Assessing the long-term impact of air liberalization on international air passenger demand: A new model up to 2050

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ABSTRACT
We present a new model to project international air transport passenger demand up to 2050. The model is used to assess the long-term impact on air passenger demand of continuing or obstructing liberalization, especially the liberalization of traffic rights and price setting. Our results show that existing industry forecasts may be somewhat optimistic. A sustained growth in international air passenger demand relies on a continuous liberalization and especially on the network being able to grow with demand. In all cases, the growth will slow down after 2030 as a result of slowing down of global income and population growth as well as saturation of the network.
1. INTRODUCTION

Historically, air passenger traffic has grown at an average annual rate of 9% between 1960 and 2000 and around 5% since. The past growth has been partly driven by growth in average income, population and demographics. It is also widely accepted that market liberalization, by driving prices down and fostering the creation of new connections, new carriers and new business models, has played a significant role in maintaining growth in passenger demand.

The impact of liberalization on prices and network structure – and eventually on demand is well documented through numerous case studies looking at historical data. There is a wide body of literature on the subject, starting from the domestic deregulation in the United States in 1978 (1,2,3). Several studies use variables representing the extent of liberalization between two countries within regression of demand volumes or air fares. Maillebiau and Hansen (4), for example, analyze the impact of liberalization between the United States and European countries in the 1990s using dummy variables (free price or capacity setting =1, otherwise =0). This type of analysis has flourished since ICAO made available a list of air service agreements between countries and the seminal work of Gönenc and Nicoletti (5). The Air Liberalization Index of the World Trade Organization, derived from the list of air service agreements recorded by ICAO, also serves as basis for several studies (6,7). Generally, studies on air liberalization use linear regression (6,7,8). One study (9) incorporates the dummy variables into a gravity-type model. In all cases, the parameters associated with liberalization indicate positive impact of liberalization on demand and negative impact on prices. (4,10) indicate further that liberalization may have a positive impact on the number of routes and the frequencies served between two countries.

The historical impact of air liberalization on air transport demand is thus well documented. However, the potential long-term effects of continuing air liberalization, and in particular the liberalization of traffic rights, or on the contrary, obstructing the future process of liberalization, remain unclear and has been overlooked in research.

At the global level, several long-term aviation forecasts are produced by stakeholders. The most commonly referred projections are the Boeing Current Market Outlook (11) and the Airbus Global Market Forecast (12). They sometimes serve as basis for other forecasting work, for instance on CO₂ emissions (13). The International Civil Aviation Organization (ICAO) (14) and the International Air Transport Association (IATA) projections are also routinely quoted. Several other manufacturers publish their own forecasts (15,16). All the above forecasts share the view that the average annual growth in global Revenue Passenger Kilometers (RPKs) in the two coming decades will be around 5%, continuing the current trend. Regional breakdowns indicate stronger growth in developing economies, especially in Asia. IATA’s projections are slightly more conservative, suggesting an annual average growth around 4%.

There is a limited access to underlying data and methodologies, making it difficult to further assess these results (17). However, most of the long-term forecasting models seem to rely on trend continuation, assuming that the gain in competitiveness from liberalization observed in the past will continue in the coming decades. Further, these models do not take into account possible indirect routings. They use true origin-destination demand or on-flight demand as dependent variable without considering the possibility for different itineraries. Finally, the relation between supply and demand is mostly one sided; increase in passenger demand leads to increased available seat kilometers and, in turn, to more aircraft movements. Induced demand and indirect demand do not seem to enter any of these models.
Indeed, studies on the future consequences of air liberalization are lacking. We aim at shedding light on this issue and assess the long-term impact of two characteristics (prices and connectivity) of air liberalization under different scenarios on aviation demand by developing a new international air passenger model.

Our model evaluates future international air travel volumes up to 2050 according to several contrasting scenarios which reflect different evolution pathways for the global air market. The model presents several new features. First, the geographical precision of the model allows for studying the impact of indirect routes on travel demand. Second, the model takes into account the dynamics of network evolution. Finally, we look at characteristics of air liberalization and how this translates into passenger demand at the global level under a coherent framework rather than adopting a piecemeal approach comparing before and after on selected markets.

We hope that this new work also contributes to discussion on air passenger forecasts more broadly. To that end, we describe the model and data in detail, making it also subject to changes and improvements. This work is part of ITF Transport Outlook prepared by the International Transport Forum at the OECD. The model is built flexibly and can support the analysis of various policy options for aviation.

The remaining of the paper is organized as follows. After an overview of the modeling framework (Section 2), Sections 3 and 4 detail the new global air passenger model in detail. Section 5 provides results about international air passenger demand under alternative liberalization scenarios. Finally, in Section 6, we discuss some of the implications of our results and present future research needs.

2. OVERVIEW OF THE MODELING FRAMEWORK

The international air passenger model projects international passenger volumes up to 2050 based on alternative air liberalization scenarios. The model is structures in three main components:

- A gravitational model for the estimation of true origin-destination demand.
- A route choice model.
- A network evolution model.

Figure 1 introduces the workflow of the model with the three main components, their inputs and outputs.
FIGURE 1 Main components and workflow of the forecasting procedures

The gravitational model estimates origin-destination passenger demand by looking at the different drivers of air travel. The route choice model assigns this demand onto the network by analyzing the different possible routes between each origin and destination. These two models are jointly calibrated with on-flight passenger volume data obtained from ICAO, with 2010 as a base year.

Data sources
The model relies on well-established sources. Underlying economic projections (GDP and trade) come from the OECD and population forecasts from the United Nations. The air network is built with the Innovata Schedules Reference Service, and completed with information on price gathered from Skyscanner. Finally, ICAO provided demand data for the base-year, which we cross-checked and completed with open sources such as Eurostat, the American, Australian and Chilean civil aviation authorities.

Geographical representation of the world and the air network
The world is divided into 310 regions, each represented by its main airport (in 2010) in terms of departing seat capacity. Cities are aggregated to regions using an adapted p-median procedure over all the cities around the world classified by the United Nations in 2010 (2,539 cities). The objective function for this aggregation is based on the minimization of a distance function which includes two components: GDP density and geographical distance. This procedure is explained in more detail in (18). Regions do not cross national boundaries but large countries are divided into multiple regions. For instance, the United States is divided into 20 regions.

The air network for the model results from the aggregation of the full SRS database at the region pair level. Out of the 95,790 possible direct links (all pairs of regions, except those having the same region as origin and destination), we find 8,649 actually existed in 2010. One of the main features of this new forecasting exercise is that it takes into account indirect routes. These are reconstructed using up to two connections. The frequency of an indirect route is set to be the minimum of the frequencies of all the flights of the route. The waiting time at a transfer airport comes from the maximum of frequency of the inward and outward flights.
3. GRAVITATIONAL AND ROUTE CHOICE MODELS

Gravitational model framework
We use a gravity-type formula to model the demand for air transport at a passenger origin-destination level. Tested specifications include regional socio-economic variables and some variables from the supply side. Mathematically, all tested specifications have the following form:

\[ d_{ij} = \frac{E_i A_j T_{ij}}{C_{ij}} \]

Where \( d_{ij} \) is the (true od) demand between region \( i \) and \( j \), \( E_i \) is the emission potential for \( i \), \( A_j \) is the attraction potential for region \( j \), \( T_{ij} \) represents the socio-economic relations (such as trade or emigration) and \( C_{ij} \) the (generalised) travel time between the two regions.

Route choice model
The route choice model allocates passengers on the different possible itineraries for a single origin-destination pair. The final model has a nested structure based on the number of required stop for the itinerary. The variables in the utility of each route are; travel time (including the estimated transfer time), price, frequency, and transfer penalty. A Box-Cox transform is applied to travel time to account for the different impact of travel time savings depending on the base travel time.

Calibration process
The only data available for calibration was on-flight origin-destination counts for all international air links and the proportion of direct, one-stop and two-stop flights between large markets (Europe-North America for instance). As a result, we were not able to calibrate the two models described in the previous sections separately. We therefore carried out a joint calibration. The problem is similar to the question of estimating an origin-destination matrix on the road network using traffic counts coming from cordon survey and the methodology adopted closely resembles that explained in (19). Schematically, the procedure finds the set of parameters which minimize the difference between the observed demand and the estimated demand on all arcs.

Given a set of values for the parameters, the estimated on-flight demand \( d_k \) for each link \( k \), by summing up the demand for all paths that use link \( k \) is:

\[ d_k = \sum_{i,j} \sum_{p \in P_{ij}} \pi_p d_{ij}. \]

The objective function to minimize is then the sum of absolute errors for all international links:

\[ \Delta = \sum_k |d_k - d^0_k|, \]

where \( d^0_k \) is the observed on-flight demand for link \( k \). This gives a set of parameters that are later slightly modified by rerunning the calibration but adding to the objective function a comparison between estimated and observed proportions of direct trips.

Following this calibration procedure multiple times with different set of parameters allows for variable selection. Two considerations are important in this process:

- The quality of the fit, as measured by the goodness-of-fit function as well as other measures of calibration quality, such as errors by markets (see the next paragraph).
Avoiding over-fitting. The problem is especially acute for the selection of supply variables in the generalized cost. Including frequency, or the log-sum, yield extremely high level of fit but only reflect the adaptation of supply to demand rather than the impact of supply on demand.

Calibration results
The quality of the calibration is overall good, with global numbers obtained accurately. The average error on the 310 links is 13% in 2010 and 21% when applying the model to 2008. At the country pair level, these errors go down to 7% and 9%. Some origin-destination pairs stand out, especially touristic areas (e.g. in the Caribbean islands). Including a tourism indicator in the model could solve this issue. As a side note, model calibration and assessment would improve significantly if origin-destination or routing data were available.

The estimates and the coefficients for the models are shown in Table 1. The final model has the following form:

\[
E = A = \text{GDP}^{a_{GDP}} \text{radius}^{a_{\text{radius}}} \text{pop}^{a_{\text{pop}}}
\]

\[
T = \text{trade}^{a_{\text{trade}} \text{migration}^{a_{\text{migration}}}} (1 + a_{\text{language}} \delta_{\text{language}})(1 + a_{\text{rail}} \delta_{\text{rail}})
\]

\[
C = \text{time}^{a_{\text{time}_{\text{short}}} \text{time}_{\text{>4h}}^{a_{\text{time}_{\text{long}}}} \text{time}_{\text{>4h}}^{a_{\text{time}_{\text{>4h}}}}} \exp(a_{\text{competition}} h + a_{\text{transfer}} \text{transfers})
\]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravity model</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Regional variables</strong></td>
<td></td>
</tr>
<tr>
<td>GDP – 2010 M$</td>
<td>0.4</td>
</tr>
<tr>
<td>Population in cities above 1M</td>
<td>0.08</td>
</tr>
<tr>
<td>Equivalent radius – km</td>
<td>-0.05</td>
</tr>
<tr>
<td><strong>Inter-regional variables</strong></td>
<td></td>
</tr>
<tr>
<td>Service trade – 2010 M$</td>
<td>0.05</td>
</tr>
<tr>
<td>Common language</td>
<td>0.4</td>
</tr>
<tr>
<td>Migration – persons</td>
<td>0.07</td>
</tr>
<tr>
<td>Presence of rail link</td>
<td>-0.4</td>
</tr>
<tr>
<td><strong>Link variables</strong></td>
<td></td>
</tr>
<tr>
<td>Minimum travel time (&lt;4 h)</td>
<td>0.1</td>
</tr>
<tr>
<td>Minimum travel time (&gt;4 h)</td>
<td>0.3</td>
</tr>
<tr>
<td>Minimum number of transfers</td>
<td>-2.5</td>
</tr>
<tr>
<td><strong>Price related variables</strong></td>
<td></td>
</tr>
<tr>
<td>H-index (&gt;3500 km)</td>
<td>0.3</td>
</tr>
<tr>
<td>Presence of LCC (&lt; 3500 km)</td>
<td>-0.4</td>
</tr>
<tr>
<td><strong>Routing model</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Alternative-level variables</strong></td>
<td></td>
</tr>
<tr>
<td>Travel time – h</td>
<td>0.05</td>
</tr>
<tr>
<td>Box-Cox power transform</td>
<td>0.3</td>
</tr>
<tr>
<td>Frequency – per day</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Nest-level variables</strong></td>
<td></td>
</tr>
<tr>
<td>Penalty for one stop (with direct)</td>
<td>-5.0</td>
</tr>
<tr>
<td>Penalty for two stops (with direct)</td>
<td>-3.1</td>
</tr>
<tr>
<td>Penalty for one stop (no direct)</td>
<td>0</td>
</tr>
<tr>
<td>Penalty for two stops (no direct)</td>
<td>-19.6</td>
</tr>
<tr>
<td><strong>Nest coefficients</strong></td>
<td></td>
</tr>
<tr>
<td>One transfer</td>
<td>1.2</td>
</tr>
<tr>
<td>Two transfers</td>
<td>3.1</td>
</tr>
</tbody>
</table>

TABLE 1 Estimates of the parameters for the gravity and route choice models
Elasticity to GDP
The elasticity in this cross-sectional study is much lower than the elasticity resulting from the analysis of panel or historical data (20), a result also found in (9). To be comparable, the elasticity found here needs to be multiplied by 2 (GDP at origin and destination) and to incorporate the effect of trade, which grows with GDP. An elasticity of trade to GDP of 1 results in a value of 0.95 for the elasticity of origin-destination passenger volumes to GDP, still lower than one. There is much debate on the difference between elasticities resulting from cross-sectional and panel models, or short-term versus long-term elasticity; the level of aggregation (country-to-country, route, etc.) also impacts elasticity values. We could identify three effects which may play a role in the observed differences:

- The gravity model controls for some supply parameters that are not accounted for in all historical models, such as effective competition and the presence of low-cost carriers.
- Despite some attempts at introducing several GDP coefficients (by main market, distance or income), no significant differences could be found. The model retains a single GDP-elasticity for the whole world. It may be that the very high values found in some historical studies result from unobserved changes in the specific market to which they apply rather than an intrinsic effect of GDP.
- The elasticity in this model measures the changes in true origin-destination passenger volumes, rather than changes in RPKs or on-flight passengers.

Elasticity to travel time
Elasticity to travel time is also very small, especially for short routes (less than 4 hours). On the contrary, the minimum number of stops has a very significant impact on travel demand: all other things being equal, the unavailability of a direct link divides the number of passengers by \( \exp(2.5)=12 \). This is a sensitive point of the model because the parameter also reflects the current match of the air network to demand.

Impact of prices
Even though price data was available for this study, we do not include it directly as an element of the gravity model because one year of data alone does not allow to assess the dynamics of price evolution satisfactorily (in the case of the network, four years of data were available over the decade 2004-2013). However, a detailed analysis of this data (see Section 5 for more detail) shows that effective competition and, for short-haul markets, the presence of low-cost carriers explains most of the differences in kilometric prices. Including these two variables directly into the gravity model greatly improves the quality of its fit.

Panel terms
Because calibration and prediction occur at a detailed level (310 regions), systematic panel terms would result in over-fitting and destroy any potential effect of other variables. However, regional variations are observed and yield consistent over or under estimation of passenger traffic. As an intermediate solution, two panel terms per sub-continent are fitted to the data. They complement the control variables already included in the model: equivalent radius of the country (more travel from regions belonging to countries with few domestic opportunities) and common languages (more exchanges between regions having one common official language). Two other variables act as de facto control variables because they remain constant throughout the studied period, even though different evolution paths could form the basis of new scenarios. These are migration numbers and presence of rail link.
NETWORK EVOLUTION MODEL

Introduction

One essential feature of the air network lies in its constant evolution, adapting to demand or commercial constraints. Because our forecasts do not differentiate between airports and airlines, it is difficult to fully render the mechanisms underlying changes in the air network. In any case, such a detailed exercise is not relevant given the long time horizon of the model. However, observations at the region-pair level reveal interesting phenomena which will serve as basis for the different network evolution scenarios.

The literature documents many cases where liberalization has led to lower prices, increased connectivity (in particular at secondary airports served by low-cost carriers) and to an overall increase in the supply of air transport services. The increase of passenger demand following air liberalization can be traced back to one of these three aspects. We take the view that future scenarios of air liberalization can be formulated in terms of network evolution.

Price and connectivity form the basis of the scenarios. The question of capacity is not studied: for a given origin-destination pair, we assume frequency and capacity grow to accommodate any increase in demand. Frequency at the region pair level results of a simple elasticity model, with values ranging from 0.5 to 0.7 depending on frequency and distance. This is a simplification, as air service agreements may define capacity and/or frequency limits. However, due to computational constraints, it was not possible to keep track of all passenger movements and compare them with capacity.

Competition

One desired effect of liberalization is increased competition between airlines. There is much debate about the best way to measure competition in the aviation market, relating to what constitutes a market and which airlines are actually competing.

The question of actual competition versus potential competition has arisen because of the emergence of global alliances and the development of code-sharing. Here, the constraint lies in the data available. The SRS database indicates the operating airline but does not give full information about code-shares. We compute competition at the level of the alliance, or that of the airline for airlines outside of alliances, with a single indicator: the Herfindahl–Hirschman Index (HHI), or h-index. To take into account indirect routes, a QSI weighted h-index is used. It was first introduced in (21) and is of wide use in competition assessment for instance in (22, 23, 24). The parameters for transfer penalties and QSI computation in this paper are taken from (22) with the exception that minimum travel time is the real minimum travel time from the available air network and is not derived from distance.

Another crucial question lies in the way to define markets. Looking at airport or city pairs obviates competition between parallel routes, especially when low-cost carriers serve secondary airports (23). Competition here is computed at the metropolitan area code level. Most secondary airports used by low-cost carriers are thus linked to the main airport in the area.

Figure 2 summarizes some results from the competition indicators. It presents the evolution of competition inside or between world regions, measured through the weighted average of h-indices, the weights being the available seat capacity. The weighted indicator is relatively stable at such a scale, short of a significant upwards trend from 2010 to 2013. This may be the result of consolidation in the market, with many Asian and Latin American airlines joining global alliances.
At first sight, competition within Western Europe appears very high. This stems from the
definition of relevant indirect routes, which is mostly adapted for long-distance. Within Western
Europe, there are very few indirect routes having a QSI greater than 0 and this restricts the
number of viable pairs. An ordinary least-square regression shows that, on average, h-index
decreases by approximately 0.1 for each 2500 km. To some extent, the same effect applies to
relations between Europe and North America: the number of indirect routes is limited by the
Atlantic Ocean.

These remarks show that a single definition of a competition indicator may not be
relevant. This does not have a large impact on the model, as it is found that the effect of
competition measured through the h-index only applies for long-haul (distance greater than 3500
km), with low-cost carriers having the most impact for short-haul. Moreover, the biggest impact
in the long-term for long-haul is for markets currently highly uncompetitive, such as Africa.

FIGURE 2: Average h-indices within or between world regions, weighted for available seat
capacity.

In order to build scenarios, plausible paths for the evolution of this competition indicator
need to be defined. Aside from regional differences we find that h-indices are on average
positively impacted by distance and frequency. This frequency includes indirect routes, their
frequency weighted similarly to the competition indicators. For future scenarios, this means that
h-indices need to stay plausible given the distance and frequency considered. Moreover, if new
links are added to the network, all related h-indices tend to decrease.

Prices
The data on prices consists of all requests made by the website’s users between November 2012
and October 2013 for return economy trips between any of the main airports associated with the
310 regions in the model. For each request, the price or prices of interest to the user are recorded
with the following information: date of the request, origin and departure, date outbound and
inbound, airline, price, number of stops outbound and inbound.
An ordinary least square regression controlling for departure month and advance purchase allows deriving kilometric prices that depend on the competition environment. Table 2 summarizes the results of this analysis. The main conclusion for the modeling is that competition and low-cost carriers have a very significant impact on prices and this impact is strongest for direct flights.

**TABLE 2: Estimates for the coefficients of the price model. All coefficients are significant at a 0.1% level, R-square 0.82. Prices in 2013 GBP.**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Direct</th>
<th>One stop</th>
<th>Two stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>345</td>
<td>463</td>
<td>831</td>
</tr>
<tr>
<td>LCC (distance&lt;3500km)</td>
<td>-129</td>
<td>-156</td>
<td>-283</td>
</tr>
<tr>
<td>Interaction distance h-index (distance&gt;3500km)</td>
<td>0.16</td>
<td>0.010</td>
<td>0.034</td>
</tr>
</tbody>
</table>

At the moment, the price model only plays a role for route choice. The model does not attempt to realistically explain prices between competitors: for a given origin-destination pair, all itineraries with the same number of stops have the same price. However, it is enough to differentiate the comparative advantage of direct and indirect routes in different competition environments. Moreover, having prices in the route choice models allows the study of more detailed price effects in the future.

We do not include prices in the gravity model as such because they would enter the same equation as GDP. Forecasting the future would require carefully assessing the evolution of prices. Rather, the two main drivers of price resulting from liberalization are included; competition and presence/absence of low-cost carriers.

**Connectivity**

Another aspect of air liberalization relates to connectivity. The exact motivation for an airline to open (or close) a direct link varies according to the airline business model and current financial state. However, observing the network at the intermediate level chosen in the model allows drawing some conclusions. We carry out a binomial regression of the presence of a direct link as a function of economic mass, competition and distance. For a given distance and economic mass, competition significantly increases the probability of a direct link to exist (see Table 3 below). However, the coefficient for low-cost carrier is negative. Low-cost carriers are overall present in the most profitable markets. This can be observed globally, as in this model, but also regionally. One possible explanation lies in the reliance of low-cost carriers on induced demand, which implies going for relations where there is a potential for induced demand.
TABLE 3: Estimates for the coefficients of the binomial regression for link presence between regions. All coefficients are significant at a 0.1% level.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.291558</td>
</tr>
<tr>
<td>log(economic mass)</td>
<td>0.556137</td>
</tr>
<tr>
<td>Log(distance)</td>
<td>-1.564890</td>
</tr>
<tr>
<td>LCC (distance&lt;3500 km)</td>
<td>-0.286060</td>
</tr>
<tr>
<td>h-index (distance&gt;3500 km)</td>
<td>-1.743298</td>
</tr>
</tbody>
</table>

5. INTERNATIONAL AIR PASSENGER DEMAND UP TO 2050

Alternative network evolution scenarios

We create three different scenarios for the evolution of the air network. They reflect the range of outcomes for international air passenger demand up to 2050 and consist of a lower bound (static network scenario, no further air traffic liberalization), an upper bound (dynamic network scenario, complete open skies) and an intermediate scenario. Each scenario is characterized by three elements: competition levels, entry of low-cost carriers for short haul routes, and ease of new direct link creation.

In the static network scenario, we assume no evolution on the supply side from 2010 onwards. In terms of prices, this means that low-cost carriers do not enter new origin-destination pairs and that h-indices are kept constant throughout the period. In terms of connectivity, the number of direct connections remains the same between 2010 and 2050.

On the contrary, in the dynamic network scenario the network is flexible. Connectivity increases and new links are being created whenever the probability of the presence of a link is higher than 0.5 in the model. Low-cost carriers penetrate new markets following the same rule. There is an overall increase in competition. By 2030, the h-index for all origin-destination pairs decreases to the lowest observed level in 2010 for each origin-destination pairs of similar distance, frequency and part of the same pair of sub-continents. Using the price model, this corresponds on average to 30% decrease in price for flights between Europe and North-America from 2010 to 2030 (in constant prices). Prices in Africa decrease by up to 60%.

The intermediate scenario models a future where the network responds to external growth factors. In this scenario, connectivity increases but the threshold for a new link to be created is set at twice the market (sub-continent pair) average. This limits the creation of induced demand. There is a natural increase of competition because of the new links but no exogenous decrease in the h-index as in the dynamic network scenario. The number of relations with a low cost carrier remains constant throughout the period.

Results

Table 4 summarizes our preliminary results for international air passenger volumes up to 2050. It shows the growth in demand, measured in revenue passenger kilometers. It also shows the number of regions that are directly connected in the network under the three scenarios (2010=100).

As expected, the air passenger volumes will continue to grow strongly in the future, albeit with significant differences between the three alternative scenarios from 2.7% in the static scenario to 5.7% in the dynamic scenario. Existing industry forecasts generally span to 2030 and, as discussed in the introduction, assume the past trends to continue with around 5% growth in
global revenue passenger kilometres. Our model yields results generally below those provided in other models except for the dynamic scenario. This reinforces our impression that most of the existing models assume that the current air liberalization trends will continue in the coming decades. This also shows that the currently observed levels of growth can only continue in the coming decades if the air network is flexible enough to sustain the exogenous growth in passenger volumes – due to economic and demographic growth – and create induced demand. However, in the dynamic scenario, the number of direct connections grows almost as fast as demand. This suggests that reaching growth levels above 5% may require an expansion of the air network that is unsustainable.

Growth in RPKs slows down after 2030 in all our scenarios. There are two main underlying reasons for this slowing down. In the static scenario, slower growth after 2030 is driven by underlying GDP and population projections, which are slowing down and even saturating (for example population growth is assumed to saturate in China by 2030). In the intermediate and dynamic scenarios, the lower growth rate in demand after 2030 is mainly caused by the fact that the network reaches saturation – reducing the inductive impact of further air liberalization.

### TABLE 4: Revenue Passenger Kilometres and direct connections (between model regions) in 2030 and 2050, 2010=100

<table>
<thead>
<tr>
<th>Scenario</th>
<th>RPKs (CAGR %)</th>
<th>Direct connections</th>
<th>RPKs (CAGR, %)</th>
<th>Direct connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>172 (2.7)</td>
<td>100</td>
<td>277 (2.6)</td>
<td>100</td>
</tr>
<tr>
<td>Intermediate</td>
<td>234 (4.3)</td>
<td>181</td>
<td>466 (3.9)</td>
<td>245</td>
</tr>
<tr>
<td>Dynamic</td>
<td>302 (5.7)</td>
<td>289</td>
<td>634 (4.7)</td>
<td>454</td>
</tr>
</tbody>
</table>

Figure 3 presents our results for major regions (at the sub-continent level). It shows the impact of economic mass shifting to Asia. The biggest growth in demand will take place in relation to developing countries, especially in Asia. In the dynamic scenario, demand growth for intra-Asian routes is above 8%. There are also strong predicted increase Latin America and Africa but from much lower initial levels. At contrary, demand in relation to developed economies witness smaller than average growth rates in all scenarios.

The difference between the static and more dynamic scenarios is larger in developing regions. This is driven by less mature networks in these regions, able to grow quickly and significantly. At contrary, the gap between the scenarios is small for developed regions where the air network is already close to saturation.
FIGURE 3: Regional breakdown of revenue passenger kilometers.
6. CONCLUSION

This paper introduces a new model to project international air transport passenger demand up to 2050. It aims at fulfilling the research gap on modelling and measuring the long-term impact of future air liberalization on international air passenger demand.

Our results show that a sustained growth in international air passenger demand relies on the network being able to expand and stimulate traffic. The existing industry forecasts can only realise if we see a continuation of air liberalisation trends of the past. This is particularly the case for developing regions (and especially Asia) where the impact of further liberalization has a larger impact on the number of routes and the frequencies provided as the network is still less mature. In all cases, the growth will slow down after 2030 as a result of slowing down of global income and population growth as well as saturation of the network in the dynamic scenarios. Indeed, we estimate that existing forecasts may be somewhat optimistic as the growth in the air network in our dynamic scenario is almost as strong as the growth in demand. This is potentially not sustainable on the long term.

Our model in its current form has several limitations. We do not take into account emergence of new global hubs or potential new business models – both potentially having significant impact on future air demand. Currently, our route choice model is calibrated using demand data for one benchmark year possibly affecting our results. However, we are already in the process of improving the model using several years of data. We are also aware that calibrating the model with other data, such as passenger surveys or true origin-destination data, could potentially significantly improve our results.

Already in its current form, the potential uses of the existing outputs of our model for policy analysis are broad. Apart from the traditional analysis of air passenger demand, the model can be used to estimate future CO₂ emissions of aviation and impacts of alternative mitigation strategies, among others.

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