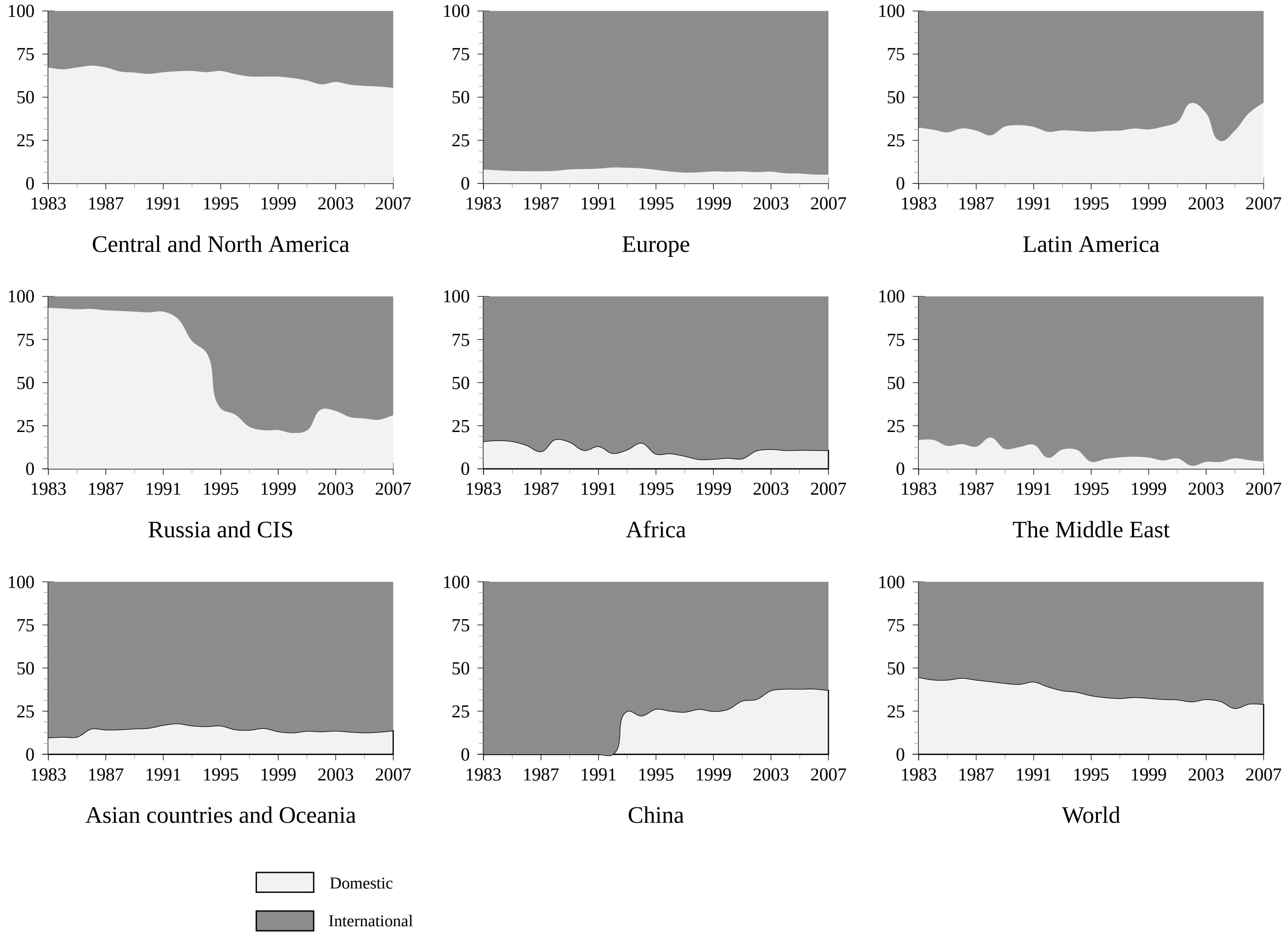


Figure 6: Evolution of the repartition of passengers' (lightgray) vs. freight (darkgray) traffic (expressed in RTK) within each zone and for the world (1983-2007). Source: Authors, from ICAO data.



Central and North America

Europe

Latin America

Russia and CIS

Africa

The Middle East

Asian countries and Oceania

China

World

Figure 7: Evolution of the repartition of domestic (lightgray) vs. international (darkgray) traffic (expressed in RTK) within each zone and for the world (1983-2007). Source: Authors, from ICAO data.

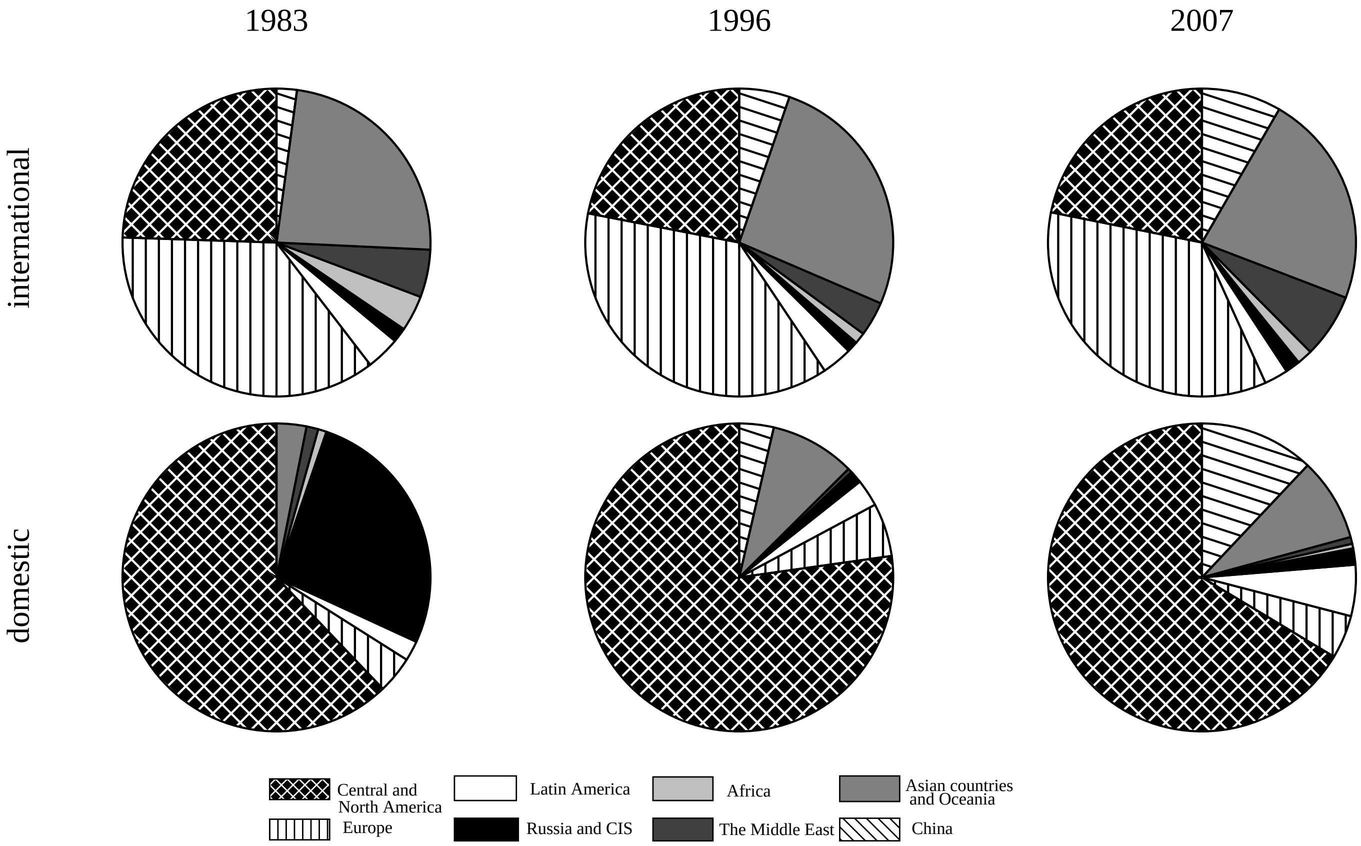
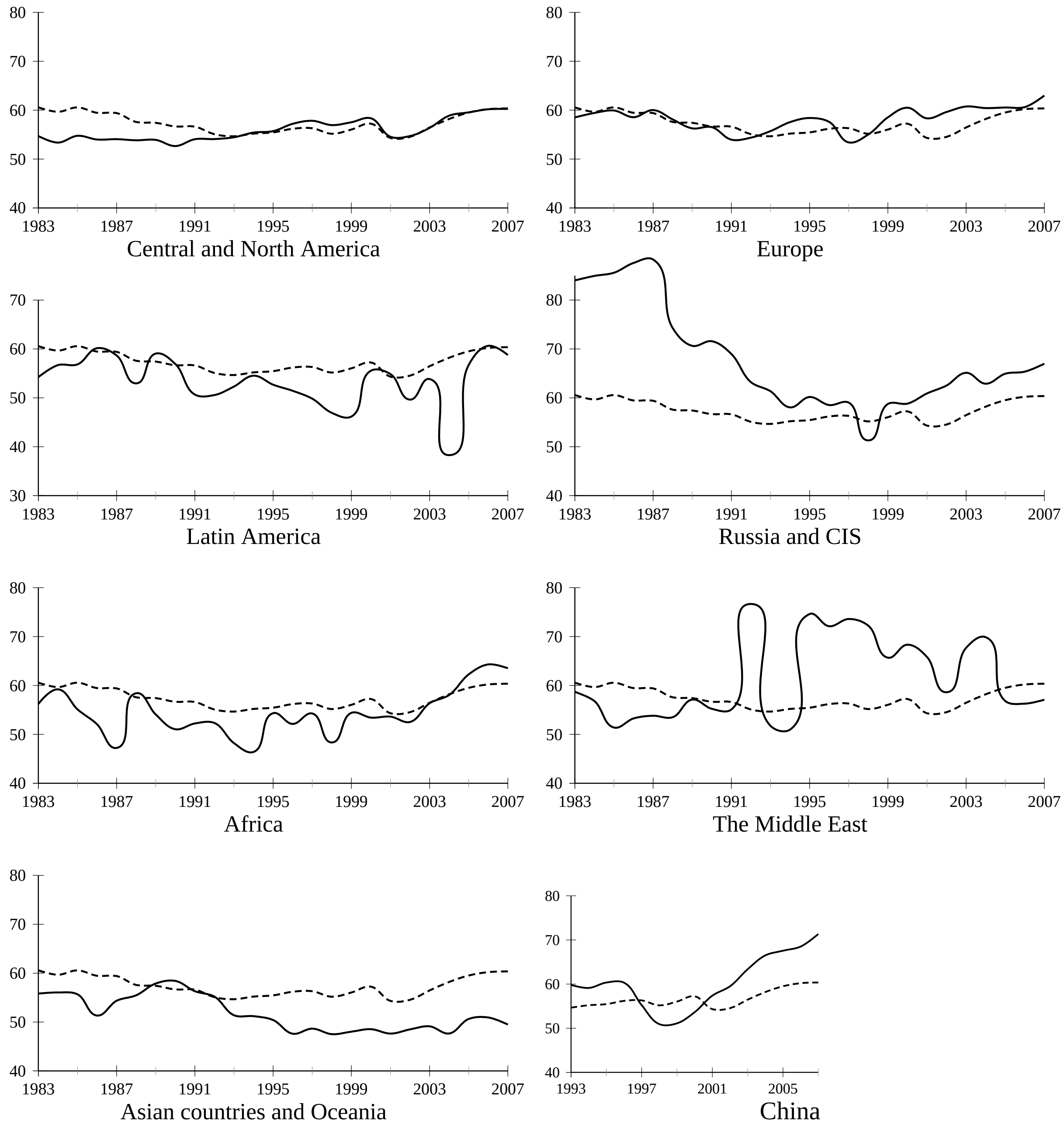


Figure 8: Repartition of international (top) and domestic (bottom) air traffic (expressed in RTK) by zone in 1983 (left panel), 1996 (middle panel) and 2007 (right panel). Source: Authors, from ICAO data.



Central and North America

Europe

Latin America

Russia and CIS

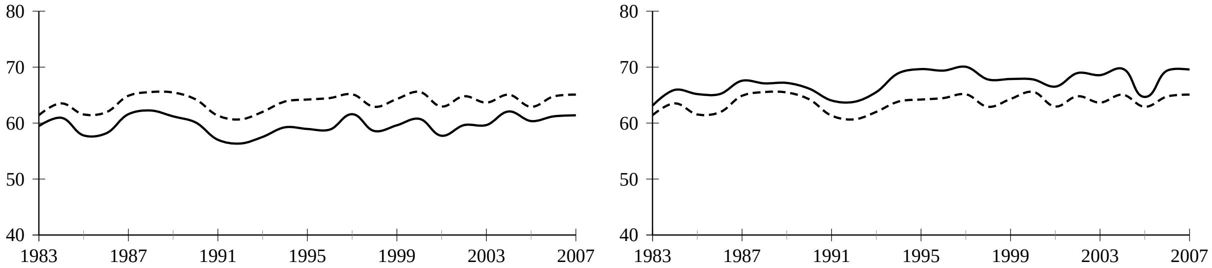
Africa

The Middle East

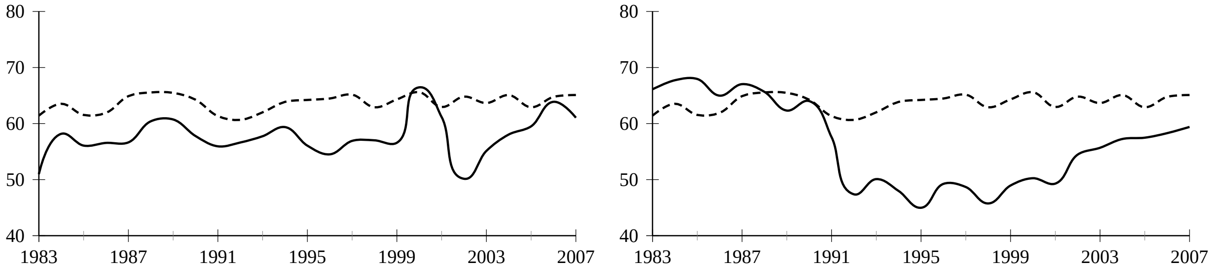
Asian countries and Oceania

China

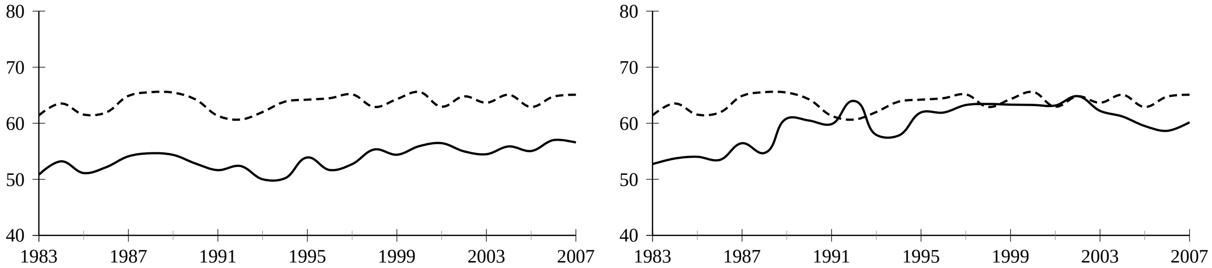
Figure 10: Evolution of each zone's domestic Weight Load Factors (solid line) compared to World's Domestic Weight Load Factors (dashed line) (1983-2007). Source: Authors, from ICAO data.



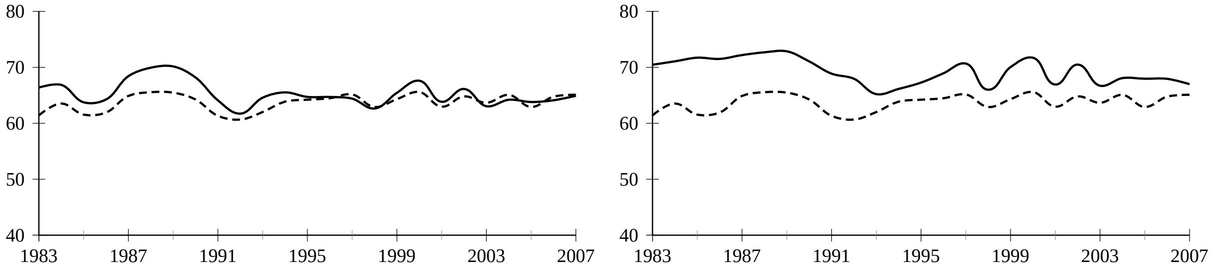
Central and North America Europe



Latin America Russia and CIS



Africa The Middle East



Asian countries and Oceania China

Figure 12: Evolution of each zone's international weight load factors (solid line) compared to world's international weight load factors (dashed line). Source: Authors, from ICAO data.

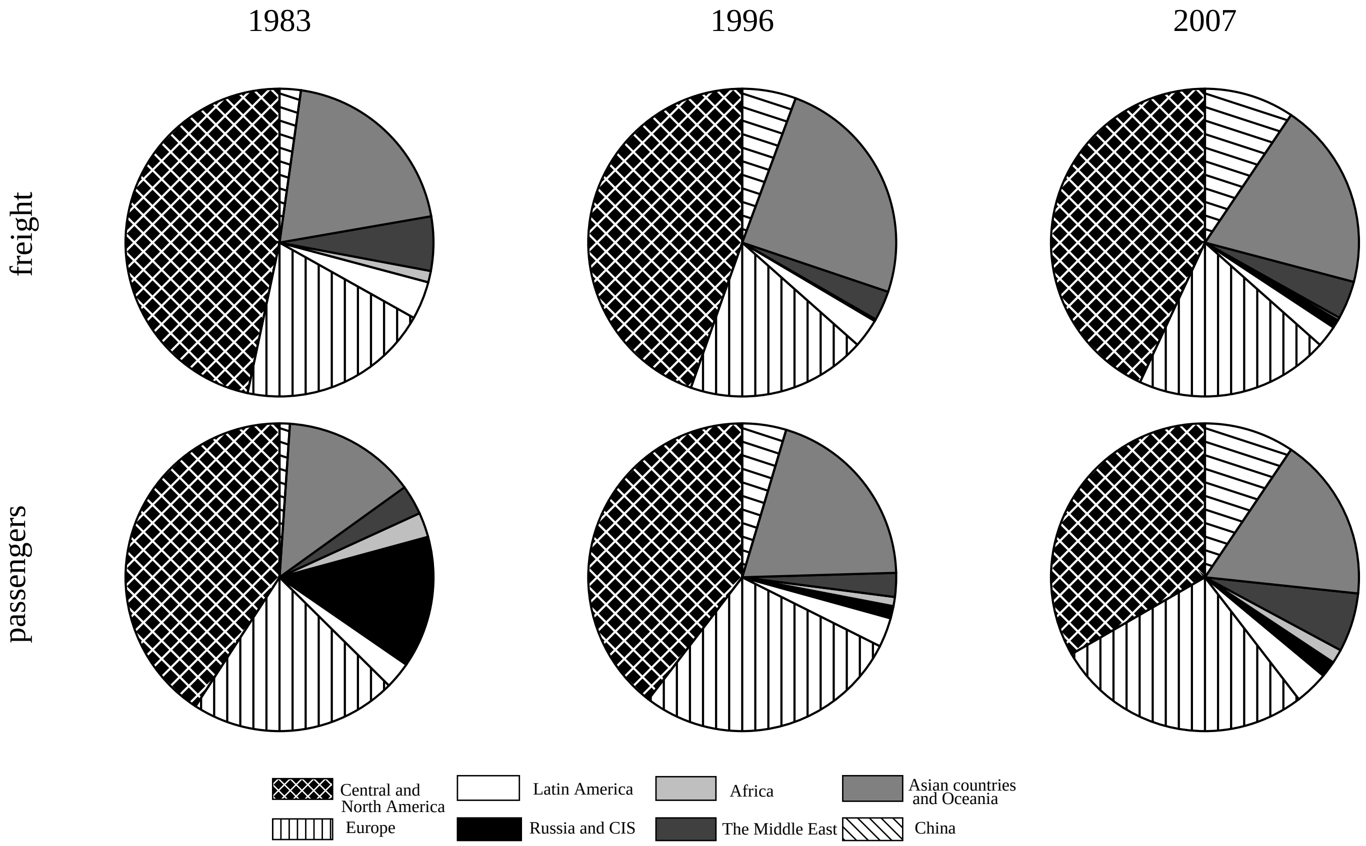


Figure 13: Repartition of freight (top) and passengers (bottom) air traffic (expressed in RTK) by zone in 1983 (left panel), 1996 (middle panel) and 2007 (right panel). Source: Authors, from ICAO data.

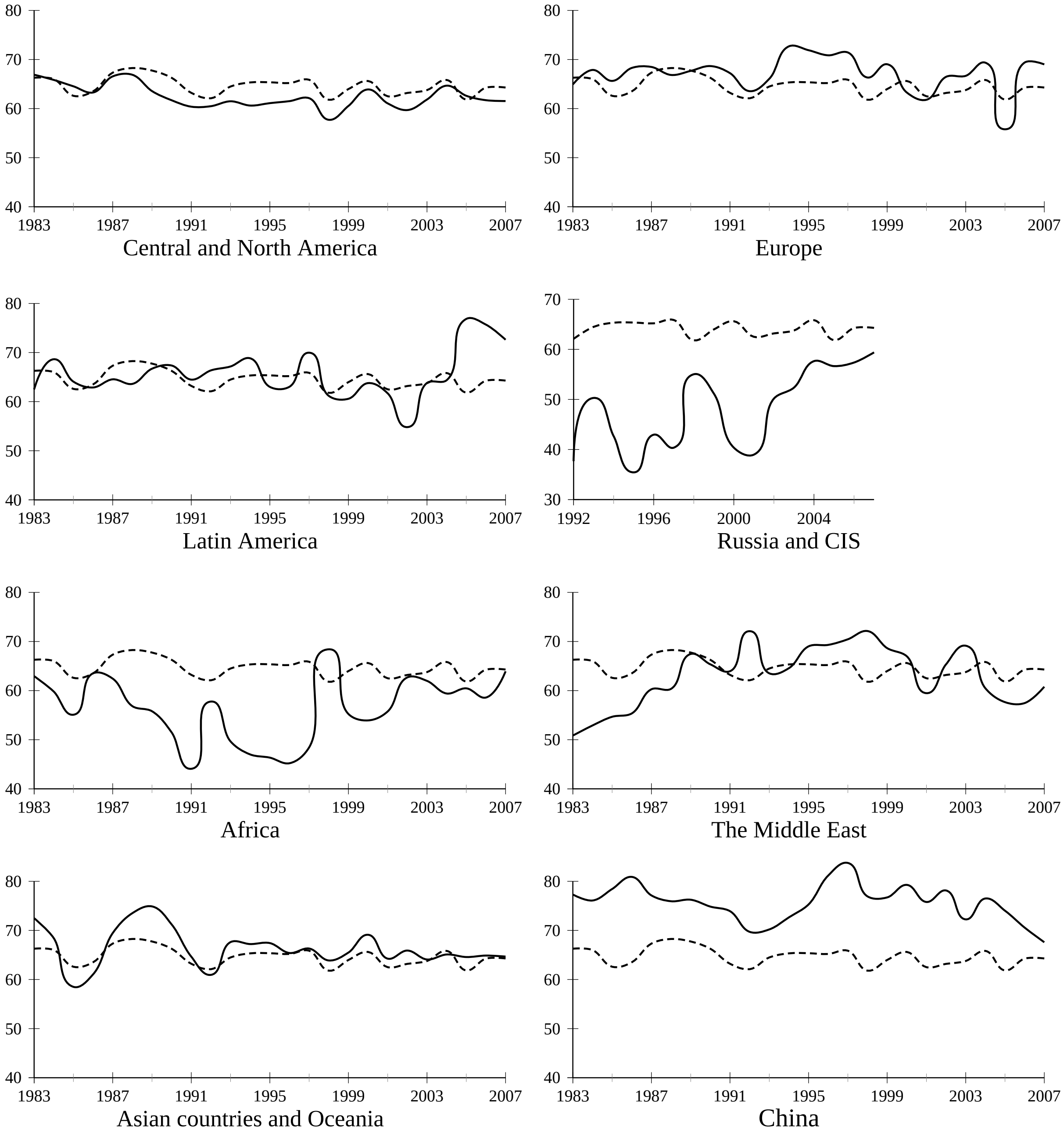
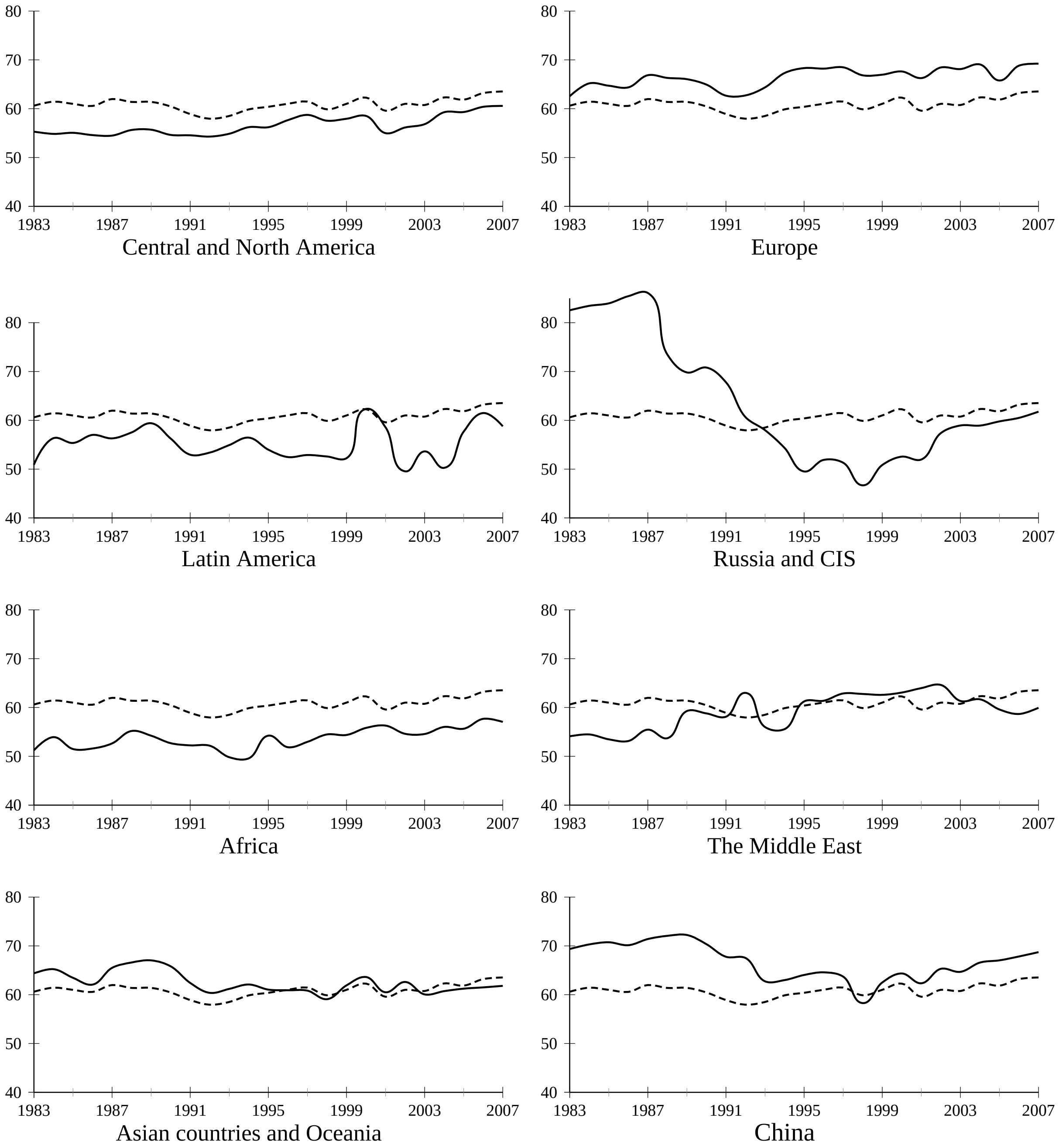

Central and North America
Europe
Latin America
Russia and CIS
Africa
The Middle East
Asian countries and Oceania
China

Figure 15: Evolution of each zone's freight Weight Load Factors (solid line) compared to World's Weight Load Factors (dashed line) (1983-2007). Source: Authors, from ICAO data.



Central and North America

Europe

Latin America

Russia and CIS

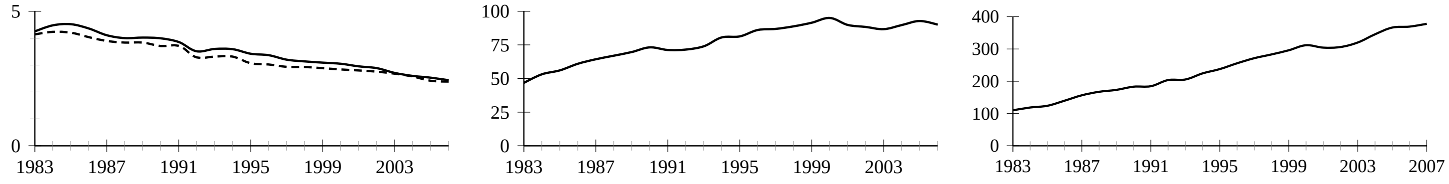
Africa

The Middle East

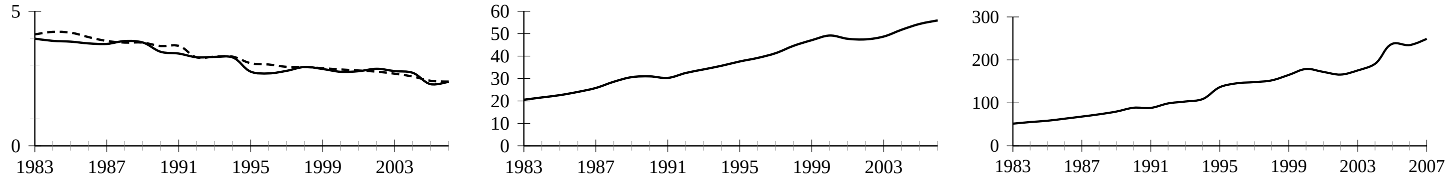
Asian countries and Oceania

China

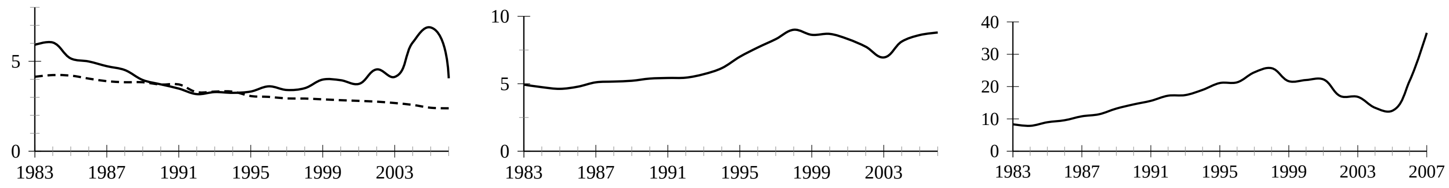
Figure 17: Evolution of each zone's passengers' weight load factors (solid line) compared to world's passengers' weight load factors (dashed line) (1983-2007). Source: Authors, from ICAO data.



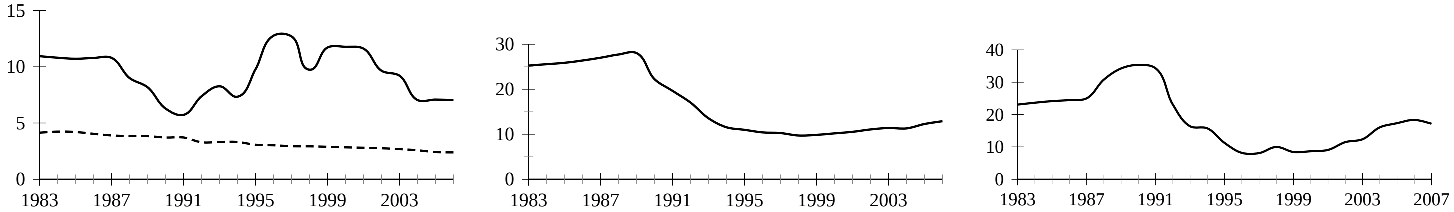
Central and North America



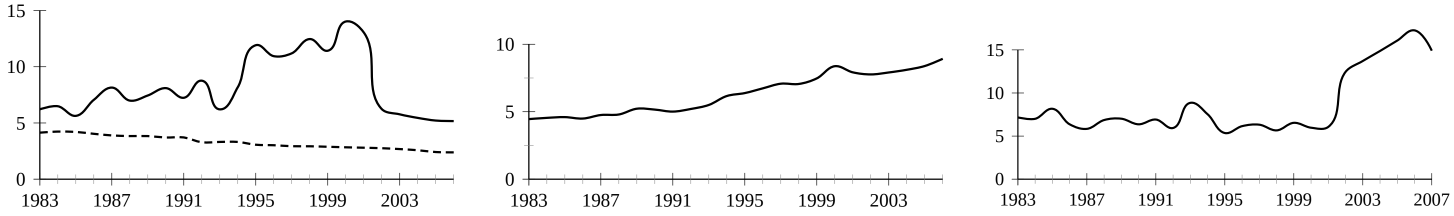
Europe



Latin America

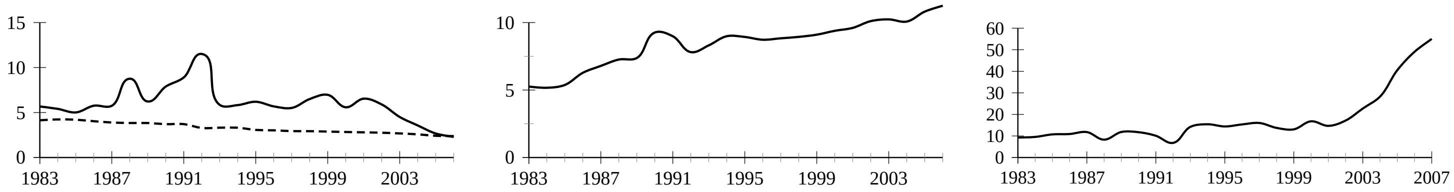


Russia and CIS

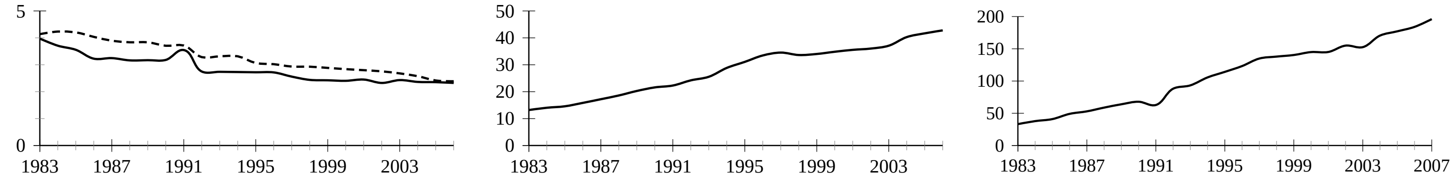


Africa

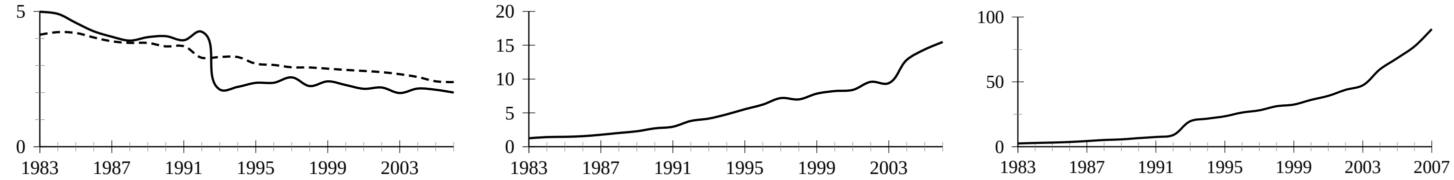
Figure 20: Comparison of the evolution of aggregated (domestic+international) EE coefficients by region against the world (left panel), evolution of Jet-Fuel consumption (expressed in Mtoe) (middle panel), and evolution of air traffic (expressed in ATK (billion)) by region (right panel). Source: Authors, from ICAO and IEA data. (*Figure continued on next page*).



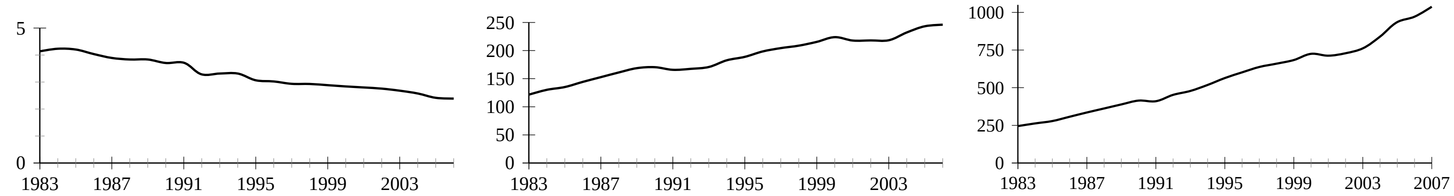
The Middle East



Asian countries and Oceania

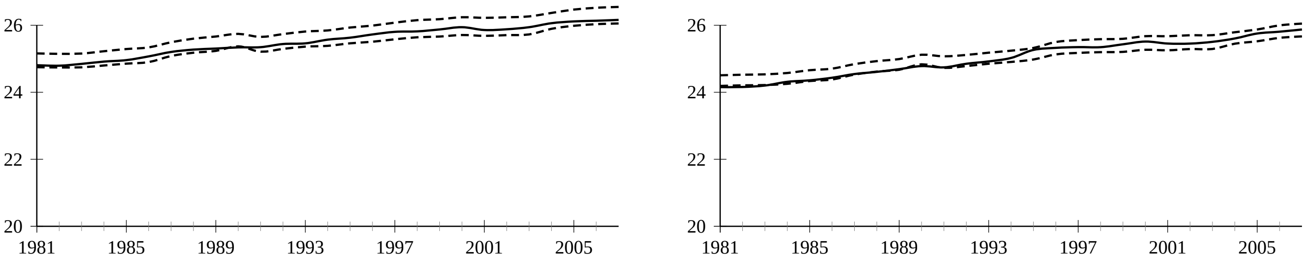


China



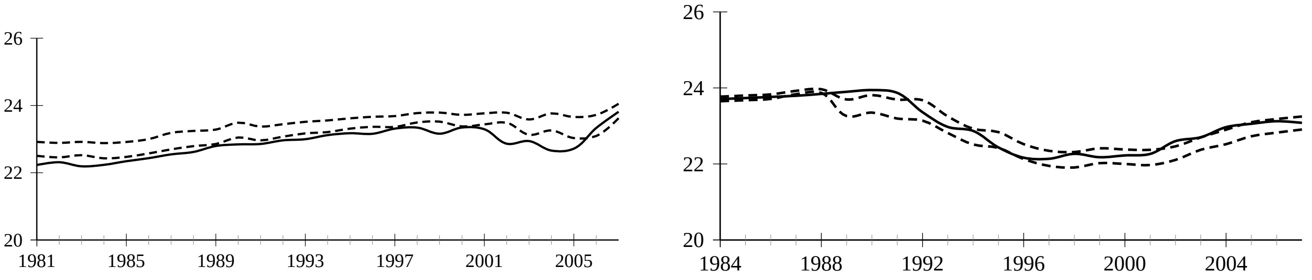
World

Figure 20: Comparison of the evolution of aggregated (domestic+international) EE coefficients by region against the world (left panel), evolution of Jet-Fuel consumption (expressed in Mtoe) (middle panel), and evolution of air traffic (expressed in ATK (billion)) by region (right panel). Source: Authors, from ICAO and IEA data.



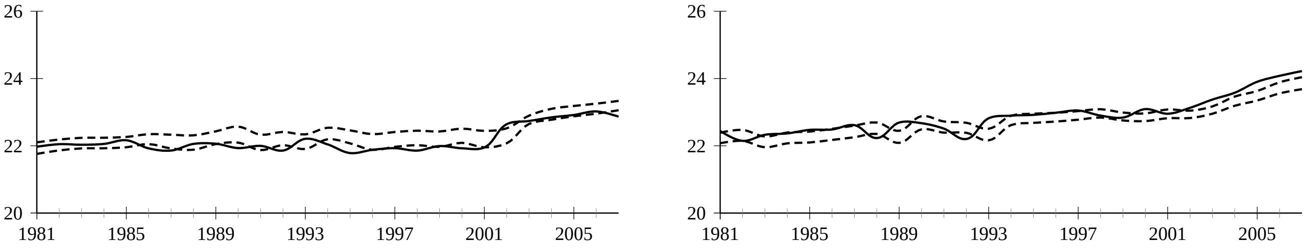
Central and North America

Europe



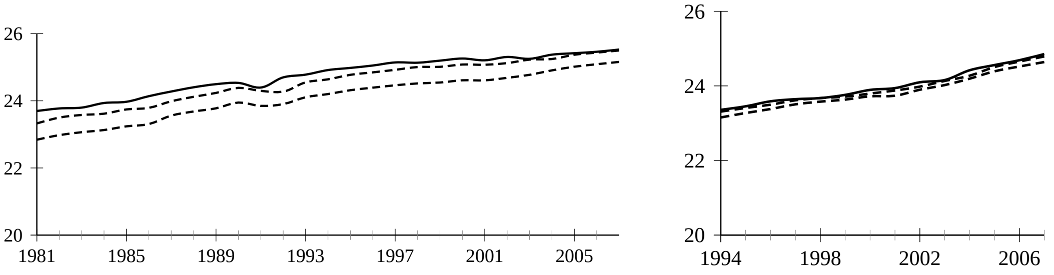
Latin America

Russia and CIS



Africa

The Middle East



Asian countries and Oceania

China

Figure 24: In-sample predictions and evolution of each region's air traffic (ln RTK) between 1981 and 2007. Solid line: ICAO data, dashed lines: 95 % Interval Predictions.

NB: in-sample predicted values are not reported in order to not overload the figures.

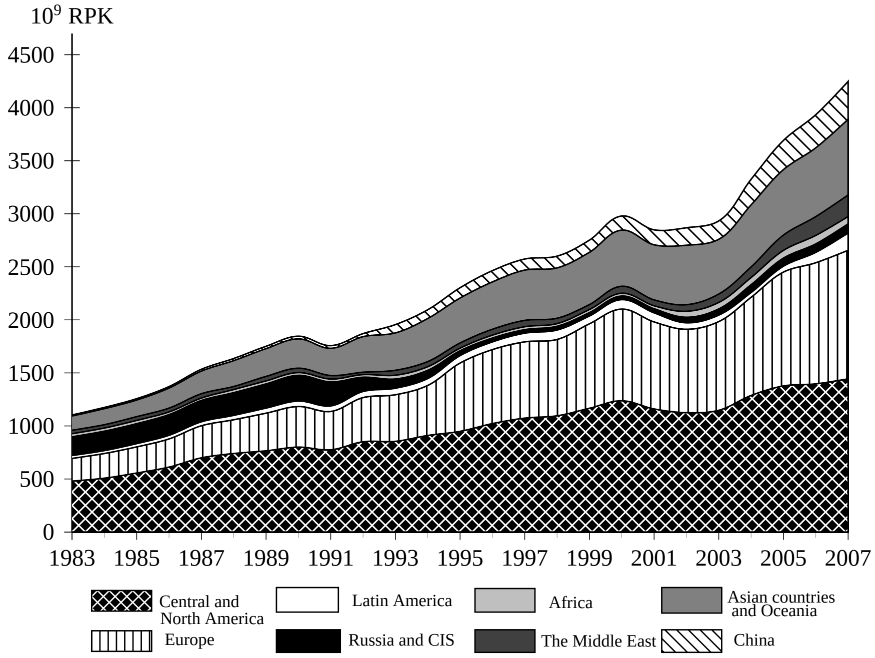


Figure 30: Evolution of Passenger's Air Traffic (expressed in RPK (billion)) by Zone during 1983-2007. Source: Authors, from ICAO data.

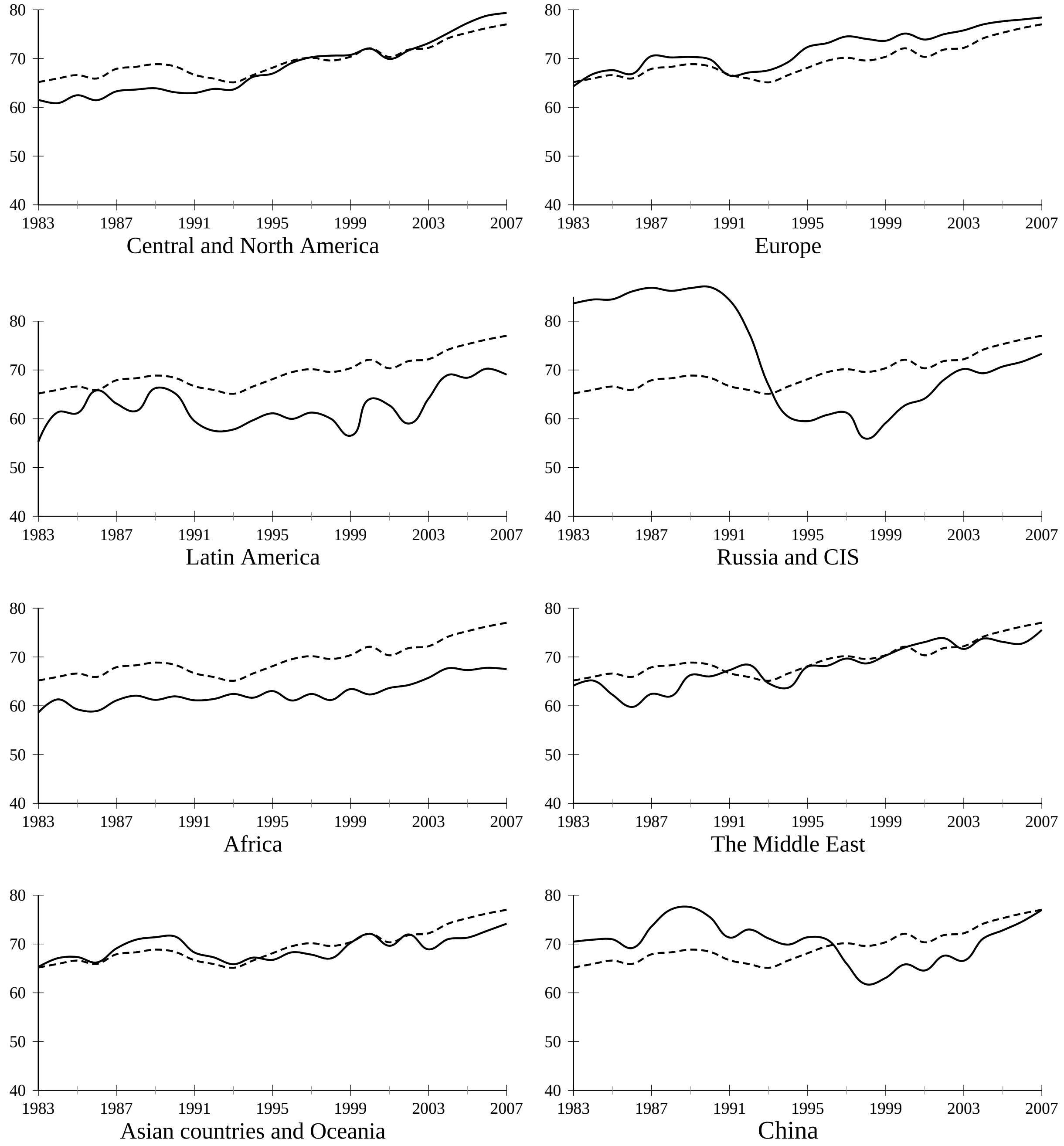


Figure 31: Evolution of each zone’s passengers’ load factors (solid line) compared to world’s passengers’ load factors (dashed line) (1983-2007). Source: Authors, from ICAO data.

List of Tables

		Mean values			Yearly average growth rates		
		1983	1996	2006	Sub-periods		Whole period
					1983-1996	1996-2006	1983-2006
Central and North America	**RTK**	61.79	148.68	223.90	7.06%	4.31%	5.87%
	ATK	109.97	255.69	369.31	6.77%	3.79%	5.47%
	WLF	56.18%	58.15%	60.63%	0.27%	0.46%	0.35%
	Mtoe	46.725	86.065	89.983	4.89%	0.49%	2.98%
Europe	**RTK**	32.37	99.64	161.46	8.32%	5.17%	6.95%
	ATK	51.61	145.63	234.42	7.88%	4.44%	6.38%
	WLF	62.73%	68.42%	68.88%	0.70%	0.13%	0.45%
	Mtoe	20.551	39.193	55.909	5.09%	3.62%	4.45%
Latin America	**RTK**	4.33	11.41	13.56	7.86%	5.76%	6.94%
	ATK	8.34	21.31	21.69	7.63%	2.85%	5.55%
	WLF	51.98%	53.54%	62.52%	0.32%	2.01%	1.06%
	Mtoe	4.934	7.687	8.797	3.58%	1.66%	2.74%
Russia and CIS	**RTK**	19.05	4.22	11.03	-9.24%	10.88%	-0.49%
	ATK	23.08	8.15	18.34	-6.08%	9.24%	0.58%
	WLF	82.54%	51.83%	60.14%	-3.35%	1.62%	-1.19%
	Mtoe	25.265	10.412	12.901	-6.19%	2.24%	-2.53%
Africa	**RTK**	3.69	3.18	9.96	0.32%	14.80%	6.62%
	ATK	7.16	6.15	17.26	0.70%	14.00%	6.48%
	WLF	51.61%	51.70%	57.71%	0.09%	1.13%	0.54%
	Mtoe	4.453	6.732	8.923	3.31%	2.96%	3.16%
The Middle East	**RTK**	4.97	9.58	28.70	8.89%	13.02%	10.69%
	ATK	9.27	15.35	49.04	8.34%	13.93%	10.77%
	WLF	53.63%	62.42%	58.52%	1.34%	-0.62%	0.49%
	Mtoe	5.258	8.728	11.247	4.38%	2.59%	3.60%
Asian countries and Oceania	**RTK**	21.63	75.79	114.13	10.61%	4.35%	7.89%
	ATK	33.19	123.20	183.96	11.06%	4.16%	8.06%
	WLF	65.19%	61.52%	62.04%	-0.40%	0.13%	-0.17%
	Mtoe	13.187	33.460	42.779	7.45%	2.52%	5.31%
China	**RTK**	1.76	17.52	52.72	21.16%	11.89%	17.13%
	ATK	2.49	26.33	77.36	22.15%	11.52%	17.52%
	WLF	70.46%	66.54%	68.15%	-0.42%	0.31%	-0.10%
	Mtoe	1.246	6.225	15.475	13.33%	10.03%	11.90%
World	**RTK**	149.63	370.05	615.49	7.28%	5.34%	6.44%
	ATK	245.16	601.84	971.41	7.19%	4.97%	6.22%
	WLF	61.03%	61.49%	63.36%	0.07%	0.33%	0.18%
	Mtoe	121.621	198.502	246.013	3.88%	2.20%	3.15%

Table 1: Air Traffic (expressed in RTK and ATK). Weight Load Factors and Jet-Fuel Consumption for each zone (expressed in Mtoe) during 1983-2006. Source: Authors, from ICAO and IEA data.

		Mean values		
		1983	**1996**	**2006**
Central and North America	**RTK**	41.29%	40.18%	36.38%
	ATK	44.86%	42.49%	38.02%
	Mtoe	38.42%	43.36%	36.58%
Europe	**RTK**	21.64%	26.93%	26.23%
	ATK	21.05%	24.20%	24.13%
	Mtoe	16.90%	19.74%	22.73%
Latin America	**RTK**	2.90%	3.08%	2.20%
	ATK	3.40%	3.54%	2.23%
	Mtoe	4.06%	3.87%	3.58%
Russia and CIS	**RTK**	12.74%	1.14%	1.79%
	ATK	9.42%	1.36%	1.89%
	Mtoe	20.77%	5.25%	5.24%
Africa	**RTK**	2.47%	0.86%	1.62%
	ATK	2.92%	1.02%	1.78%
	Mtoe	3.66%	3.39%	3.63%
The Middle East	**RTK**	3.32%	2.59%	4.66%
	ATK	3.78%	2.55%	5.05%
	Mtoe	4.32%	4.40%	4.57%
Asian countries and Oceania	**RTK**	14.46%	20.48%	18.54%
	ATK	13.54%	20.47%	18.94%
	Mtoe	10.84%	16.86%	17.39%
China	**RTK**	1.18%	4.74%	8.57%
	ATK	1.02%	4.38%	7.96%
	Mtoe	1.02%	3.14%	6.29%

Table 2: World Repartition of Air Traffic (expressed in RTK (billion) and ATK (billion)) and Jet-Fuel Consumption (expressed in Mtoe) by Zone (1983–2006). Source: Authors, from ICAO data.

		Mean values		
		1983	**1996**	**2007**
Central and North America	**Passengers (RTK)**	90.88%	86.62%	81.51%
	Freight (RTK)	9.12%	13.38%	18.49%
	Passengers (ATK)	92.34%	87.35%	81.75%
	Freight (ATK)	7.66%	12.65%	18.25%
Europe	**Passengers (RTK)**	92.47%	91.55%	88.36%
	Freight (RTK)	7.53%	8.45%	11.64%
	Passengers (ATK)	92.72%	91.84%	88.33%
	Freight (ATK)	7.28%	8.16%	11.67%
Latin America	**Passengers (RTK)**	88.92%	88.11%	89.73%
	Freight (RTK)	11.08%	11.89%	10.27%
	Passengers (ATK)	90.78%	89.90%	91.52%
	Freight (ATK)	9.22%	10.10%	8.48%
Russia and CIS	**Passengers (RTK)**	100.00%	99.48%	91.85%
	Freight (RTK)	0.00%	0.52%	8.15%
	Passengers (ATK)	100.00%	99.37%	91.56%
	Freight (ATK)	0.00%	0.63%	8.44%
Africa	**Passengers (RTK)**	96.11%	97.87%	96.62%
	Freight (RTK)	3.89%	2.13%	3.38%
	Passengers (ATK)	96.81%	97.57%	96.98%
	Freight (ATK)	3.19%	2.43%	3.02%
The Middle East	**Passengers (RTK)**	86.19%	85.43%	88.02%
	Freight (RTK)	13.81%	14.57%	11.98%
	Passengers (ATK)	85.43%	86.88%	88.16%
	Freight (ATK)	14.57%	13.12%	11.84%
Asian countries and Oceania	**Passengers (RTK)**	88.82%	85.56%	84.11%
	Freight (RTK)	11.18%	14.44%	15.89%
	Passengers (ATK)	89.95%	86.41%	84.71%
	Freight (ATK)	10.05%	13.59%	15.29%
China	**Passengers (RTK)**	84.71%	85.63%	85.03%
	Freight (RTK)	15.29%	14.37%	14.97%
	Passengers (ATK)	86.07%	88.22%	84.82%
	Freight (ATK)	13.93%	11.78%	15.18%
World	**Passengers (RTK)**	91.93%	87.94%	85.07%
	Freight (RTK)	8.07%	12.06%	14.93%
	Passengers (ATK)	92.57%	88.63%	85.22%
	Freight (ATK)	7.43%	11.37%	14.78%

Table 3: Repartition of Air Traffic (expressed in RTK (billion) and ATK (billion)) within each zone (1983-2007): passenger *vs.* freight. Source: Authors, from ICAO data.

			Mean values	
		1983	1996	2006
Central and North America	**Domestic (RTK)**	67.21%	63.36%	56.16%
	International (RTK)	32.79%	36.64%	43.84%
	Domestic (ATK)	69.02%	64.40%	56.58%
	International (ATK)	30.98%	35.60%	43.42%
	Domestic (Mtoe)	81.74%	76.89%	77.35%
	International (Mtoe)	18.26%	23.11%	22.65%
Europe	**Domestic (RTK)**	8.05%	6.86%	5.09%
	International (RTK)	91.95%	93.14%	94.91%
	Domestic (ATK)	8.63%	8.15%	5.78%
	International (ATK)	91.37%	91.85%	94.22%
	Domestic (Mtoe)	24.90%	20.49%	18.83%
	International (Mtoe)	75.10%	79.51%	81.17%
Latin America	**Domestic (RTK)**	32.33%	30.43%	40.93%
	International (RTK)	67.67%	69.57%	59.07%
	Domestic (ATK)	30.99%	31.67%	42.20%
	International (ATK)	69.01%	68.33%	57.80%
	Domestic (Mtoe)	55.06%	53.86%	43.28%
	International (Mtoe)	44.94%	46.14%	56.72%
Russia and CIS	**Domestic (RTK)**	93.37%	31.47%	28.47%
	International (RTK)	6.63%	68.53%	71.53%
	Domestic (ATK)	91.72%	27.87%	26.20%
	International (ATK)	8.28%	72.13%	73.80%
	Domestic (Mtoe)	0.00%	47.89%	47.08%
	International (Mtoe)	100.00%	52.11%	52.92%
Africa	**Domestic (RTK)**	15.96%	8.90%	10.80%
	International (RTK)	84.04%	91.10%	89.20%
	Domestic (ATK)	14.65%	8.82%	9.70%
	International (ATK)	85.35%	91.18%	90.30%
	Domestic (Mtoe)	20.26%	32.04%	35.55%
	International (Mtoe)	79.74%	67.96%	64.45%
The Middle East	**Domestic (RTK)**	16.69%	5.70%	4.98%
	International (RTK)	83.31%	94.30%	95.02%
	Domestic (ATK)	15.25%	4.94%	5.18%
	International (ATK)	84.75%	95.06%	94.82%
	Domestic (Mtoe)	10.05%	9.25%	7.31%
	International (Mtoe)	89.95%	90.75%	92.69%
Asian countries and Oceania	**Domestic (RTK)**	9.65%	14.38%	12.90%
	International (RTK)	90.35%	85.62%	87.10%
	Domestic (ATK)	11.28%	18.58%	15.72%
	International (ATK)	88.72%	81.42%	84.28%
	Domestic (Mtoe)	30.28%	31.30%	23.27%
	International (Mtoe)	69.72%	68.70%	76.73%
China	**Domestic (RTK)**	0.00%	25.15%	37.96%
	International (RTK)	100.00%	74.85%	62.04%
	Domestic (ATK)	n.a.	27.74%	37.77%
	International (ATK)	100.00%	72.26%	62.23%
	Domestic (Mtoe)	35.04%	43.63%	55.22%
	International (Mtoe)	64.96%	56.37%	44.78%
World	**Domestic (RTK)**	44.67%	32.96%	29.23%
	International (RTK)	55.33%	67.04%	70.77%
	Domestic (ATK)	45.00%	36.07%	30.76%
	International (ATK)	55.00%	63.93%	69.24%
	Domestic (Mtoe)	42.66%	50.12%	45.73%
	International (Mtoe)	57.34%	49.88%	54.27%

Table 4: Repartition of Air Traffic (expressed in RTK (billion) and ATK (billion)) and Jet-Fuel consumption (expressed in Mtoe) within each zone (1983-2006): domestic *vs.* international. Source: Authors, from ICAO and IEA data.

		Mean values		
		1983	**1996**	**2007**
Central and North America	**Domestic (RTK)**	62.13%	77.23%	66.39%
	International (RTK)	24.47%	21.96%	21.85%
	Domestic (ATK)	68.80%	75.86%	66.52%
	International (ATK)	25.27%	23.66%	23.16%
Europe	**Domestic (RTK)**	3.90%	5.61%	4.56%
	International (RTK)	35.95%	37.41%	34.92%
	Domestic (ATK)	4.04%	5.47%	4.37%
	International (ATK)	34.98%	34.76%	32.67%
Latin America	**Domestic (RTK)**	2.10%	2.85%	5.36%
	International (RTK)	3.55%	3.20%	2.49%
	Domestic (ATK)	2.34%	3.11%	5.51%
	International (ATK)	4.27%	3.78%	2.66%
Russia and CIS	**Domestic (RTK)**	26.62%	1.09%	1.72%
	International (RTK)	1.53%	1.17%	1.55%
	Domestic (ATK)	19.19%	1.05%	1.55%
	International (ATK)	1.42%	1.53%	1.70%
Africa	**Domestic (RTK)**	0.88%	0.23%	0.48%
	International (RTK)	3.76%	1.17%	1.62%
	Domestic (ATK)	0.95%	0.25%	0.45%
	International (ATK)	4.54%	1.46%	1.87%
The Middle East	**Domestic (RTK)**	1.24%	0.45%	0.72%
	International (RTK)	5.00%	3.64%	6.75%
	Domestic (ATK)	1.28%	0.35%	0.76%
	International (ATK)	5.83%	3.79%	7.30%
Asian countries and Oceania	**Domestic (RTK)**	3.13%	8.94%	8.74%
	International (RTK)	23.61%	26.16%	22.46%
	Domestic (ATK)	3.39%	10.55%	10.66%
	International (ATK)	21.84%	26.07%	22.53%
China	**Domestic (RTK)**	0.00%	3.61%	12.03%
	International (RTK)	2.13%	5.29%	8.35%
	Domestic (ATK)	0.00%	3.37%	10.18%
	International (ATK)	1.85%	4.95%	8.11%

Table 5: World Repartition of Domestic and International Air Traffic (expressed in RTK (billion) and ATK (billion)) by Zone (1983–2007). Source: Authors, from ICAO data.

		Mean values			Yearly average growth rates		
					Sub-periods		Whole period
		1983	1996	2007	1983-1996	1996-2007	1983-2007
Central and North America	**RTK**	41.52	94.20	127.26	6.50%	2.77%	4.78%
	ATK	75.90	164.65	211.23	6.14%	2.29%	4.36%
	WLF	54.71%	57.21%	60.25%	0.34%	0.47%	0.40%
Europe	**RTK**	2.60	6.83	8.74	7.70%	2.26%	5.17%
	ATK	4.45	11.87	13.88	7.83%	1.43%	4.85%
	WLF	58.52%	57.60%	63.00%	-0.12%	0.82%	0.31%
Latin America	**RTK**	1.40	3.47	10.27	7.22%	10.37%	8.65%
	ATK	2.58	6.75	17.49	7.66%	9.04%	8.29%
	WLF	54.23%	51.44%	58.75%	-0.40%	1.21%	0.33%
Russia and CIS	**RTK**	17.79	1.33	3.28	-18.08%	8.58%	-6.79%
	ATK	21.17	2.27	4.91	-15.77%	7.25%	-5.91%
	WLF	84.02%	58.52%	66.98%	-2.74%	1.23%	-0.94%
Africa	**RTK**	0.59	0.28	0.91	-5.50%	11.29%	1.85%
	ATK	1.05	0.54	1.44	-4.95%	9.31%	1.34%
	WLF	56.22%	52.14%	63.52%	-0.58%	1.81%	0.51%
The Middle East	**RTK**	0.83	0.54	1.37	-3.16%	8.77%	2.13%
	ATK	1.41	0.75	2.41	-4.69%	11.11%	2.25%
	WLF	58.69%	72.12%	57.09%	1.60%	-2.10%	-0.12%
Asian countries and Oceania	**RTK**	2.08	10.90	16.74	13.55%	3.98%	9.06%
	ATK	3.74	22.89	33.85	14.95%	3.62%	9.61%
	WLF	55.82%	47.61%	49.48%	-1.22%	0.35%	-0.50%
China	**RTK**	-	4.40	23.06	-	16.24%	-
	ATK	-	7.30	32.32	-	14.48%	-
	WLF	-	60.31%	71.35%	-	1.54%	-
World	**RTK**	66.84	121.98	191.68	4.74%	4.19%	4.49%
	ATK	110.33	217.06	317.55	5.34%	3.52%	4.50%
	WLF	60.58%	56.20%	60.36%	-0.58%	0.65%	-0.02%

Table 6: Domestic Air Traffic (expressed in RTK (billion) and ATK (billion)) and Weight Load Factors for each zone during 1983-2007. Source: Authors, from ICAO data.

		Mean values		
		1983	**1996**	**2007**
Central and North America	**Passengers (RTK)**	93.51%	87.38%	85.63%
	Freight (RTK)	6.49%	12.62%	14.37%
	Passengers (ATK)	94.62%	87.95%	85.50%
	Freight (ATK)	5.38%	12.05%	14.50%
Europe	**Passengers (RTK)**	95.77%	98.53%	98.72%
	Freight (RTK)	4.23%	1.47%	1.28%
	Passengers (ATK)	95.66%	98.21%	98.36%
	Freight (ATK)	4.34%	1.79%	1.64%
Latin America	**Passengers (RTK)**	90.37%	89.38%	95.21%
	Freight (RTK)	9.63%	10.62%	4.79%
	Passengers (ATK)	91.20%	91.19%	95.48%
	Freight (ATK)	8.80%	8.81%	4.52%
Russia and CIS	**Passengers (RTK)**	100.00%	99.65%	100.00%
	Freight (RTK)	0.00%	0.35%	0.00%
	Passengers (ATK)	100.00%	99.62%	99.99%
	Freight (ATK)	0.00%	0.38%	0.01%
Africa	**Passengers (RTK)**	99.30%	99.93%	97.69%
	Freight (RTK)	0.70%	0.07%	2.31%
	Passengers (ATK)	99.01%	99.93%	97.62%
	Freight (ATK)	0.99%	0.07%	2.38%
The Middle East	**Passengers (RTK)**	97.87%	100.00%	99.53%
	Freight (RTK)	2.13%	0.00%	0.47%
	Passengers (ATK)	96.77%	99.99%	98.86%
	Freight (ATK)	3.23%	0.01%	1.14%
Asian countries and Oceania	**Passengers (RTK)**	98.66%	99.65%	99.89%
	Freight (RTK)	1.34%	0.35%	0.11%
	Passengers (ATK)	98.26%	99.63%	99.89%
	Freight (ATK)	1.74%	0.37%	0.11%
China	**Passengers (RTK)**	-	100.00%	99.09%
	Freight (RTK)	-	0.00%	0.91%
	Passengers (ATK)	-	100.00%	98.85%
	Freight (ATK)	-	0.00%	1.15%
World	**Passengers (RTK)**	95.53%	89.83%	90.01%
	Freight (RTK)	4.47%	10.17%	9.99%
	Passengers (ATK)	95.81%	90.44%	89.88%
	Freight (ATK)	4.19%	9.56%	10.12%

Table 7: Repartition of Domestic Air Traffic (expressed in RTK (billion) and ATK (billion)) within each zone (1983-2007): passenger *vs.* freight. Source: Authors, from ICAO data.

		Mean values			Yearly average growth rates		
		1983	1996	2007	Sub-periods		Whole period
					1983-1996	1996-2007	1983-2007
Central and North America	**RTK**	20.26	54.47	102.39	7.90%	5.90%	6.98%
	ATK	34.07	91.03	166.79	7.85%	5.66%	6.84%
	WLF	59.47%	59.84%	61.39%	0.05%	0.23%	0.13%
Europe	**RTK**	29.76	92.80	163.64	9.14%	5.29%	7.36%
	ATK	47.15	133.76	235.25	8.35%	5.27%	6.93%
	WLF	63.12%	69.38%	69.56%	0.73%	0.02%	0.41%
Latin America	**RTK**	2.93	7.93	11.67	7.95%	3.57%	5.92%
	ATK	5.75	14.56	19.12	7.40%	2.51%	5.13%
	WLF	50.97%	54.51%	61.04%	0.52%	1.03%	0.75%
Russia and CIS	**RTK**	1.26	2.89	7.27	6.59%	8.72%	7.56%
	ATK	1.91	5.88	12.23	9.04%	6.89%	8.04%
	WLF	66.11%	49.24%	59.40%	-2.24%	1.72%	-0.45%
Africa	**RTK**	3.10	2.89	7.61	-0.54%	9.18%	3.80%
	ATK	6.11	5.60	13.45	-0.67%	8.28%	3.34%
	WLF	50.82%	51.66%	56.57%	0.13%	0.83%	0.45%
The Middle East	**RTK**	4.14	9.03	31.64	6.18%	12.07%	8.84%
	ATK	7.85	14.59	52.58	4.88%	12.36%	8.24%
	WLF	52.72%	61.91%	60.18%	1.24%	-0.26%	0.55%
Asian countries and Oceania	**RTK**	19.54	64.89	105.28	9.67%	4.50%	7.27%
	ATK	29.45	100.30	162.19	9.89%	4.47%	7.37%
	WLF	66.38%	64.70%	64.91%	-0.20%	0.03%	-0.09%
China	**RTK**	1.76	13.11	39.12	16.70%	10.44%	13.79%
	ATK	2.49	19.02	58.39	16.90%	10.73%	14.03%
	WLF	70.46%	68.93%	66.99%	-0.17%	-0.26%	-0.21%
World	**RTK**	82.79	248.06	468.64	8.81%	5.95%	7.49%
	ATK	134.83	384.78	720.05	8.40%	5.86%	7.23%
	WLF	61.41%	64.47%	65.09%	0.38%	0.09%	0.24%

Table 8: International Air Traffic (expressed in RTK and ATK) and Weight Load Factors for each zone during 1983-2007. Source: Authors, from ICAO data.

		Mean values		
		1983	1996	2007
Central and North America	**Passengers (RTK)**	85.49%	85.30%	76.39%
	Freight (RTK)	14.51%	14.70%	23.61%
	Passengers (ATK)	87.28%	86.27%	77.00%
	Freight (ATK)	12.72%	13.73%	23.00%
Europe	**Passengers (RTK)**	92.18%	91.04%	87.81%
	Freight (RTK)	7.82%	8.96%	12.19%
	Passengers (ATK)	92.45%	91.28%	87.74%
	Freight (ATK)	7.55%	8.72%	12.26%
Latin America	**Passengers (RTK)**	88.22%	87.55%	84.91%
	Freight (RTK)	11.78%	12.45%	15.09%
	Passengers (ATK)	90.59%	89.30%	87.90%
	Freight (ATK)	9.41%	10.70%	12.10%
Russia and CIS	**Passengers (RTK)**	100.00%	99.39%	88.17%
	Freight (RTK)	0.00%	0.61%	11.83%
	Passengers (ATK)	100.00%	99.27%	88.17%
	Freight (ATK)	0.00%	0.73%	11.83%
Africa	**Passengers (RTK)**	95.50%	97.67%	96.50%
	Freight (RTK)	4.50%	2.33%	3.50%
	Passengers (ATK)	96.43%	97.34%	96.91%
	Freight (ATK)	3.57%	2.66%	3.09%
The Middle East	**Passengers (RTK)**	83.85%	84.55%	87.52%
	Freight (RTK)	16.15%	15.45%	12.48%
	Passengers (ATK)	83.39%	86.20%	87.67%
	Freight (ATK)	16.61%	13.80%	12.33%
Asian countries and Oceania	**Passengers (RTK)**	87.77%	83.19%	81.60%
	Freight (RTK)	12.23%	16.81%	18.40%
	Passengers (ATK)	88.89%	83.40%	81.54%
	Freight (ATK)	11.11%	16.60%	18.46%
China	**Passengers (RTK)**	84.71%	80.80%	76.74%
	Freight (RTK)	15.29%	19.20%	23.26%
	Passengers (ATK)	86.07%	83.69%	77.06%
	Freight (ATK)	13.93%	16.31%	22.94%
World	**Passengers (RTK)**	89.03%	87.01%	83.05%
	Freight (RTK)	10.97%	12.99%	16.95%
	Passengers (ATK)	89.93%	87.61%	83.17%
	Freight (ATK)	10.07%	12.39%	16.83%

Table 9: Repartition of International Air Traffic (expressed in RTK and ATK) within each zone (1983-2007): passenger *vs.* freight. Source: Authors, from ICAO data.

		Mean values		
		1983	1996	2007
Central and North America	**Freight (RTK)**	46.67%	44.59%	43.07%
	Passengers (RTK)	40.82%	39.58%	33.32%
	Freight (ATK)	46.24%	47.26%	45.00%
	Passengers (ATK)	44.75%	41.87%	34.95%
Europe	**Freight (RTK)**	20.20%	18.86%	20.35%
	Passengers (RTK)	21.76%	28.03%	27.12%
	Freight (ATK)	20.62%	17.36%	18.96%
	Passengers (ATK)	21.09%	25.08%	24.89%
Latin America	**Freight (RTK)**	3.98%	3.04%	2.29%
	Passengers (RTK)	2.80%	3.09%	3.51%
	Freight (ATK)	4.23%	3.15%	2.03%
	Passengers (ATK)	3.34%	3.59%	3.79%
Russia and CIS	**Freight (RTK)**	0.00%	0.05%	0.87%
	Passengers (RTK)	13.85%	1.29%	1.73%
	Freight (ATK)	0.00%	0.08%	0.94%
	Passengers (ATK)	10.17%	1.52%	1.78%
Africa	**Freight (RTK)**	1.19%	0.15%	0.29%
	Passengers (RTK)	2.58%	0.96%	1.47%
	Freight (ATK)	1.26%	0.22%	0.29%
	Passengers (ATK)	3.06%	1.13%	1.63%
The Middle East	**Freight (RTK)**	5.69%	3.13%	4.01%
	Passengers (RTK)	3.12%	2.52%	5.17%
	Freight (ATK)	7.42%	2.94%	4.25%
	Passengers (ATK)	3.49%	2.50%	5.48%
Asian countries and Oceania	**Freight (RTK)**	20.03%	24.53%	19.67%
	Passengers (RTK)	13.97%	19.93%	18.27%
	Freight (ATK)	18.32%	24.46%	19.55%
	Passengers (ATK)	13.16%	19.96%	18.78%
China	**Freight (RTK)**	2.23%	5.64%	9.44%
	Passengers (RTK)	1.08%	4.61%	9.41%
	Freight (ATK)	1.91%	4.53%	8.98%
	Passengers (ATK)	0.95%	4.36%	8.70%

Table 10: World Repartition of Freight and Passenger Air Traffic (expressed in RTK and ATK) by Zone (1983–2007). Source: Authors, from ICAO data.

		Mean values			Yearly average growth rates		
		1983	1996	2007	Sub-periods		Whole period
					1983-1996	1996-2007	1983-2007
Central and North America	**RTK**	5.63	19.89	42.46	10.19%	7.13%	8.78%
	ATK	8.42	32.34	68.99	10.91%	7.13%	9.16%
	WLF	66.90%	61.52%	61.54%	-0.64%	0.00%	-0.35%
Europe	**RTK**	2.43	8.41	20.06	10.00%	8.22%	9.18%
	ATK	3.75	11.87	29.07	9.26%	8.48%	8.90%
	WLF	64.92%	70.85%	69.00%	0.67%	-0.24%	0.25%
Latin America	**RTK**	0.48	1.35	2.25	8.31%	4.72%	6.65%
	ATK	0.76	2.15	3.10	8.23%	3.39%	5.98%
	WLF	62.49%	63.04%	72.61%	0.07%	1.29%	0.63%
Russia and CIS	**RTK**	-	0.02	0.86	-	39.45%	-
	ATK	-	0.05	1.44	-	35.40%	-
	WLF	-	42.96%	59.40%	-	2.99%	-
Africa	**RTK**	0.14	0.067	0.28	-5.64%	14.07%	2.93%
	ATK	0.22	0.14	0.45	-3.21%	10.53%	2.86%
	WLF	62.94%	45.21%	63.93%	-2.51%	3.20%	0.07%
The Middle East	**RTK**	0.68	1.39	3.95	5.60%	9.94%	7.57%
	ATK	1.35	2.01	6.51	3.12%	11.25%	6.77%
	WLF	50.84%	69.31%	60.79%	2.41%	-1.19%	0.75%
Asian countries and Oceania	**RTK**	2.41	10.94	19.38	12.32%	5.33%	9.06%
	ATK	3.33	16.73	29.97	13.21%	5.44%	9.58%
	WLF	72.49%	65.40%	64.67%	-0.79%	-0.10%	-0.47%
China	**RTK**	0.26	2.51	9.30	18.77%	12.62%	15.91%
	ATK	0.34	3.10	13.77	18.32%	14.51%	16.56%
	WLF	77.31%	81.17%	67.59%	0.38%	-1.65%	-0.56%
World	**RTK**	12.07	44.62	98.57	10.58%	7.47%	9.14%
	ATK	18.20	68.42	153.32	10.72%	7.61%	9.28%
	WLF	66.29%	65.21%	64.29%	-0.13%	-0.13%	-0.13%

Table 11: Freight Traffic (expressed in RTK and ATK) and Weight Load Factors for each zone during 1983-2007. Source: Authors, from ICAO data.

		Mean values		
		1983	**1996**	**2007**
Central and North America	**Domestic (RTK)**	47.82%	59.76%	43.06%
	International (RTK)	52.18%	40.24%	56.94%
	Domestic (ATK)	48.52%	61.35%	44.40%
	International (ATK)	51.48%	38.65%	55.60%
Europe	**Domestic (RTK)**	4.53%	1.19%	0.56%
	International (RTK)	95.47%	98.81%	99.44%
	Domestic (ATK)	5.15%	1.79%	0.78%
	International (ATK)	94.85%	98.21%	99.22%
Latin America	**Domestic (RTK)**	28.09%	27.19%	21.84%
	International (RTK)	71.91%	72.81%	78.16%
	Domestic (ATK)	29.58%	27.62%	25.47%
	International (ATK)	70.42%	72.38%	74.53%
Russia and CIS	**Domestic (RTK)**	-	20.98%	0.00%
	International (RTK)	-	79.02%	100.00%
	Domestic (ATK)	-	16.82%	0.05%
	International (ATK)	-	83.18%	99.95%
Africa	**Domestic (RTK)**	2.87%	0.28%	7.37%
	International (RTK)	97.13%	99.72%	92.63%
	Domestic (ATK)	4.56%	0.26%	7.61%
	International (ATK)	95.44%	99.74%	92.39%
The Middle East	**Domestic (RTK)**	2.58%	0.00%	0.16%
	International (RTK)	97.42%	100.00%	99.84%
	Domestic (ATK)	3.38%	0.00%	0.42%
	International (ATK)	96.62%	100.00%	99.58%
Asian countries and Oceania	**Domestic (RTK)**	1.15%	0.35%	0.10%
	International (RTK)	98.85%	99.65%	99.90%
	Domestic (ATK)	1.95%	0.50%	0.12%
	International (ATK)	98.05%	99.50%	99.88%
China	**Domestic (RTK)**	0.00%	0.00%	2.24%
	International (RTK)	100.00%	100.00%	97.76%
	Domestic (ATK)	0.00%	0.00%	2.71%
	International (ATK)	100.00%	100.00%	97.29%
World	**Domestic (RTK)**	24.76%	27.80%	19.42%
	International (RTK)	75.24%	72.20%	80.58%
	Domestic (ATK)	25.41%	30.31%	20.95%
	International (ATK)	74.59%	69.69%	79.05%

Table 12: Repartition of Freight Traffic (expressed in RTK and ATK) within each zone (1983-2007): domestic *vs.* international. Source: Authors, from ICAO data.

		Mean values			Yearly average growth rates		
		1983	1996	2007	Sub-periods		Whole period
					1983-1996	1996-2007	1983-2007
Central and North America	**RTK**	56.15	128.78	187.19	6.59%	3.46%	5.14%
	ATK	101.55	223.35	309.03	6.25%	3.00%	4.75%
	WLF	55.30%	57.66%	60.57%	0.32%	0.45%	0.38%
Europe	**RTK**	29.93	91.23	152.32	8.95%	4.77%	7.01%
	ATK	47.85	133.75	220.05	8.23%	4.63%	6.56%
	WLF	62.55%	68.21%	69.22%	0.67%	0.13%	0.42%
Latin America	**RTK**	3.85	10.05	19.69	7.65%	6.31%	7.03%
	ATK	7.57	19.15	33.51	7.40%	5.22%	6.39%
	WLF	50.91%	52.47%	58.77%	0.23%	1.04%	0.60%
Russia and CIS	**RTK**	19.05	4.20	9.69	-10.97%	7.89%	-2.77%
	ATK	23.08	8.10	15.70	-7.74%	6.20%	-1.59%
	WLF	82.54%	51.89%	61.77%	-3.51%	1.60%	-1.20%
Africa	**RTK**	3.55	3.11	8.24	-1.02%	9.26%	3.57%
	ATK	6.94	6.00	14.45	-1.11%	8.32%	3.10%
	WLF	51.23%	51.86%	57.04%	0.09%	0.87%	0.45%
The Middle East	**RTK**	4.28	8.18	29.06	5.10%	12.21%	8.30%
	ATK	7.92	13.33	48.49	4.09%	12.45%	7.84%
	WLF	54.10%	61.38%	59.95%	0.98%	-0.21%	0.43%
Asian countries and Oceania	**RTK**	19.22	64.84	102.64	9.81%	4.26%	7.23%
	ATK	29.85	106.46	166.07	10.27%	4.12%	7.41%
	WLF	64.37%	60.91%	61.81%	-0.42%	0.13%	-0.17%
China	**RTK**	1.49	15.00	52.87	19.43%	12.13%	16.03%
	ATK	2.15	23.23	76.94	20.08%	11.50%	16.07%
	WLF	69.36%	64.58%	68.72%	-0.55%	0.57%	-0.04%
World	**RTK**	137.56	325.42	561.75	6.85%	5.09%	6.04%
	ATK	226.95	533.41	884.27	6.79%	4.70%	5.83%
	WLF	60.61%	61.01%	63.53%	0.05%	0.37%	0.20%

Table 13: Passengers’ Air Traffic (expressed in RTK and ATK) and Weight Load Factors for each zone during 1983-2007. Source: Authors, from ICAO data.

		Mean values		
		1983	1996	2007
Central and North America	**Domestic (RTK)**	69.15%	63.92%	58.22%
	International (RTK)	30.85%	36.08%	41.78%
	Domestic (ATK)	70.72%	64.84%	58.44%
	International (ATK)	29.28%	35.16%	41.56%
Europe	**Domestic (RTK)**	8.34%	7.39%	5.67%
	International (RTK)	91.66%	92.61%	94.33%
	Domestic (ATK)	8.91%	8.72%	6.20%
	International (ATK)	91.09%	91.28%	93.80%
Latin America	**Domestic (RTK)**	32.86%	30.87%	49.67%
	International (RTK)	67.14%	69.13%	50.33%
	Domestic (ATK)	31.14%	32.13%	49.83%
	International (ATK)	68.86%	67.87%	50.17%
Russia and CIS	**Domestic (RTK)**	93.37%	31.52%	33.92%
	International (RTK)	6.63%	68.48%	66.08%
	Domestic (ATK)	91.72%	27.94%	31.28%
	International (ATK)	8.28%	72.06%	68.72%
Africa	**Domestic (RTK)**	16.49%	9.08%	10.87%
	International (RTK)	83.51%	90.92%	89.13%
	Domestic (ATK)	14.98%	9.03%	9.75%
	International (ATK)	85.02%	90.97%	90.25%
The Middle East	**Domestic (RTK)**	18.95%	6.68%	4.72%
	International (RTK)	81.05%	93.32%	95.28%
	Domestic (ATK)	17.28%	5.68%	4.92%
	International (ATK)	82.72%	94.32%	95.08%
Asian countries and Oceania	**Domestic (RTK)**	10.72%	16.75%	16.30%
	International (RTK)	89.28%	83.25%	83.70%
	Domestic (ATK)	12.32%	21.43%	20.36%
	International (ATK)	87.68%	78.57%	79.64%
China	**Domestic (RTK)**	0.00%	29.37%	43.22%
	International (RTK)	100.00%	70.63%	56.78%
	Domestic (ATK)	0.00%	31.45%	41.52%
	International (ATK)	100.00%	68.55%	58.48%
World	**Domestic (RTK)**	46.42%	33.67%	30.71%
	International (RTK)	53.58%	66.33%	69.29%
	Domestic (ATK)	46.58%	36.80%	32.28%
	International (ATK)	53.42%	63.20%	67.72%

Table 14: Repartition of Passengers' Air Traffic (expressed in RTK and ATK) within each zone (1983-2007): domestic *vs.* international. Source: Authors, from ICAO data.

		Mean values			Yearly average growth rates (EE gains)			Rate of change
		Sub-periods		Whole period	Sub-periods		Whole period	
		1983-1996	1996-2006	1983-2006	1983-1996	1996-2006	1983-2006	1983-2006
Central and North America	**Aggregated**	3.93E-07	2.90E-07	3.49E-07	-1.78%	-3.18%	**-2.39%**	-42.65%
	Domestic	4.58E-07	3.62E-07	4.16E-07	-1.71%	-1.86%	-1.78%	-33.80%
	International	2.60E-07	1.80E-07	2.25E-07	-1.04%	-5.27%	-2.91%	-49.25%
Europe	**Aggregated**	3.52E-07	2.71E-07	3.18E-07	-2.97%	-1.20%	**-2.20%**	-40.10%
	Domestic	8.75E-07	7.31E-07	8.17E-07	-3.99%	1.40%	-1.68%	-32.35%
	International	3.02E-07	2.35E-07	2.74E-07	-2.58%	-1.25%	-2.00%	-37.22%
Latin America	**Aggregated**	4.22E-07	4.35E-07	4.31E-07	-3.73%	1.18%	**-1.63%**	-31.42%
	Domestic	7.21E-07	6.24E-07	6.81E-07	-4.05%	-3.81%	-3.95%	-60.41%
	International	2.85E-07	3.31E-07	3.08E-07	-3.46%	5.03%	0.14%	3.34%
Russia and CIS	**Aggregated**	n.a.	1.00E-06	n.a.	n.a.	**-5.79%**	n.a.	-44.92% *
	Domestic	n.a.	2.09E-06	n.a.	n.a.	-5.37%	n.a.	-42.39% *
	International	n.a.	6.89E-07	n.a.	n.a.	-5.86%	n.a.	-45.33% *
Africa	**Aggregated**	7.81E-07	9.18E-07	8.30E-07	4.45%	-7.22%	**-0.80%**	-16.79%
	Domestic	1.80E-06	3.94E-06	2.69E-06	12.51%	-7.14%	3.50%	120.60%
	International	6.60E-07	6.78E-07	6.62E-07	2.65%	-7.63%	-1.95%	-36.43%
The Middle East	**Aggregated**	6.75E-07	5.07E-07	6.02E-07	0.02%	-8.68%	**-3.86%**	-59.56%
	Domestic	5.53E-07	1.00E-06	7.36E-07	8.40%	-11.23%	-0.62%	-13.29%
	International	7.08E-07	4.87E-07	6.14E-07	-0.79%	-8.46%	-4.20%	-62.75%
Asian countries and Oceania	**Aggregated**	3.17E-07	2.44E-07	2.85E-07	-2.88%	-1.54%	**-2.30%**	-41.46%
	Domestic	5.87E-07	4.03E-07	5.08E-07	-6.31%	-2.80%	-4.80%	-67.73%
	International	2.69E-07	2.10E-07	2.44E-07	-2.35%	-0.79%	-1.67%	-32.18%
China	**Aggregated**	n.a.	2.22E-07	n.a.	n.a.	**-1.65%**	n.a.	-15.37% *
	Domestic	n.a.	3.53E-07	n.a.	n.a.	-2.37%	n.a.	-21.32% *
	International	n.a.	1.56E-07	n.a.	n.a.	-2.45%	n.a.	-21.94% *
World	**Aggregated**	4.17E-07	2.98E-07	3.66E-07	-3.09%	-2.61%	**-2.88%**	-48.95%
	Domestic	4.52E-07	4.17E-07	4.36E-07	-0.20%	-1.95%	-0.96%	-19.94%
	International	3.96E-07	2.35E-07	3.28E-07	-5.23%	-2.56%	-4.08%	-61.62%

Table 15: EE coefficients (ktoe/ATK) for each zone and worldwide. Means values and growth rates during 1983-2006. Source: Authors, from ICAO and IEA data.

Note: $*$ means that rates of change are not computed for the whole period, but for the second sub-period.

		Mean values			Yearly average growth rates			Rate of change
		Sub-periods		Whole period	Sub-periods		Whole period	
		1983-1996	1996-2006	1983-2006	1983-1996	1996-2006	1983-2006	1983-2006
Central and North America	**Zone's aggregated EE / World's aggregated EE**	0.95	0.97	0.96	1.36%	-0.59%	0.51%	12.34%
	Zone's domestic EE / World's domestic EE	1.01	0.87	0.95	-1.52%	0.09%	-0.82%	-17.31%
	Zone's international EE / World's international EE	0.69	0.76	0.71	4.41%	-2.78%	1.22%	32.24%
Europe	**Zone's aggregated EE / World's aggregated EE**	0.85	0.91	0.88	0.13%	1.44%	0.70%	17.33%
	Zone's domestic EE / World's domestic EE	1.94	1.76	1.87	-3.80%	3.41%	-0.73%	-15.50%
	Zone's international EE / World's international EE	0.79	1.00	0.88	2.79%	1.35%	2.16%	63.58%
Latin America	**Zone's aggregated EE / World's aggregated EE**	1.00	1.49	1.22	-0.66%	3.88%	1.29%	34.33%
	Zone's domestic EE / World's domestic EE	1.59	1.50	1.56	-3.86%	-1.90%	-3.02%	-50.55%
	Zone's international EE / World's international EE	0.74	1.45	1.05	1.86%	7.79%	4.40%	169.25%
Russia and CIS	**Zone's aggregated EE / World's aggregated EE**	n.a.	3.34	n.a.	n.a.	-3.27%	n.a.	-28.26% *
	Zone's domestic EE / World's domestic EE	n.a.	4.95	n.a.	n.a.	-3.49%	n.a.	-29.87% *
	Zone's international EE / World's international EE	n.a.	2.91	n.a.	n.a.	-3.38%	n.a.	-29.12% *
Africa	**Zone's aggregated EE / World's aggregated EE**	1.95	3.03	2.39	7.78%	-4.74%	2.15%	62.99%
	Zone's domestic EE / World's domestic EE	4.00	9.27	6.22	12.73%	-5.30%	4.51%	175.54%
	Zone's international EE / World's international EE	1.80	2.83	2.21	8.31%	-5.20%	2.22%	65.63%
The Middle East	**Zone's aggregated EE / World's aggregated EE**	1.66	1.67	1.66	3.21%	-6.24%	-1.01%	-20.78%
	Zone's domestic EE / World's domestic EE	1.23	2.37	1.71	8.61%	-9.46%	0.35%	8.31%
	Zone's international EE / World's international EE	1.90	2.04	1.95	4.68%	-6.06%	-0.13%	-2.95%
Asian countries and Oceania	**Zone's aggregated EE / World's aggregated EE**	0.76	0.82	0.79	0.21%	1.10%	0.60%	14.66%
	Zone's domestic EE / World's domestic EE	1.29	0.96	1.15	-6.12%	-0.87%	-3.87%	-59.70%
	Zone's international EE / World's international EE	0.70	0.90	0.79	3.04%	1.82%	2.51%	76.71%
China	**Zone's aggregated EE / World's aggregated EE**	n.a.	0.75	n.a.	n.a.	0.98%	n.a.	10.22% *
	Zone's domestic EE / World's domestic EE	n.a.	0.81	n.a.	n.a.	-0.43%	n.a.	-4.22% *
	Zone's international EE / World's international EE	n.a.	0.67	n.a.	n.a.	0.12%	n.a.	1.19% *

Table 16: Comparison of EE coefficients (ktoe/ATK) between zones using world's EE coefficients as benchmark (1983-2006). Source: Authors, from ICAO and IEA data.

Note: a ratio >(<) 1 means that the region's energy efficiency is inferior (superior) to the world's energy efficiency. These ratios are provided for the aggregated (domestic+international), domestic, and international travels.

Note: ∗ means that rates of change are not computed for the whole period, but for the second sub-period.

		Mean values			Yearly average growth rates			Rate of change
		Sub-periods		Whole period	Sub-periods		Whole period	
		1983-1996	1996-2006	1983-2006	1983-1996	1996-2006	1983-2006	1983-2006
Central and North America	**Zone's domestic EE / Zone's aggregated EE**	1.16	1.25	1.20	0.06%	1.36%	0.63%	15.44%
	Zone's international EE / Zone's aggregated EE	0.66	0.62	0.64	0.74%	-2.16%	-0.53%	-11.50%
	Zone's domestic EE / Zone's international EE	**1.77**	**2.06**	**1.85**	-0.68%	3.60%	1.16%	30.44%
Europe	**Zone's domestic EE / Zone's aggregated EE**	2.46	2.71	2.57	-1.05%	2.63%	0.53%	12.94%
	Zone's international EE / Zone's aggregated EE	0.86	0.87	0.86	0.40%	-0.05%	0.20%	4.81%
	Zone's domestic EE / Zone's international EE	**2.87**	**3.13**	**2.99**	-1.45%	2.68%	0.33%	7.76%
Latin America	**Zone's domestic EE / Zone's aggregated EE**	1.69	1.44	1.57	-0.34%	-4.93%	-2.36%	-42.27%
	Zone's international EE / Zone's aggregated EE	0.68	0.75	0.72	0.28%	3.81%	1.80%	50.69%
	Zone's domestic EE / Zone's international EE	**2.53**	**1.89**	**2.21**	-0.61%	-8.42%	-4.09%	-61.69%
Russia and CIS	**Zone's domestic EE / Zone's aggregated EE**	n.a.	2.04	n.a.	n.a.	0.45%	n.a.	4.59% *
	Zone's international EE / Zone's aggregated EE	n.a.	0.69	n.a.	n.a.	-0.07%	n.a.	-0.75% *
	Zone's domestic EE / Zone's international EE	n.a.	**2.99**	n.a.	n.a.	0.53%	n.a.	5.38% *
Africa	**Zone's domestic EE / Zone's aggregated EE**	2.30	4.29	3.24	7.71%	0.09%	4.33%	165.11%
	Zone's international EE / Zone's aggregated EE	0.86	0.74	0.81	-1.72%	-0.43%	-1.16%	-23.60%
	Zone's domestic EE / Zone's international EE	**2.72**	**5.81**	**4.06**	9.60%	0.53%	5.56%	247.03%
The Middle East	**Zone's domestic EE / Zone's aggregated EE**	0.82	1.93	1.28	8.37%	-2.79%	3.37%	114.41%
	Zone's international EE / Zone's aggregated EE	1.05	0.96	1.01	-0.81%	0.24%	-0.36%	-7.91%
	Zone's domestic EE / Zone's international EE	**0.80**	**2.02**	**1.21**	9.26%	-3.02%	3.74%	132.81%
Asian countries and Oceania	**Zone's domestic EE / Zone's aggregated EE**	1.81	1.65	1.74	-3.52%	-1.28%	-2.56%	-44.88%
	Zone's international EE / Zone's aggregated EE	0.85	0.87	0.86	0.55%	0.76%	0.64%	15.86%
	Zone's domestic EE / Zone's international EE	**2.15**	**1.91**	**2.05**	-4.05%	-2.03%	-3.18%	-52.43%
China	**Zone's domestic EE / Zone's aggregated EE**	n.a.	1.58	n.a.	n.a.	-0.73%	n.a.	-7.03% *
	Zone's international EE / Zone's aggregated EE	n.a.	0.70	n.a.	n.a.	-0.81%	n.a.	-7.77% *
	Zone's domestic EE / Zone's international EE	n.a.	**2.27**	n.a.	n.a.	0.08%	n.a.	0.80% *
World	**Zone's domestic EE / Zone's aggregated EE**	1.10	1.41	1.23	2.99%	0.68%	1.98%	56.83%
	Zone's international EE / Zone's aggregated EE	0.94	0.79	0.88	-2.21%	0.05%	-1.23%	-24.82%
	Zone's domestic EE / Zone's international EE	**1.14**	**1.78**	**1.33**	5.31%	0.63%	3.25%	108.60%

Table 17: Comparison of domestic and international EE coefficients (ktoe/ATK) within each zone (1983-2006). Source: Authors, from ICAO data.

Note: a ratio >(<) 1 means that the energy efficiency of the kind of travel in numerator is inferior (superior) to the kind of travel in denominator. These ratios aim at comparing. within each region, *(i)* the domestic vs. aggregated (domestic+international) EE coefficients mean values, *(ii)* the international vs. aggregated (domestic+international) EE coefficients mean values, and *(iii)* the domestic *vs.* international EE coefficients mean values.

Note: * means that rates of change are not computed for the whole period, but for the second sub-period.

Regions (Energy gains hypothesis)	**RTK** (10^9) **(mean growth rate per year)**		**Corresponding ATK** (10^9) **(mean growth rate per year)**		**Jet fuel-Ton** (10^3) **(consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-3.18%)	246.2	405.9 (3.0%)	403.9	627.5 (2.6%)	86.96 38.7%	77.98 29.9%	-10%	-0.6%
Europe (-2.97%)	163.5	310.0 (3.9%)	235.2	413.1 (3.5%)	49.78 22.2%	52.37 20.1%	5%	0.4%
Latin America (-2.73%)	28.5	64.7 (5.0%)	47.1	89.3 (3.9%)	16.68 7.4%	16.57 6.4%	-1%	0.04%
Russia and CIS (-5.79%)	9.6	21.1 (4.9%)	15.4	28.1 (3.8%)	9.03 4.0%	6.00 2.3%	-34%	-2.2%
Africa (-7.22%)	9.9	30.0 (6.7%)	17.3	47.6 (6.2%)	7.25 3.2%	5.59 2.1%	-23%	-1.5%
The Middle East (-8.68%)	24.1	48.7 (4.5%)	39.9	74.3 (4.0%)	7.19 3.2%	2.86 1.1%	-60%	-5.0%
Asian countries and Oceania (-2.88%)	98.6	296.4 (6.9%)	158.2	465.2 (6.8%)	32.71 14.6%	58.52 22.4%	79%	3.7%
China (-1.65%)	56.9	215.0 (8.2%)	82.8	296.7 (7.9%)	15.10 6.7%	40.77 15.6%	170%	6.1%
World (-3.22%)*	637.4	1391.8 (4.7%)	999.8	2041.9 (4.3%)	224.69 100%	260.67 100%	16%	0.9%

‘*Green energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region's name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region's Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.
* This figure corresponds to the world level energy gains (per year until 2025) resulting from regional energy gains hypothesis as defined in the ‘*Green energy gains*’ traffic efficiency improvements scenario.

Table 24: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
***‘IMF GDP growth rates’* air traffic forecasts scenario**.

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-2.61%)	246.1	391.2 (2.8%)	403.8	604.8 (2.4%)	87.95 38.5%	84.04 31.2%	-4%	-0.3%
Europe (-2.61%)	163.3	287.7 (3.5%)	235.0	383.5 (3.0%)	50.10 21.9%	52.15 19.3%	4%	0.3%
Latin America (-2.61%)	28.5	62.7 (4.8%)	47.1	86.5 (3.7%)	17.06 7.5%	20.00 7.4%	17%	1.0%
Russia and CIS (-2.61%)	9.6	19.1 (4.2%)	15.3	25.4 (3.2%)	9.63 4.2%	10.19 3.8%	6%	0.5%
Africa (-2.61%)	9.9	27.6 (6.2%)	17.2	43.8 (5.6%)	7.97 3.5%	12.92 4.8%	62%	2.9%
The Middle East (-2.61%)	24.0	42.3 (3.7%)	39.7	64.6 (3.2%)	8.15 3.6%	8.45 3.1%	4%	0.5%
Asian countries and Oceania (-2.61%)	98.3	253.8 (6.0%)	157.7	398.4 (5.8%)	32.79 14.4%	52.82 19.6%	61%	3.1%
China (-2.61%)	56.7	184.4 (7.3%)	82.5	254.5 (6.9%)	14.76 6.5%	29.03 10.8%	97%	4.1%
World (-2.61%)	636.5	1268.9 (4.2%)	998.4	1861.5 (3.8%)	228.40 100%	269.59 100%	18%	1.0%

‘*Homogeneous energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft’s available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region’s name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{T\,jet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region’s Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.

Table 25: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
‘*Low GDP growth rates*’ Air traffic forecasts scenario.

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-3.18%)	246.1	391.2 (2.8%)	403.8	604.8 (2.4%)	86.92 38.7%	75.17 31.6%	-14%	-0.9%
Europe (-2.97%)	163.3	287.7 (3.5%)	235.0	383.5 (3.0%)	49.73 22.2%	48.61 20.4%	-2%	-0.1%
Latin America (-2.73%)	28.5	62.7 (4.8%)	47.1	86.5 (3.7%)	16.67 7.4%	16.06 6.7%	-4%	-0.14%
Russia and CIS (-5.79%)	9.6	19.1 (4.2%)	15.3	25.4 (3.2%)	9.01 4.0%	5.42 2.3%	-40%	-2.8%
Africa (-7.22%)	9.9	27.6 (6.2%)	17.2	43.8 (5.6%)	7.23 3.2%	5.14 2.2%	-29%	-2.0%
The Middle East (-8.68%)	24.0	42.3 (3.7%)	39.7	64.6 (3.2%)	7.16 3.2%	2.49 1.0%	-65%	-5.8%
Asian countries and Oceania (-2.88%)	98.3	253.8 (6.0%)	157.7	398.4 (5.8%)	32.61 14.5%	50.11 21.1%	54%	2.8%
China (-1.65%)	56.7	184.4 (7.3%)	82.5	254.5 (6.9%)	15.05 6.7%	34.97 14.7%	132%	5.2%
World (-3.22%)*	636.5	1268.9 (4.2%)	998.4	1861.5 (3.8%)	224.38 100%	237.96 100%	6%	0.4%

‘*Green energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region's name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region's Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.
* This figure corresponds to the world level energy gains (per year until 2025) resulting from regional energy gains hypothesis as defined in the ‘*Green energy gains*’ traffic efficiency improvements scenario.

Table 26: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
‘*Low GDP growth rates*’ Air traffic forecasts scenario.

Regions (Energy gains hypothesis)	RTK (10^9) (mean growth rate per year)		Corresponding ATK (10^9) (mean growth rate per year)		Jet fuel-Ton (10^3) (consumption of the region-%)		% variation of Jet-Fuel (2008-2025)	Mean growth rate per year of Jet-Fuel (2008-2025)
	2008	2025	2008	2025	2008	2025		
Central and North America (-2.61%)	246.3	421.0 (3.2%)	404.1	650.9 (2.8%)	88.02 38.4%	90.43 28.0%	3%	0.2%
Europe (-2.61%)	163.7	333.7 (4.4%)	235.4	444.8 (3.9%)	50.20 21.9%	60.50 18.8%	21%	1.2%
Latin America (-2.61%)	28.6	66.8 (5.2%)	47.1	92.2 (4.1%)	17.08 7.5%	21.31 6.6%	25%	1.4%
Russia and CIS (-2.61%)	9.6	23.4 (5.5%)	15.4	31.1 (4.4%)	9.68 4.2%	12.49 3.9%	29%	1.7%
Africa (-2.61%)	10.0	32.7 (7.2%)	17.3	51.8 (6.7%)	8.00 3.5%	15.26 4.7%	91%	3.9%
The Middle East (-2.61%)	24.2	56.0 (5.4%)	40.1	85.4 (4.9%)	8.21 3.6%	11.17 3.5%	36%	2.1%
Asian countries and Oceania (-2.61%)	98.9	345.7 (7.9%)	158.7	542.6 (7.8%)	32.99 14.4%	71.95 22.3%	118%	5.0%
China (-2.61%)	57.1	250.3 (9.2%)	83.0	345.4 (8.8%)	14.85 6.5%	39.40 12.2%	165%	6.0%
World (-2.61%)	638.3	1529.5 (5.3%)	1001.2	2244.2 (4.9%)	229.02 100%	322.49 100%	41%	2.1%

'*Homogeneous energy gains*' traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft's available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region's name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region's Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.

Table 27: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
'*High GDP growth rates*' Air traffic forecasts scenario.

Regions (Energy gains hypothesis)	**RTK (10^9) (mean growth rate per year)**		**Corresponding ATK (10^9) (mean growth rate per year)**		**Jet fuel-Ton (10^3) (consumption of the region-%)**		**% variation of Jet-Fuel** (2008-2025)	**Mean growth rate per year of Jet-Fuel** (2008-2025)
	2008	**2025**	**2008**	**2025**	**2008**	**2025**		
Central and North America (-3.18%)	246.3	421.0 (3.2%)	404.1	650.9 (2.8%)	86.99 38.7%	80.89 28.3%	-7%	-0.4%
Europe (-2.97%)	163.7	333.7 (4.4%)	235.4	444.8 (3.9%)	49.83 22.1%	56.38 19.7%	13%	0.8%
Latin America (-2.73%)	28.6	66.8 (5.2%)	47.1	92.2 (4.1%)	16.69 7.4%	17.10 6.0%	2%	0.22%
Russia and CIS (-5.79%)	9.6	23.4 (5.5%)	15.4	31.1 (4.4%)	9.06 4.0%	6.65 2.3%	-27%	-1.6%
Africa (-7.22%)	10.0	32.7 (7.2%)	17.3	51.8 (6.7%)	7.26 3.2%	6.07 2.1%	-16%	-1.0%
The Middle East (-8.68%)	24.2	56.0 (5.4%)	40.1	85.4 (4.9%)	7.22 3.2%	3.29 1.1%	-54%	-4.2%
Asian countries and Oceania (-2.88%)	98.9	345.7 (7.9%)	158.7	542.6 (7.8%)	32.81 14.6%	68.25 23.9%	108%	4.7%
China (-1.65%)	57.1	250.3 (9.2%)	83.0	345.4 (8.8%)	15.14 6.7%	47.47 16.6%	214%	7.0%
World (-3.22%)*	638.3	1529.5 (5.3%)	1001.2	2244.2 (4.9%)	224.99 100%	286.10 100%	27%	1.5%

‘*Green energy gains*’ traffic efficiency improvements scenario

Notes:
The first two columns present 2008 and 2025 air traffic forecasts expressed in RTK (first column) and ATK (second column).
ATK are computed from RTK forecasts using the following equations: $RTK = WLF \times ATK \Leftrightarrow ATK = \frac{RTK}{WLF}$ with WLF the percentage of an aircraft’s available ton effectively occupied during a flight. Because airlines never fully fill their aircrafts, $ATK > RTK$ (see Section 2.1 for more details). Assumptions on the evolution of WLF between 2008 and 2025 are detailed in Section 4.2.
In the first two columns, figures into brackets represent yearly mean growth rate of air traffic forecasts between 2008 and 2025. Note that for each zone and at the world level, the yearly mean growth rate of air traffic forecasts *expressed in ATK* is always inferior to the yearly mean growth rate of air traffic forecasts *expressed in RTK*.

The other three columns concern Jet-Fuel forecasts.
The third column presents 2008 and 2025 Jet-Fuel forecasts expressed in Ton (10^3). For each geographical region, Jet-Fuel forecasts are computed from ATK using *i)* Energy Efficiency (EE) coefficients presented in Section 3 and *ii)* a regional energy gains hypothesis. Energy gains hypothesis are indicated into brackets under each geographical region’s name. These figures correspond to the EE coefficient yearly mean growth rate hypothesis. A negative sign means an energy efficiency improvement hypothesis as $EE_{i,t} = \frac{Tjet_{i,t}}{ATK_{i,t}}$ with $EE_{i,t}$ the abbreviation for EE coefficient in zone i at time t. Thus defined, EE may be interpreted as the quantity of Jet-Fuel (Tjet, expressed in ton of Jet-Fuel) required to power the transportation of one ton over one kilometer (ATK). A decrease of EE coefficients means then that quantities of Jet-Fuel required to power the transportation of one ton over one kilometer have decreased.
In the third column, figures expressed in % terms indicate the share of each region’s Jet-Fuel consumption in 2008 and 2025.
The fourth and the fifth column indicate, respectively, the % variation and the corresponding yearly mean growth rate of Jet-Fuel forecasts between 2008 and 2025.
* This figure corresponds to the world level energy gains (per year until 2025) resulting from regional energy gains hypothesis as defined in the ‘*Green energy gains*’ traffic efficiency improvements scenario.

Table 28: Air Traffic (expressed in 10^9 RTK and 10^9 ATK) and Jet-Fuel (expressed in Ton (10^3)) Forecasts for the years 2008 and 2025. Forecasts are presented at the world level (last line) and for each geographical regions (other lines).
‘*High GDP growth rates*’ Air traffic forecasts scenario.

		Mean values			Yearly average growth rates		
		1983	1996	2007	Sub-periods		Whole period
					1983-1996	1996-2007	1983-2007
Central and North America	**RPK**	479.53	1 022.09	1 444.00	5.99%	3.19%	4.70%
	ASK	779.16	1 478.83	1 819.70	5.05%	1.90%	3.60%
	PLF	61.54%	69.11%	79.35%	0.90%	1.26%	1.06%
Europe	**RPK**	214.22	697.56	1 212.24	9.51%	5.15%	7.49%
	ASK	333.19	953.36	1 545.70	8.42%	4.49%	6.60%
	PLF	64.30%	73.17%	78.43%	1.00%	0.63%	0.83%
Latin America	**RPK**	27.56	72.61	162.63	7.74%	7.61%	7.68%
	ASK	49.90	121.08	235.60	7.06%	6.24%	6.68%
	PLF	55.22%	59.97%	69.03%	0.64%	1.29%	0.93%
Russia and CIS	**RPK**	176.47	36.47	86.43	-11.42%	8.16%	-2.93%
	ASK	210.98	59.99	117.86	-9.22%	6.33%	-2.40%
	PLF	83.64%	60.79%	73.33%	-2.43%	1.72%	-0.55%
Africa	**RPK**	28.91	27.48	69.12	-0.39%	8.75%	3.70%
	ASK	49.35	44.99	102.36	-0.71%	7.76%	3.09%
	PLF	58.59%	61.08%	67.52%	0.32%	0.92%	0.59%
The Middle East	**RPK**	32.67	55.34	203.10	4.14%	12.55%	7.91%
	ASK	50.95	81.15	268.86	3.65%	11.50%	7.18%
	PLF	64.13%	68.20%	75.54%	0.47%	0.93%	0.68%
Asian countries and Oceania	**RPK**	134.55	446.32	713.53	9.66%	4.36%	7.20%
	ASK	206.03	653.53	962.07	9.29%	3.58%	6.63%
	PLF	65.31%	68.29%	74.17%	0.34%	0.75%	0.53%
China	**RPK**	9.65	106.09	357.05	20.25%	11.66%	16.23%
	ASK	13.70	149.64	463.80	20.19%	10.83%	15.81%
	PLF	70.48%	70.90%	76.98%	0.05%	0.75%	0.37%
World	**RPK**	1 103.60	2 463.99	4 248.13	6.37%	5.08%	5.78%
	ASK	1 693.29	3 542.62	5 515.99	5.84%	4.11%	5.04%
	PLF	65.17%	69.55%	77.01%	0.50%	0.93%	0.70%

Table 29: Passengers' Air Traffic (expressed in RPK (billion) and ASK (billion)) and Passenger Load Factors for each zone during 1983-2007. Source: Authors, from ICAO data.

Note: the above table corresponds to Table 13, expressed in RPK rather than in RTK.

		Mean values		
		1983	**1996**	**2007**
Central and North America	**Domestic (RPK)**	73.03%	68.84%	67.09%
	International (RPK)	26.97%	31.16%	32.91%
	Domestic (ASK)	74.36%	69.95%	66.75%
	International (ASK)	25.64%	30.05%	33.25%
Europe	**Domestic (RPK)**	11.43%	9.61%	7.51%
	International (RPK)	88.57%	90.39%	92.49%
	Domestic (ASK)	11.33%	10.73%	8.40%
	International (ASK)	88.67%	89.27%	91.60%
Latin America	**Domestic (RPK)**	42.28%	38.54%	58.75%
	International (RPK)	57.72%	61.46%	41.25%
	Domestic (ASK)	39.06%	40.17%	59.80%
	International (ASK)	60.94%	59.83%	40.20%
Russia and CIS	**Domestic (RPK)**	94.15%	34.23%	36.26%
	International (RPK)	5.85%	65.77%	63.74%
	Domestic (ASK)	92.46%	34.22%	36.42%
	International (ASK)	7.54%	65.78%	63.58%
Africa	**Domestic (RPK)**	20.42%	11.10%	12.99%
	International (RPK)	79.58%	88.90%	87.01%
	Domestic (ASK)	18.16%	10.38%	12.03%
	International (ASK)	81.84%	89.62%	87.97%
The Middle East	**Domestic (RPK)**	24.74%	11.05%	7.02%
	International (RPK)	75.26%	88.95%	92.98%
	Domestic (ASK)	21.58%	8.95%	6.97%
	International (ASK)	78.42%	91.05%	93.03%
Asian countries and Oceania	**Domestic (RPK)**	15.55%	25.96%	24.79%
	International (RPK)	84.45%	74.04%	75.21%
	Domestic (ASK)	16.42%	27.18%	26.17%
	International (ASK)	83.58%	72.82%	73.83%
China	**Domestic (RPK)**	0.00%	43.47%	59.24%
	International (RPK)	100.00%	56.53%	40.76%
	Domestic (ASK)	0.00%	42.44%	58.67%
	International (ASK)	100.00%	57.56%	41.33%
World	**Domestic (RPK)**	53.23%	39.86%	37.63%
	International (RPK)	46.77%	60.14%	62.37%
	Domestic (ASK)	52.29%	41.19%	37.77%
	International (ASK)	47.71%	58.81%	62.23%

Table 30: Repartition of Passengers' Air Traffic (expressed in RPK and ASK) within each zone (1983-2007): domestic *vs.* international. Source: Authors, from ICAO data.

Note: the above table corresponds to Table 14, expressed in RPK rather than in RTK.