Dobruszkes F., Vandermotten C. (2022)

Do scale and the type of markets matter?
Revisiting the determinants of passenger air services worldwide

Journal of Air Transport Management 99, 102178,
https://doi.org/10.1016/j.jairtraman.2021.102178
(POSTPRINT)

Abstract

Investigating the determinants of air traffic has become somewhat commonplace. However, previous papers have neglected to distinguish between domestic and international markets and to think about spatial units. This paper examines the factors of passenger air traffic for the whole world and considers both national and sub-national units. The study finds that the relevant factors partially diverge between domestic and international markets. It also appears that it is more valuable to consider sub-national spatial units than countries, notwithstanding econometric results. Indeed, the geography of residuals is much richer by sub-national units, while national units clearly mask centre-periphery patterns and/or significant disparities within large countries.

Keywords

Air services; Aviation; Air transport geography; Spatial units

1. Introduction

Apart from periods in which there were major economic and health crises, air transport has been growing fast over the past few decades (IATA, 2018). As a result, it is not surprising academic research on aviation has expanded in tandem with the growth of air transport (see Oum and Zhang, 2001; Ginieis et al., 2012; Duval, 2013). In this context, determining the factors of air traffic has been a recurrent goal pursued by economists, engineers and geographers since the 1950s.

However, as the next section argues, research works interested in the determinants of air traffic have usually not been very ambitious in spatial terms. Indeed, the usual spatial framework is restricted to one country as a whole or by sub-national units (usually the first level of administrative units beyond the national level, such as China's or Turkey's provinces or the states of Brazil or the US). Transnational research works are scarce and are usually limited to one specific macro-region (including Europe, South-eastern Asia and North America) or the whole world, but usually restricted to so-called world cities (e.g., Taylor et al., 2007) (see Section 2). Furthermore, the few researches that have covered the whole world have been restricted to the country level or to selected city-pairs given the difficulty of gathering coherent, sub-national statistics all over the world. However, working at the country level is not an obvious optimum. On the one hand, it is clear that despite recurrent prophecies that countries will not be relevant any more in trying to understand social, economic and political processes, countries still play a significant role in many matters (Swyngedouw, 2005; Polèse, 2005). In the context of aviation policy, countries are usually still in charge of negotiating bilateral and multilateral air transport agreements (Debbage, 2014).[1] On the other hand, countries are not

[1] The only significant exception here is the European Union, where this responsibility has been transferred to the European Commission.

spatially homogeneous entities (see, e.g., European Commission, 2020). The geography of population density, for example, does not tell the same story at the national vs. the sub-national levels (Figure 1). And, very similarly, the geography of air services at the airport level is clearly more subtle than at the national one (Figure 2). It is only at sub-national levels that the high contrasts in settlement or in air traffic (e.g., US coast vs. inland; eastern/south-eastern China vs. inland China; North Africa vs. the Sahel; etc.) are visible.

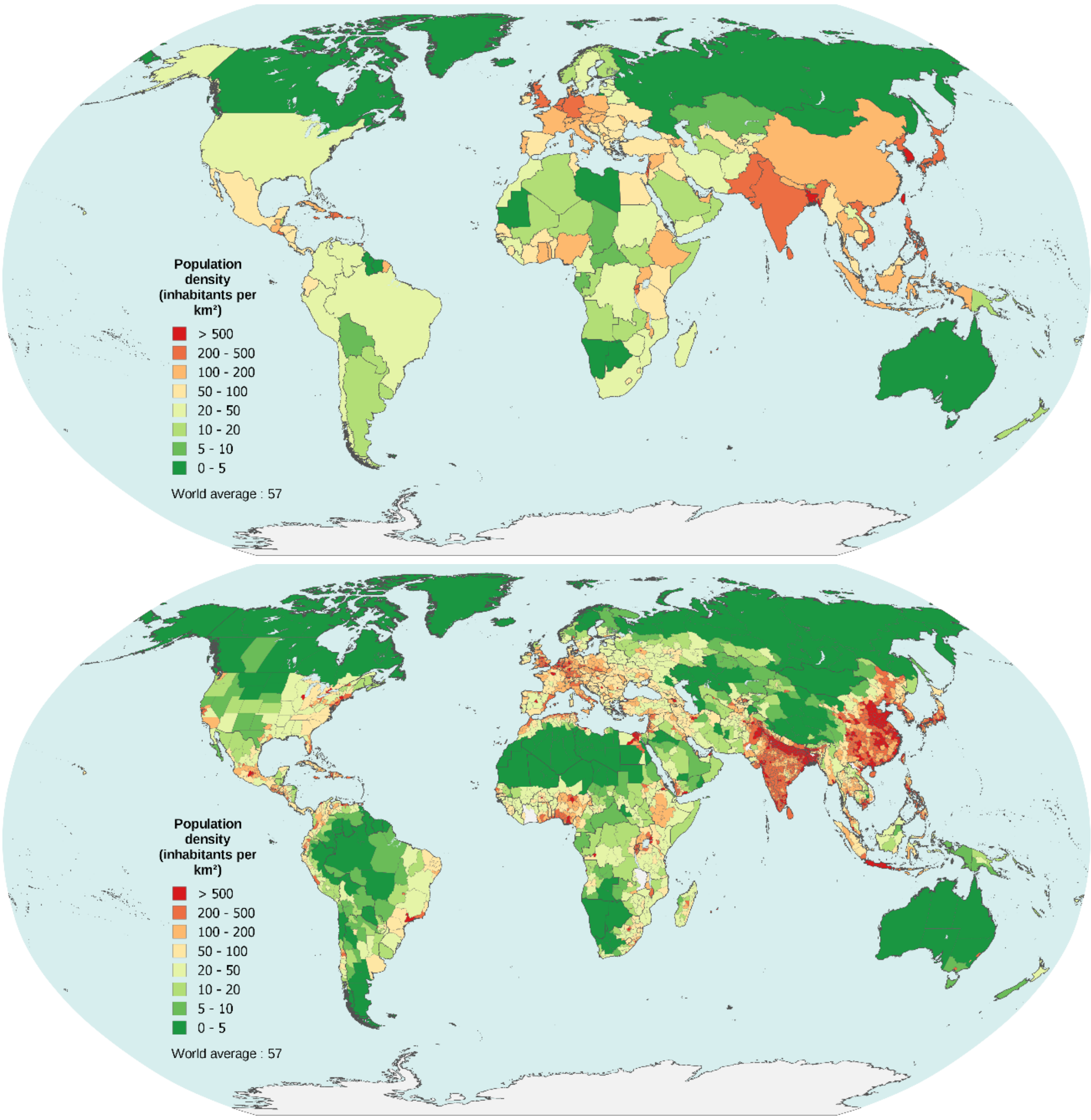

Figure 1. Population density at the national (top) vs. sub-national (bottom) levels

Source: Adapted from Didelon-Loiseau et al. (2017)

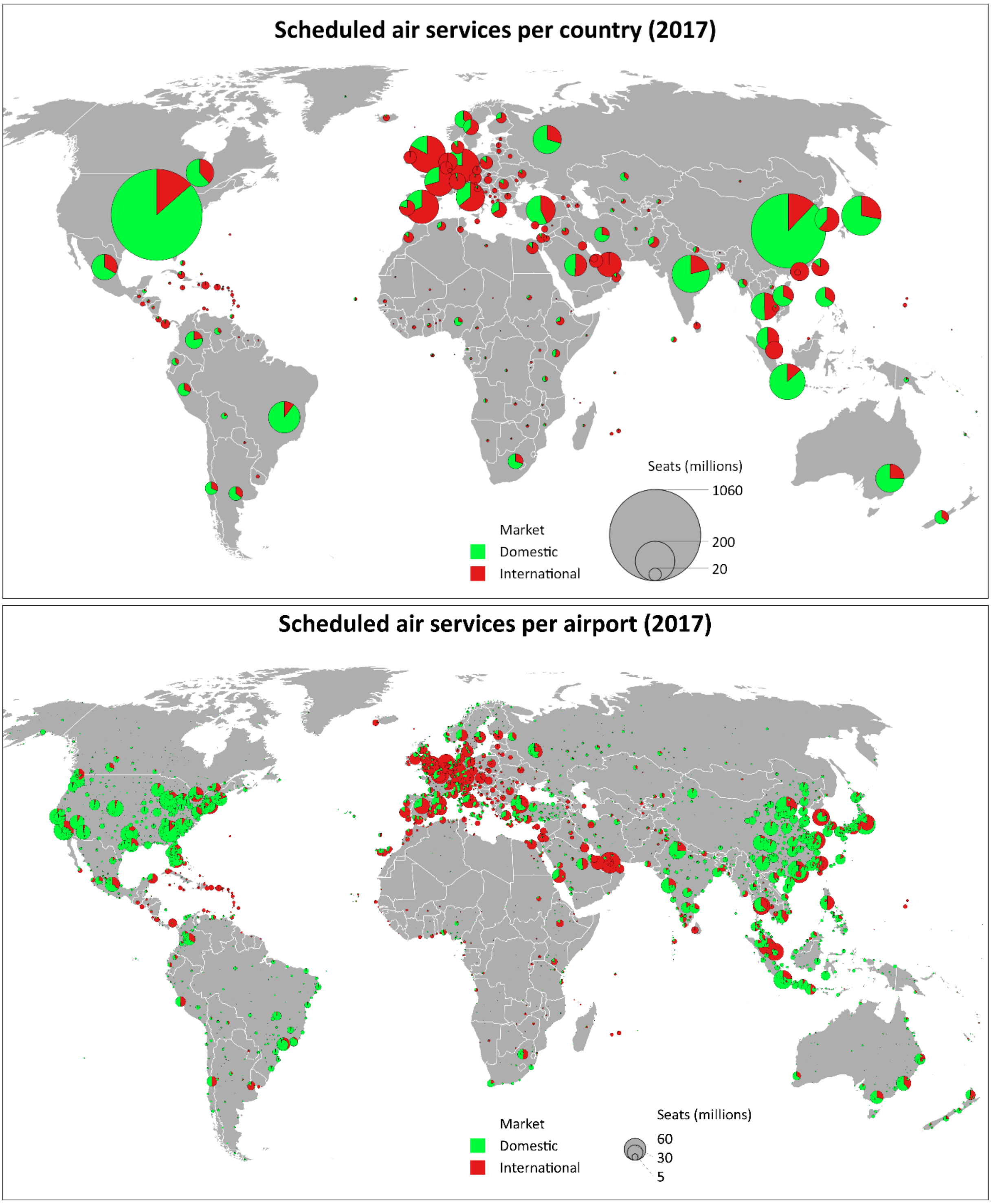

Figure 2. Air services at the national (top) vs. airport (bottom) levels
Source: OAG. Computations and maps by the authors.

Another issue in previous research works is the fact that domestic and international markets have usually not been compared (see Section 2). Either the investigation was restricted to only one market (namely, domestic or international) or no distinction was made between these two markets. However, factors that are relevant for domestic air markets are not necessarily relevant (or even play in the same direction) for international air markets, and conversely.

In this context, the paper's aim is to revisit the determinants of air services on the world scale, (1) considering separately domestic and international markets, and (2) working on two different scales, namely countries and sub-national units. The remaining parts are as follows. The next section provides a literature review, with a focus on spaces covered and scale considered by previous research. Section 3 introduces our research strategy and the data utilised. Section 4 revisits the determinants of air services through multiple regressions. It also thinks beyond the models through the investigation of the geography of the models' residuals. Finally, Section 5 concludes and proposes some avenues for further research.

2. The determinants of air services: A literature review

Many authors have investigated the interwoven relationships between places' attributes and the interactions between these places (including GDP, employment, economic structure, social and demographic characteristics, wages, migrations and trade) on the one hand, and air traffic (air services or passenger/cargo flows) on the other hand. One key aspect in such research is how the direction of causality is considered. Three perspectives have been followed. First, scholars may consciously investigate the determinants of air traffic, i.e. the impact of places' attributes and/or the interactions between places with regard to the volume and spatial pattern of air flows (e.g., Jorge-Calderón, 1997; Goetz, 1992; Boonekamp et al., 2018). Conversely, scholars have also been interested in the impacts of air traffic on the regional economy or demography (e.g., Brueckner, 2003; Green, 2007; Albalate and Fageda, 2016). Finally, scholars may be open and would thus track the direction of causality, which usually involves considering times series and an appropriate test, such as the Granger test (see, e.g., Van de Vijver, 2014; Hakim and Merkert, 2016; Koo et al., 2017; Pacheco and Fernandes, 2017; see Zhang and Graham, 2020, for a review).[2]

This paper is interested in the first approach, namely seeking the determinants of air transport. The established approach is to build multiple linear regression models to detect the factors of air traffic (demand and/or supply), their magnitude and their sign. As summarised by Dobruszkes et al. (2011), these factors basically refer to three families: (1) the potential market's size (captured, for instance, through population, GDP, stock of migrants and volume of international trade); (2) demographic, social and economic attributes (e.g., GDP per capita, share of highly skilled workers, age structure and urban functions); and (3) so-called geographical or physical attributes (e.g., climate, insularity and distance to an alternative large airport). Although this range of factors is not controversial, several authors have recently tried to add extra factors, such as intermodal competition, cultural attributes (Czepkiewicz, 2018) and supply-side attributes (such as frequency or fares) if the dependent variable relates to the demand. Furthermore, relational factors are added if the authors consider city-, region- or country-pairs (e.g., foreign trade, currency rate, migrations, belonging to the same single market, same language and former colonial link – see Mao et al., 2015, as an example).

There are two potential avenues for progress beyond this established approach. First, there is an ongoing process toward methodological improvements of econometric techniques.[3] These include, for instance, reflections about which variables are preferable (GDP vs. jobs, seats offered vs. passengers enplaned, passengers vs. passenger-km, etc.) and whether the choice affects the results (Padhan, 2019). Another direction is dealing with non-linear relations (Chang, 2012). Time is also key, considering the magnitude of the factors and/or the direction

[2] The direction of causality within the first and second approaches may also be checked, for instance, through the use of lagged variables in case of time series.

[3] Methodological improvements have been part of recent works under the auspices of the COST action TU1408 ATARD (Air Transport and Regional Development). See http://www.atard.net.

of causalities may change over time, especially if one considers short- vs. long-term impacts (Chi and Baek, 2012; Pacheco and Fernandes, 2017; Padhan, 2019; Tolcha et al., 2020). Furthermore, there are attempts to work beyond discrete spatial units (such as countries, provinces and urban areas) since both factors and impacts of air traffic may follow spatial gradients that transcend borders imposed by national and international statistical apparatuses (Adler and Volta, 2017). Finally, there is potential for more multi-country works provided heterogeneity in the definition of indicators is fixed, as it is now the case within the European Union (EU).

A second avenue for progress relates directly to geography, which includes three dimensions: *spatial coverage* (i.e., the areas included in the analysis), *spatial units* (i.e., the scale of the data utilised) and *markets* (the domestic vs. international nature of flows, considering that their spatial pattern diverges significantly (Figure 2)[4]). Table A1 (see the Appendix) lists about 50 publications interested in the ex-post analysis of the determinants of air traffic.[5] It includes the three aforementioned spatial dimensions. Spatial coverage ranges from one country to one macro-region to the world. Between one country and a macro-region, there is the case of one country in relation to a range of other countries. As for spatial units, they range from airports or urban areas to sub-national units to countries.[6]

Table 1 summarises Table A1 based on spatial coverage and spatial units. The dominant spatial universes are one single country (29 out of 53), usually treated as a whole (n=11) or by urban area (n=14). Here the US has clearly been the most investigated case, likely as a dominant market and given the availability of data. In contrast, worldwide works are scarce (n=4). In between, one finds macro-regional works, investigated either by country (n=6) or by urban area or airport (n=7). Here Europe per NUTS2 or NUTS3 spatial units[7] is the most common, thanks to the progressive availability of standardised statistics under the auspices of Eurostat (Dobruszkes et al., 2011). Furthermore, the spaces covered are poorly diverse, with the USA accounting for 13 publications and Europe for nine, while emerging and developing countries have received less attention. Table A1 also shows that only a few authors have considered pairs (of cities, sub-national units or countries). The most common approach is to consider departing or arrival traffic, and thus, the attributes related to the places of departure or arrival, respectively.

As for markets, it appears from Table A1 (Market column) that only five authors (Klodt, 2004; Hazledine, 2009; Dobruszkes et al., 2011; Kiraci, 2018; Suau-Sanchez and Voltes-Dorta, 2019) have made the distinction between domestic and international markets. Klodt (2004) did so explicitly to seek border barrier effects. The others did not explicitly justify this distinction, but the fact is that their results diverge between the two markets. In all other cases, authors have considered domestic (n=14), international (n=15) or total traffic (n=19) only, even though some authors have included the domestic or international nature of air routes as a potential factor (e.g., Boonekamp et al., 2018).

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[4] For instance, domestic traffic dominates in China, the US, South Africa and Brazil. In contrast, international traffic dominates in smaller countries like Taiwan, Cuba, Ethiopia and Germany.

[5] Several of them have been found, thanks to Wang and Song, 2010. Traffic forecasts have been included only if they also include a preliminary ex-post exercise.

[6] In practical terms, data at the city or metropolitan level are sometimes approximated through the use of second-level sub-national units (e.g., NUTS 3 in Europe) or of gridded populations (see Mao, 2015).

[7] NUTS means Nomenclature of Territorial Units for Statistics from the Nomenclature des unités territoriales statistiques in French.

		Spatial coverage				
		Single country	One country vs. other countries	Macro-region	World	Total
Spatial units	Country	11	4	6	1	22
	Sub-national	4	0	0	0	4
	Urban area or airport	14	3	7	3	27
	Total	29	7	13	4	53

Table 1. Previous research by spatial coverage and spatial units (based on Table A1).

Source	**Spatial coverage**	**Spatial units**	**Time**
Barnard and Oyen (1971)	US Midwest	Airports (60)	1966
Harvay (1951)	USA	City-pairs (at least 1,000 pax)	Sept 1948
Lisker-Melman (1978)	Mexico	International traffic from Mexico as a whole	1960-1977
Long (1969)	USA	City-pairs among the 38 largest cities	1953-1958
Straszheim (1978)	USA-Europe	North-Transatlantic market as a whole	1948-1973
Taaffe (1956)	USA	Cities (106 main markets)	1951
Taneja (1971)	USA-Europe	North-Transatlantic market as a whole	1951-1969
Thompson (1974)	Birmingham	City-pairs (3)	1960-1968
Verleger (1972)	USA	City-pairs (115)	1960-1967

Table 2. Selected older research works on the determinants on air traffic by space and time

Surprisingly, this classification of recent publications echoes early research works (Table 2), except for the fact that trans-European studies have emerged thanks to the aforementioned advent of homogenised data. In other words, while there has been progress on the econometric side, little innovation has come in terms of spatial coverage and spatial units. However, the spatial units considered in econometrics is anything but neutral. It has long been demonstrated that changing the scale of observation or (dis)aggregating spatial units may affect the results of descriptive statistics and of both econometric and spatial models. This is known as the so-called modifiable areal unit problem (MAUP) (Gehlke and Biehl, 1934; Wong, 2004; Buzzelli, 2020; see Suau-Sanchez et al., 2014, for an application to airport catchment areas). MAUP especially arises if one merges spatial units that are heterogeneous in size and/or in values. In terms of the impact of descriptive statistics Figure 1 and Figure 2 are clear examples of MAUP. Let us also consider the provision of airline capacity in Australia (Table 3). Seats per capita range from 3.23 to 10.10 at the sub-national level (states and territories), and from 0.08 to 18.95 at the sub-state level, the highest rates matching to very remote areas (namely the "outback"), including mining sites. At the country level, the ratio is 4.28, and thus hides high internal heterogeneity. As for the effect of such variations on econometric models, Figure 3 demonstrates the extent to which changing the spatial resolution of data affects regression models. Indeed, we find elasticities between air traffic and GDP depends on spatial units' size, ranging from 1.14 (by countries) to 1.53 (by NUTS2) to 1.57 (by NUTS1).[8]

Country level		**States and territories**		**Sub-state level**	
Australia	4.09	Northern Territory	10.10	Greater Darwin	10.32
				Outback	9.78
		Australian Capital Territory	5.41	Australian Capital Territory	5.41
		Queensland	5.28	Cairns	13.01
				Mackay – Isaac – Whitsunday	7.21
				Outback	6.71
				Greater Brisbane, Sunshine Coast, Gold Coast and Toowoomba	5.28
				Townsville	5.05
				Central Queensland	3.27
				Darling Downs – Maranoa	0.89
				Wide Bay	0.82
		Tasmania	4.76	Launceston and North East	5.75
				Greater Hobart and South East	5.44
				West and North West	1.77
		Western Australia	4.23	Outback North	18.95
				Outback South	4.31
				Greater Perth, Bunbury and Wheat Belt	3.63
		New South Wales	3.74	Greater Sydney	4.84
				Coffs Harbour – Grafton	2.35
				Far West and Orana	2.16
				Murray	1.73
				Riverina	1.69
				New England and North West	1.64
				Richmond-Tweed	1.34
				Newcastle, Huntervalley and Lake Macquarie	1.33
				Mid North Coast	0.97
				Central West	0.51
				Capital region and Southern Highlands and Shoalhaven	0.27
		Victoria	3.42	Greater Melbourne and Central Victoria	3.54
				North West	1.37
				Warmanbool and South West	0.08
		South Australia	3.23	Greater Adelaide and Barossa - Yorke - Mid North	3.56
				Outback	3.56
				South East	0.53

Table 3. The effect of the modifiable areal unit problem on data: airline seat capacity in Australia (seats/capita, international and domestic departures, 2017). Authors' computations based on OAG and the Australian Bureau of Statistics. The sub-state level is based on GCCSA and SA4 units (merged when no airports have passenger air services).

[8] NUTS1 and NUTS2 are Eurostat's first- and second-level sub-national units, respectively.

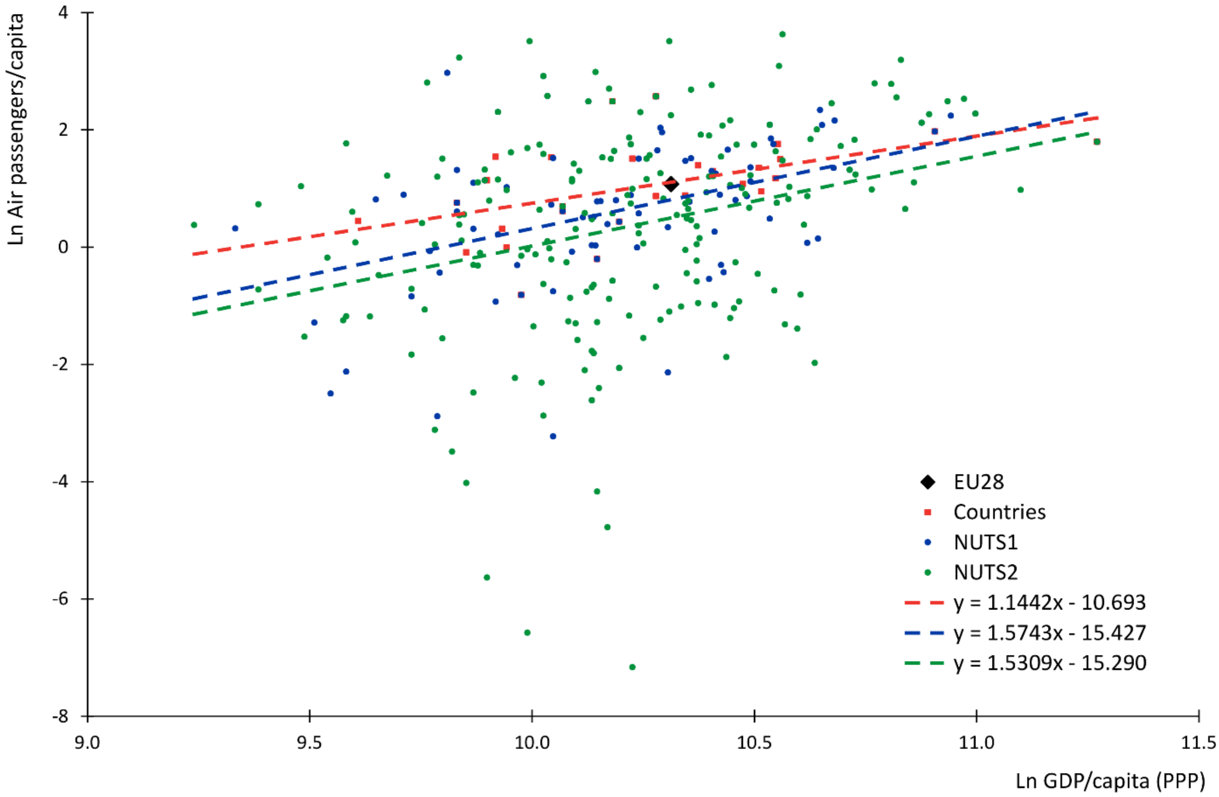

Figure 3. The effect of the modifiable areal unit problem on econometrics: Air passengers/capita against GDP/capita for various spatial resolutions in Europe (EU28 in 2017). Authors' computations based on Eurostat.

This is the context in which this paper revisits the determinants of air traffic for the whole world, and considers both the country level and sub-national units. The goal is to investigate whether the most common factors work in which spatial context, and whether there are divergences or convergences, depending on the spatial units considered as well as the markets.

3. Research strategy and data

Our analysis is based on multiple linear regression models (Eq. 1), which is traditionally considered an appropriate way to investigate the relationships between one phenomena and potential factors in both predictive and explicative perspectives (Hair et al., 2014). We considered four dependent variables in order to distinguish between international and domestic markets, both at two spatial scales, namely countries and sub-national units for larger countries.[9]

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \qquad \text{(Eq. 1)}$$

Since some (although limited) heteroscedasticity was detected, the traditional ordinary least squares (OLS) estimator has been replaced by the weighted least squares (WLS) estimator with the HC4 hypothesis[10], which is robust for heteroscedasticity issues and improves small

[9] Working at the urban area level was not possible because of data availability.

[10] The WLS estimator is a specific case of generalised least squares (GLS). Its first introduction was later labelled HC0. Then further improvements for smaller samples were named HC1 to HC4. HC4 was designed specifically to improve estimations for smaller samples that include outliers (see Zeileis, 2004). In our case, HC4 gave results close to the traditional HC0 hypothesis. Importantly, the WLS HC0 and WLS HC4 models

sample performance while also dealing with influential observations (Zeileis, 2004). In addition, we have inspected multicolinearity through variance inflation factor (VIF) values, which do not exceed values of around three in the worst cases.

3.1. Spatial units: Countries vs. sub-national units

Models are first set for countries based on the so-called ISO (International Organization for Standardization) 3166-2 codes. This involves 251 countries, of which 231 are served by commercial air services. All of them accommodate international air services, but only 157 also accommodate domestic air services.

Then, considering that differences in country size and internal heterogeneity of countries (see Figure 1) should both be taken into account, we divided larger countries as follows. The 74 countries larger than 200,000 sq km have been divided into their first sub-national statistical level (e.g., states in the US; oblasts and autonomous entities in Russia; provinces in China; states (estados) in Brazil; prefectures in Japan; states (Länder) in Germany; etc.) unless they count less than five million inhabitants. Indeed, it is expected that larger countries involve more internal air travel as well as international air links without transferring at the country's largest airport, all other things being equal. When these sub-national units were too small, they were merged to avoid spatial units with less than five million inhabitants or smaller than 200,000 sq km[11]. This limits the risk that airport catchment areas stretch over more than one single spatial unit. This also tends to prevent the non-allocation of one airport to its actual urban area (for instance, Brussels Airport is located in Flanders instead of in the Brussels-Capital Region). However, the main islands have been kept isolated as specific spatial units.[12]

All this left us with 512 areas (Figure 4). Based on population, their relative standard deviation is much lower than per country (Table 4). Among these 512 areas, 493 are served by air services (450 by international services, 422 by domestic services).

These manipulations involved to know the number of inhabitants for various administrative levels. This very time-consuming process was based on national, EU and OECD (Organisation for Economic Co-operation and Development) yearbooks and censuses, which give demographic data at sub-national levels. Data from all over the world have thus been gathered. However, given the diversity of the last available year, these figures have been fitted to the World Population Prospects data published by the UN (2017 values).

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did not change the range of significant estimators. Standard errors are only slightly different between WLS HC0 and WLS HC4. Results under the HC0 to HC3 hypotheses are available upon request.

[11] This merging concerns very large countries that may occasionally have very small sub-national units (for instance, Rhode Island and Delaware in the United States).

[12] In addition, California has been divided into north and south because it includes two very large metropolises with strong specificities.

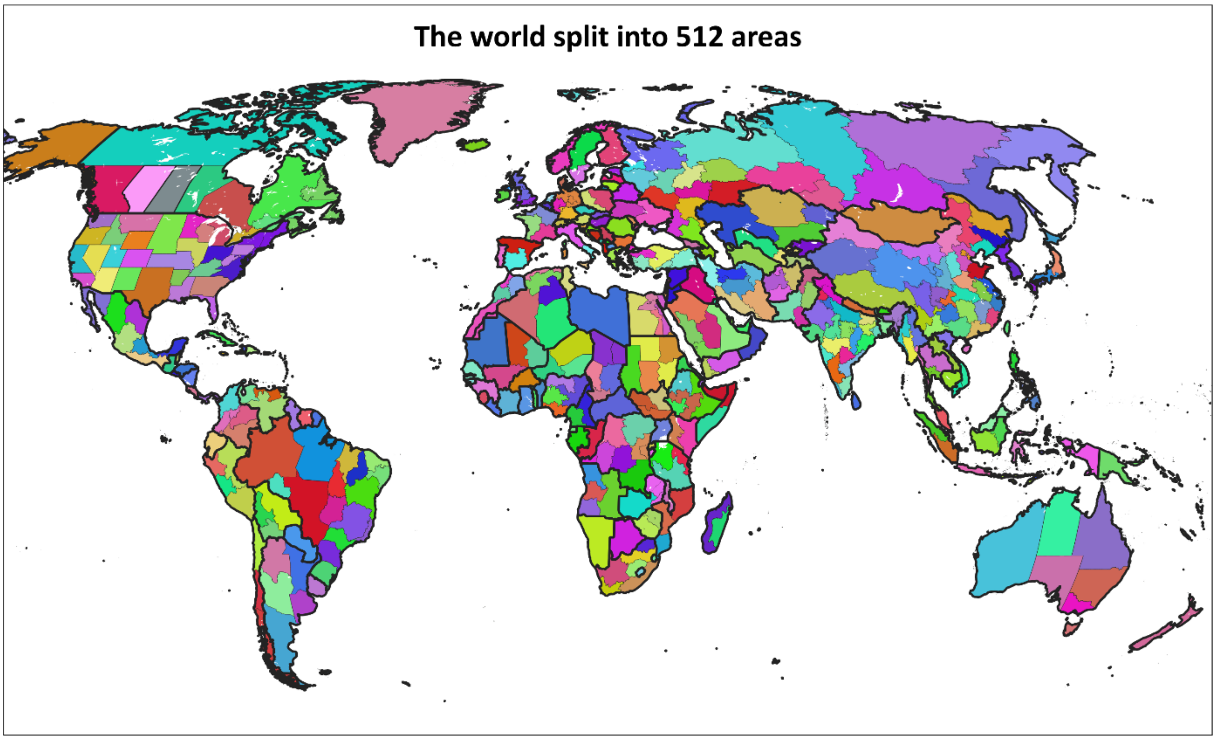

Figure 4. Considering sub-national units

Spatial units	Average (μ)	Standard deviation (σ)	Relative standard deviation (σ/μ)
Countries (n=251)	30.02	126.66	4.22
Sub-national units (n=512)	15.05	22.87	1.52

Table 4. Population by statistical level (millions)

3.2. The dependent variable: Seats/capita

In a perfect world, our dependant variable would have been the number of passengers per departing area. However, at the global level such data are comprehensively known by country at best, but not by sub-national units everywhere. Statistics published at the airport level would make it possible to aggregate the number of passengers by any spatial unit. The most comprehensive series we found was released by the Airport Council International (ACI). Unfortunately, it includes only 2,500 airports (many smaller airports being missing) while about 4,100 airports are served by commercial air services according to OAG datasets.

As a result, like some previous studies (e.g., Dobruszkes et al., 2011; Hazledine, 2009), we considered the number of seats offered by airlines on all departing regular flights.[13] The number of seats is preferred to the number of flights, since there is a wide range of aircraft capacity. Available seats are thus considered as a proxy for the number of passengers. The main issue relates to connecting passengers, which artificially increases volumes at hub airports. Actually, the same distortion also occurs with passenger figures. Another issue is that the

[13] Since air services are geographically highly symmetrical (the volume of seats between A and B is almost the same as between B and A), considering departing seats, arrival seats or total seats does not affect the results. Charter flights are excluded but they have become marginal in most markets (Ramos-Pérez and Dobruszkes, 2019). According to ICAO, they accounted for 4% of revenue passenger-km within the international markets in 2018. No information is given about domestic charters.

number of passengers is by definition equal to, or smaller than, the number of seats. Unfortunately, load factors are poorly known because competition has made this kind of information too sensitive for the airlines. In short, the options are either to consider passengers for a smaller number of airports or the number of seats for significantly more airports. Working at the global level with sub-national units, we have opted for the latter to avoid large bias in those spatial units that are served by smaller airports only.

The number of seats was extracted from OAG Schedules Analyser, a data solution scholars have used widely due to its comprehensiveness and disaggregated nature at the flight level. For each flight, fields notably include frequency, number of seats, great-circle distance and carrier. Regarding year 2017, the dataset includes 827 airlines, 4,101 airports, 74,189 airport-pairs and 209,983 operated flight codes. The fact we considered the whole year prevents biases due to seasonality in the supply (Mao et al., 2015; Reynolds-Feighan, 2018). If the dependent variable is the absolute number of seats, then the number of inhabitants is potentially a key factor to be considered. At the stage of first trials however, VIF values revealed multicollinearity issues with other potential factors.[14] As a result, we have replaced the number of seats with the number of seats per capita. This lifted all multicollinearity issues.

The dependent variable was considered in four forms (Figure 5):

- International seats/capita per country
- International seats/capita per sub-national units
- Domestic seats/capita per country
- Domestic seats/capita per sub-national units

[14] Intermediate models are available upon request.

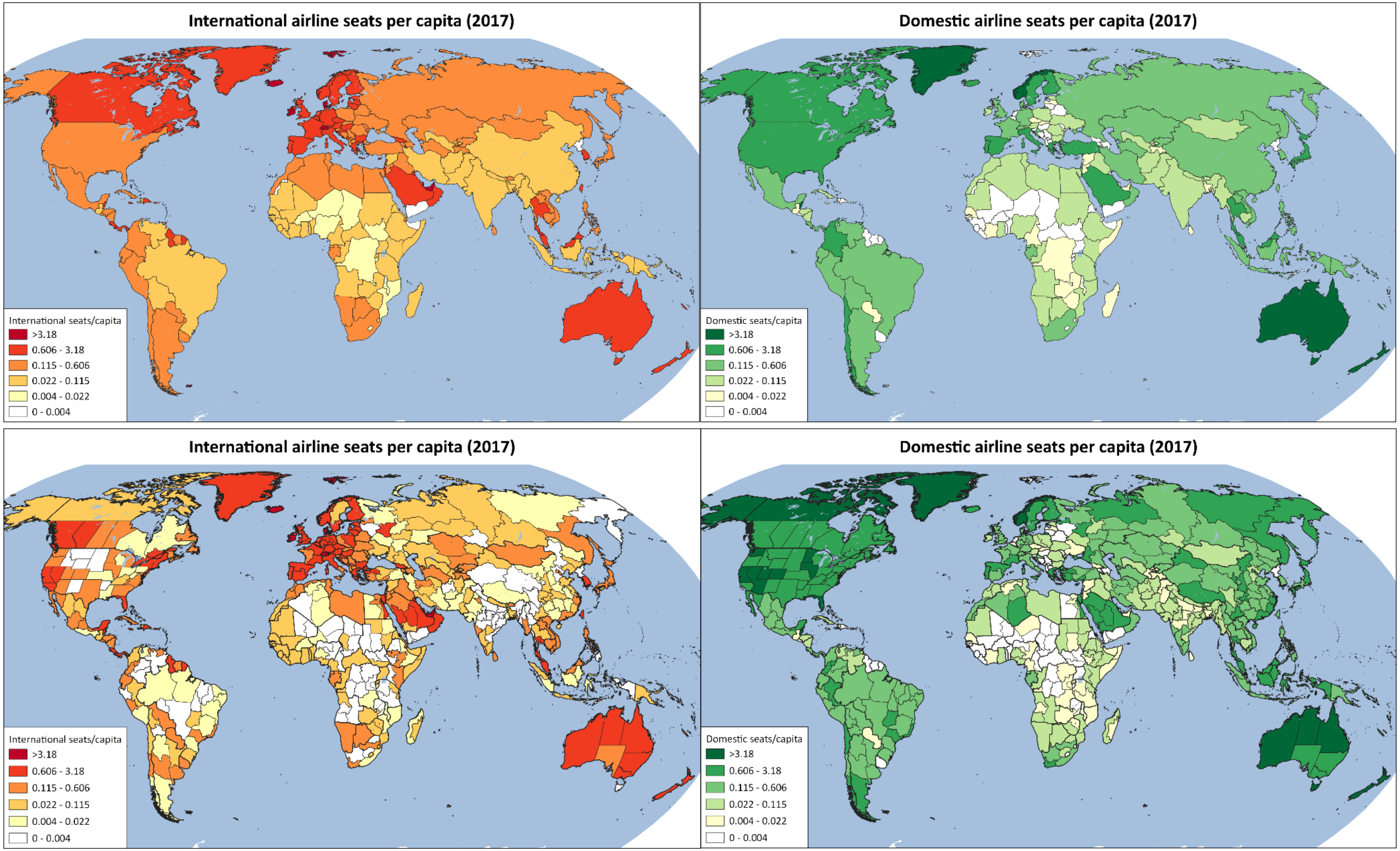

Figure 5. The four dependent variables (top: per country; bottom: per sub-national unit; left: international; right: domestic).

3.3. The independent variables

The range of potential factors comes from the existing body of literature (see Discazeaux and Polèze, 2007; Wang and Song, 2010; Dziedzic et al., 2020; Zhang and Graham, 2020). It is restricted by data availability especially at the sub-national level and by the very time-consuming task of going through the national statistics of each country split into sub-national units, even without talking about language issues. At least data for several countries could be retrieved from Eurostat and the OECD series.

GDP/CAPITA. First, we considered countries' and regions' wealth. Accordingly, we gathered the gross domestic product per capita in 2017, based on purchasing power parity. Country-wide data were extracted from the World Bank dataset. As for the sub-national level, GDP was collected from Eurostat, the OECD and official national statistics, which is a really time-consuming task. The results were fitted to the World Bank dataset (2017 values).

GLOBALISATION/CAPITA: Areas involved in globalisation processes are expected to induce more air traffic. To assess this, we used a metric developed by the Globalization and World Cities (GaWC) research group, namely the global network connectivity (GNC) index. For each so-called world city, the GaWC computed GNC based on the location of advanced producer service firms' offices all over the world (see Taylor and Derudder, 2016). The GNC values for 2016 were kindly made available to us by GaWC members. All world cities' GNC belonging to a same country or sub-national unit were then summed and divided by the number of inhabitants. Unfortunately, many countries or regions have a zero value, and this jeopardises the assumption of linear relation. As a result, the related estimators were negative and/or not significant. Accordingly, this variable was eventually dropped, but the impact of globalisation is nevertheless discussed in this paper.

BEDS/CAPITA. Tourism is well known as a key driver of air traffic. In many air markets, holidays are clearly the dominant travel purpose, well before business and VFR (visit-to-friends-and-relatives) motives (Dobruszkes et al., 2019). However, there is no unique definition of tourism. In the tourism literature and industry, one usually follows UNWTO's (2010) definition, according to which a "tourist" is an *international* "visitor" who spends at least one night away from his/her usual environment. In contrast, in the aviation literature, as well as among the public in general, "tourism" is related to travel for personal purposes (Graham and Dobruszkes, 2019). As a result, tourism statistics usually exclude domestic tourism, which remains dominant, especially in large countries. Furthermore, the number of arrivals or nights is usually not available at the sub-national levels. This led us to consider the stock of beds in commercial accommodations (i.e. short-term accommodation for paying guests) as a proxy for tourism, as Tsekeris (2009) and Sivrikaya and Tunç (2013) did before. We acknowledge we have an imperfect indicator of tourism, notably because it likely does not cover collaborative economy options (such as Airbnb), neglects load factors and excludes length of stay, and thus tourist turnover. Here too, gathering data at the sub-national level was especially time consuming. UNWTO statistics by country were utilised to fit the data.

COUNTRY AREA. The area of countries is expected to affect the provision of international air services. Smaller countries tend to induce more international air services since there is little chance to fly within their boundaries. In other words, larger countries would mean less international air services. This makes sense considering that in larger countries, more amenities that induce air travel (e.g., a spot for a vacation) remain located within the national boundaries.

COUNTRY URBAN NETWORK. For domestic services, it is expected the larger the country, the higher the probability of seeing domestic air services. However, first trials revealed that COUNTRY AREA is not significant. This made us think the propensity to fly within a country does not really depend on its area but more on actual distances between cities. Indeed, national urban networks (that is, city size and inter-city distances) are more relevant than area to understand travel within a country, especially in the following cases:

- Large countries with main cities relatively close to each other; the rest being mostly unpopulated (e.g., Algeria);
- Stretched countries, where inter-city distances are proportionally longer than suggested by the area (e.g., Chile and Norway);
- Archipelagos, where the total terrestrial area is small but the inter-island distance is long (e.g., Micronesia);
- Small countries with remote islands (e.g., Portugal).

In light of these configurations, we computed a proxy of urban networks through the measure of the average distances (in km) between airports that offer air services, weighted by each airport size in seats.

INSULARITY. Insularity is expected to induce more air services. However, one needs to consider two kinds of insularity. For international air services, **INTERNATIONAL INSULARITY** is represented by a dummy variable that takes 1 if the country or a sub-national unit can only be reasonably accessed by plane. This includes insular countries (such as Australia, Cuba, Japan and Sri Lanka) and continental countries that cannot be accessed by surface transport due to geopolitical issues (e.g., South Korea) or lack of surface transport facilities (e.g., Guyana). As for domestic air services, **INTERNAL INSULARITY** is a dummy that takes 1 if the country is divided into islands or includes island(s) that accommodate at least 5% of the national population (e.g., Indonesia, New Zealand, Philippines and Spain). The same criteria were applied for the sub-national level (e.g., the Corsica sub-national unit within France).

EUROPE. Europe is more integrated than any other continental scale region. The European Union (EU) is a political and economic union comprising 28 member states at the time of our data, which share common permanent institutions located in various cities, including three "capitals." The EU Single Market offers free movement of goods, services, capital and persons (travel but also residence) to its firms and citizens. It has been extended to Norway, Iceland, Lichtenstein and Switzerland and is thus known as the European Single Market. This involves dense flows of national and international civil servants, lobbyists, executives, scholars, students, migrants, etc. In addition, the Schengen Agreement offers freedom of travel to any person who officially resides in most member states of the European Single Market, including non-European citizens. All this would boost international travel within the European Single Market. As a result, the dummy EUROPE equals 1 for its member states.[15]

In addition, logarithm transformations have been applied on both the dependent and independent variables (except dummies) to linearise the relations. This transformation also allows us to use elasticities in the interpretation of the parameter estimates. In addition, models were filtered to include only spatial units with at least 10,000 seats to avoid atypical values and outliers.

3.4. Inspecting the spatial patterns of the residuals

Finally, our econometric analyses have been completed by the mapping of the models' residuals. Indeed, as argued by King (1969: 148):

> *"The majority of spatial patterns are highly complex and apparently result from the interplay of numerous variables, many of which have still to be identified. Therefore, in most geographic analyses there is considerable unexplained variation and the residual values can be interpreted as reflecting, in part, the effect of other possibly unknown variables (...). Hopefully, the locational arrangement of residual values will suggest other variables which might be important in accounting for the remaining variation in the dependent variable."*

This qualitative approach thus complements the quantitative one to help us think about extra factors, which were not included – and often could not been included – in the quantitative investigation. In previous research on our topic, this approach was fruitfully used by Taafe (1959), Cattan (1995), Dobruszkes et al. (2011) and Albayrak et al. (2020).

4. Revisiting the determinants of air services worldwide

4.1. The econometric perspective

Let us start with the traditional analysis of the models obtained by countries (Table 5). Considering international services first (Model 1), all estimates but the constant are significant, and with the expected sign. In addition, the adjusted R^2 is high (0.89) despite the limited number of variables. As for domestic air services (Model 2), all estimates are significant and with the expected sign, while the adjusted R^2 (0.62) is significantly lower, although still high.

[15] Before this dummy, we considered merging member states of the European Single Market so all internal flights would have been considered as domestic. However, this decreased the quality of the prediction while the dummy EUROPE helped to increase it. This is probably due to persisting barrier effects of borders in Europe (Rietveld, 2012) and to the fact that traditional European airlines are still focused on their home country, despite extensive aviation liberalisation.

	Model 1		Model 2	
Spatial units	Countries		Countries	
Market	International		Domestic	
Dependent variable	Ln INTERNATIONAL SEATS/CAPITA		Ln DOMESTIC SEATS/CAPITA	
	Estimators	Standard errors	Estimators	Standard errors
Constant	-0.482	0.543	-8.075***	2.696
Ln GDP/CAPITA	0.713***	0.073	0.541***	0.187
Ln BEDS/CAPITA	0.322***	0.049	0.389***	0.130
Ln COUNTRY AREA	-0.185***	0.025		
Ln COUNTRY URBAN NETWORK			0.856***	0.856
INTERNATIONAL INSULARITY	0.630***	0.159		
INTERNAL INSULARITY			2.592***	2.592
EUROPE	0.326**	0.138		
N	228		150	
Adjusted R²	0.89		0.62	
Variance Y	4.02		4.89	
MdAPE	25.9%		32.5%	

Significant at *** 99%, ** 95% or * 90% level of confidence

Table 5. The regression models at the country level (WLS HC4)

Let us now move to models by sub-national units (Table 6), based on the same variables utilised in Models 1 and 2. All the estimates for international air services (Model 3) and for domestic air services (Model 4) are significant and come with the expected sign. In contrast with Models 1 and 2, adjusted R^2 converge (0.65 and 0.68) while being slightly higher for domestic traffic.

At this stage, the question is which models best predict air traffic between national (Models 1 and 2) and sub-national (Models 3 and 4) units. In this regard, the R^2 metric is actually inappropriate because it is scale dependent. In other words, the higher the variance, the higher the R^2, all other things being equal. As Table 5 and Table 6 show, turning to sub-national units means an increase in the variance of international seats/capita and a decrease in the variance of domestic seats/capita. Instead of R^2, the so-called mean absolute percentage error (MAPE) has the merit of not being scale dependent. However, it is quite sensitive to outliers among the residuals. As a result, it is better to consider the median absolute percentage error (MdAPE) (Armstrong and Collopy, 1992). Bearing in mind that a lower MdAPE value means a better prediction, results show that the geography of both international seats/capita and domestic seats/capita apparently is better predicted at the country level. The reason for this is probably that when sub-national units are considered, more factors should be taken into account to explain spatial patterns. Unfortunately, to the best of our knowledge, no more independent variables are available for the whole world at the sub-national level. However, beyond MdAPE, the geography of the models' residuals should also be inspected to assess the interest of sub-national spatial units.

	Model 3		Model 4	
Spatial units	Sub-national units		Sub-national units	
Market	International		Domestic	
Dependent variable	Ln INTERNATIONAL SEATS/CAPITA		Ln DOMESTIC SEATS/CAPITA	
	Estimators	Standard errors	Estimators	Standard errors
Constant	3.009***	0.642	-6.910***	0.970
Ln GDP/CAPITA	0.287***	0.084	0.663***	0.088
Ln BEDS/CAPITA	0.526***	0.063	0.410***	0.053
Ln COUNTRY AREA	-0.323***	0.037		
Ln COUNTRY URBAN NETWORK			0.678***	0.126
INTERNATIONAL INSULARITY	0.517***	0.200		
INTERNAL INSULARITY			1.833***	0.152
EUROPE	1.101***	0.175		
N	429		409	
Adjusted R²	0.65		0.68	
Variance Y	5.17		4.10	
MdAPE	46.0%		40.6%	

Significant at *** 99%, ** 95% or * 90% level of confidence

Table 6. The regression models at the sub-national level (WLS HC4)

4.2. Thinking beyond the models: Analysing the geography of models' residuals

Figure 6 to Figure 9 unveil the gap between models' predictions and the reality through the ratio between observed and predicted seats/capita. This ratio is plotted as colour within circles that are proportional to the volume of seats. Red shades mean there are more airline seats than expected; blue shades mean less seats than expected.

First of all, it appears information is much richer at the sub-national level than at the national level. In the US, for instance, the range of residuals is remarkably wide by sub-national units (reflecting, for instance, hub-and-spoke systems or the spatial distribution of economic activity), and such reality is hidden by any nationwide model (like Models 1 and 2). As a result, there is no doubt models by sub-national units should be considered despite their less favourable MdAPE. Only models 3 and 4 will thus be discussed here.

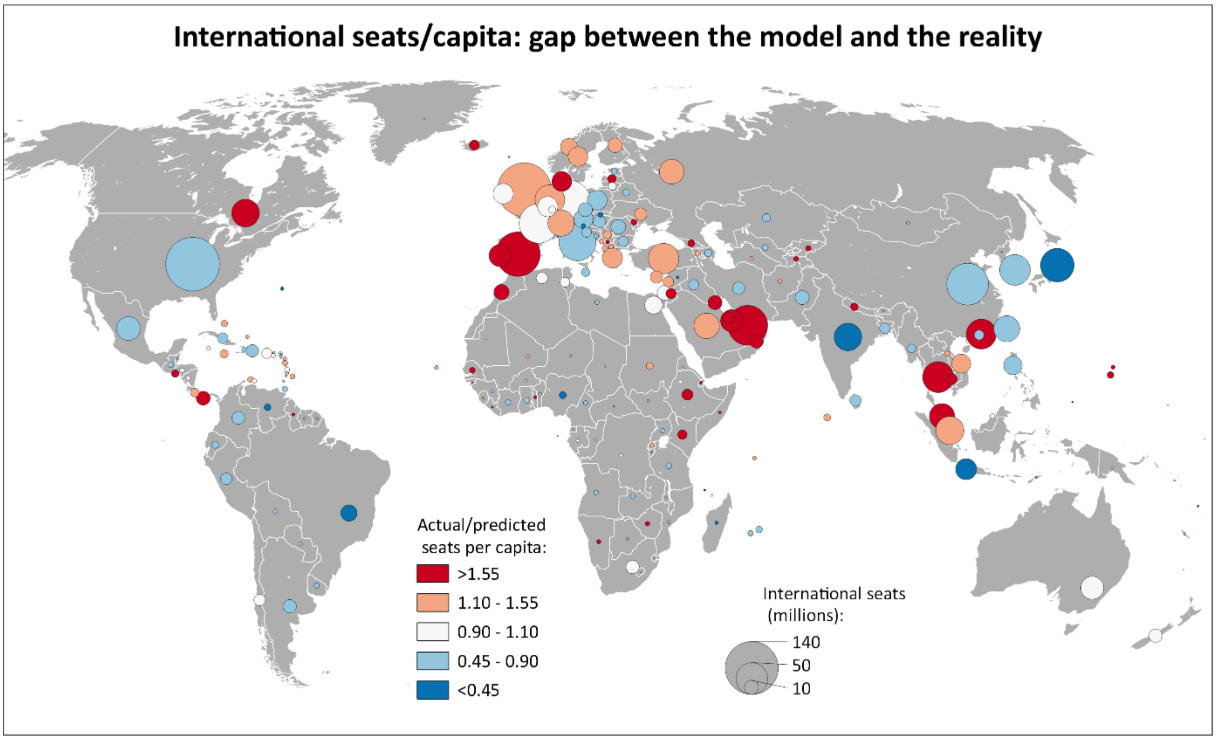

Figure 6. The gap between observed and predicted international seats/capita (Model 1, country level)

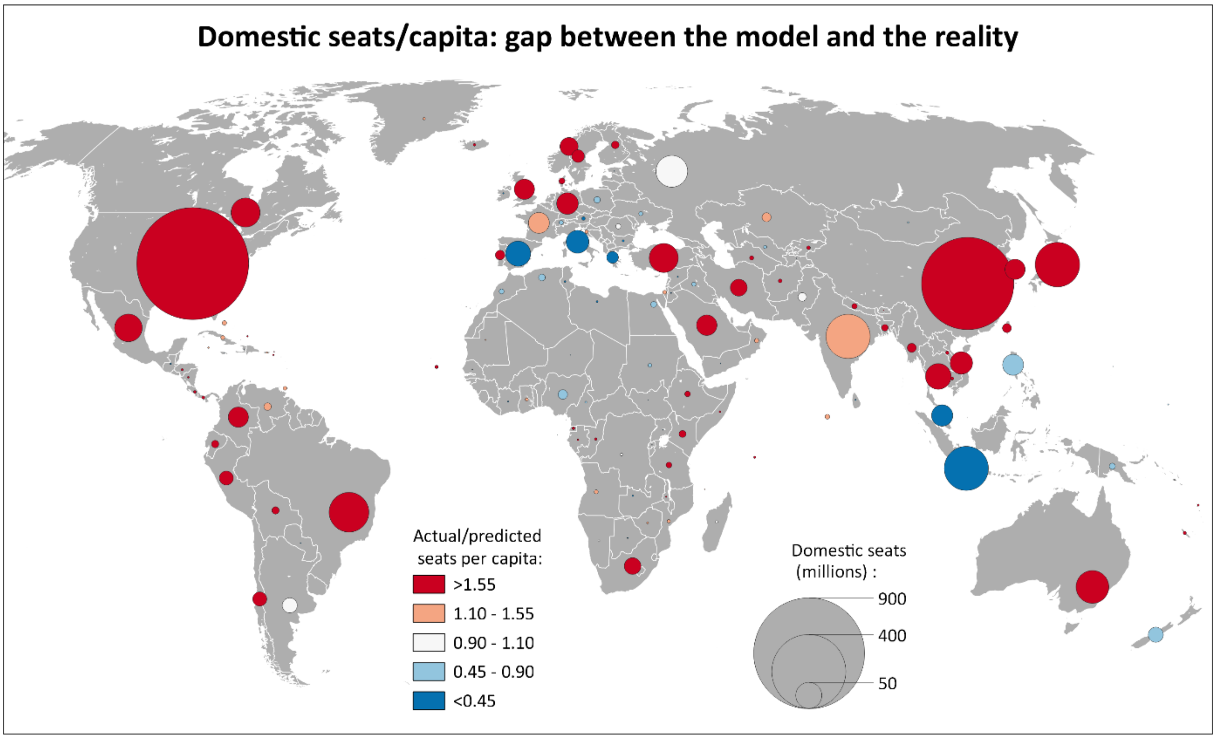

Figure 7. The gap between observed and predicted domestic seats/capita (Model 2, country level)

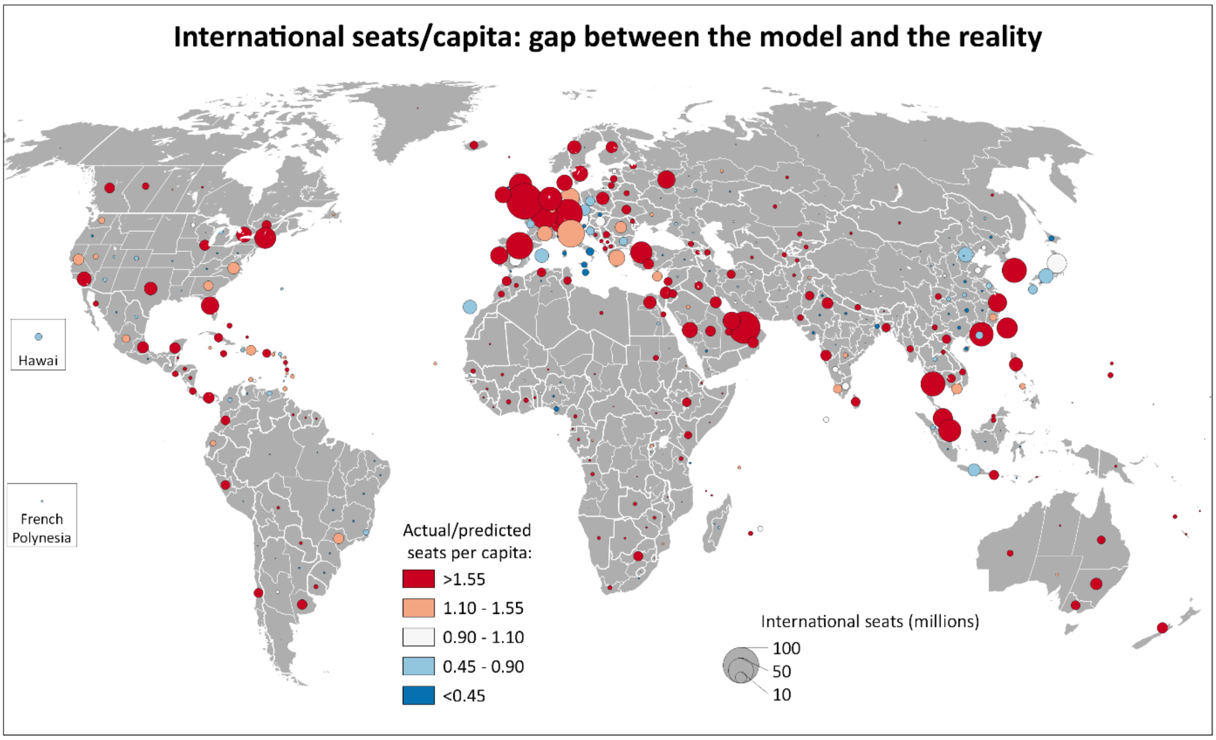

Figure 8. The gap between observed and predicted international seats/capita (Model 3, sub-national level)

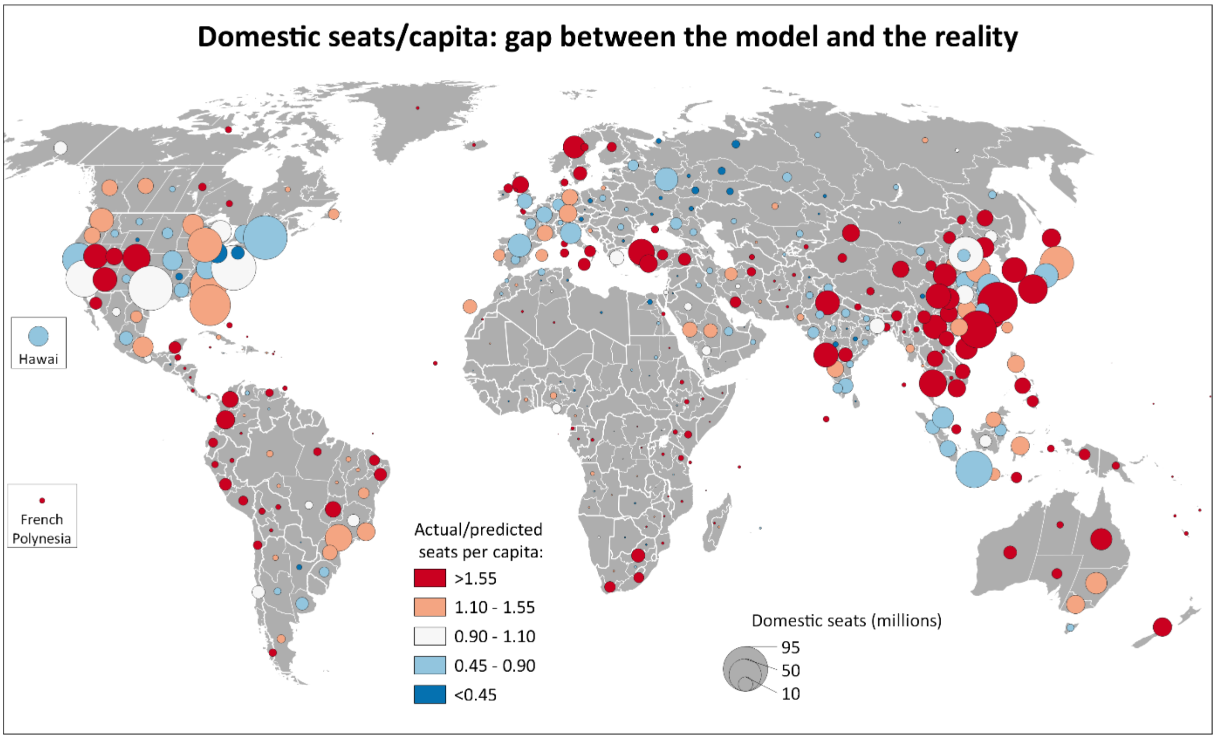

Figure 9. The gap between observed and predicted domestic seats/capita (Model 4, sub-national level)

Regarding the international model by sub-national units, Figure 8 first shows there is more traffic than predicted in most of the larger air markets, i.e., the cores of the worldwide system. There are several reasons for this. First, these units contain the so-called world cities, i.e. cities which are the main nodes of the globalised service networks and which also attract significant volumes of tourism and of migrations, both skilled and unskilled (Sassen, 1991). Key exceptions are Tokyo and Beijing, the latter being actually more a political capital, which concentrates firms coming from the former state (in contrast to Shanghai and Hong Kong, which are more internationalised cities) (see Lai, 2012). In addition, there is also more traffic than expected in those regions that accommodate large airline hubs (both international-international, like Dubai, and international-domestic, like New York). The location of these hubs overlap partly with the globalisation-related areas, even though some hubs are also located in other areas. Examples include Addis Ababa and Bangkok. All this suggests that in the framework of global centre-periphery relations, centres take advantage of self-reinforcing agglomeration effects.

In addition, there are less international air services than predicted in touristic European islands (both Mediterranean and Canarias) and in Hawaii, despite the fact that results are controlled for beds per capita and insularity. It is reasonable to think this is partly due to some lack of direct air services to these tourist areas to the point that a certain share of passengers has to connect in hubs (e.g., in Madrid or Barcelona for the Canarias and the Baleares). This could also be reinforced by the lack of globalised economic activities in these islands. In other words, residents from the Canarias and the Baleares probably fly international less than residents of Madrid or Barcelona. The same applies in Italy, considering Sicilia and Sardinia vs. Rome and Milan. In contrast, most other tourist areas are over-serviced (including the Caribbean islands, where indirect services, if any, can only be international). All this suggests BEDS/CAPITA is an imperfect measure of international tourism. Indeed, commercial accommodations are also used for domestic tourism and for non-tourism activities (especially in large, multi-function cities such as Paris or New York). In addition, load factors could be heterogeneous across places.

Furthermore, there are less air services than expected in Japan (except the Tokyo area, which is well predicted and not over-serviced like other world cities). This could reflect overall restrictive migration policies and difficulties in attracting skilled migrants (Oishi, 2021), as well as persisting geopolitical tensions with most neighbours (Hook et al., 2012), as well as the low number of paid vacation days.

As for domestic air services (Model 4), Figure 9 is full of lessons to be learned. Note that centre-periphery patterns here should be considered at the national level instead of worldwide. In Europe, the model is rather good at predicting. Contrasts relate to the availability of high-speed trains and dense motorway networks in the central areas, which involve less domestic air services than predicted (Dobruszkes et al., 2014). Conversely, remote areas (including Scotland, Nordic countries, the Mediterranean islands and the Canarias) are over-serviced. Remoteness can be reinforced by restrictive physical geography and climate, which can impose serious detours on surface trips (typically in Norway).

Similar patterns (although without high-speed rail) occur in Northern America: the two megalopolises (the northeastern range and California) are under-serviced or serviced as predicted. They are known to be highly integrated, and surface transport[16] can be an option for internal trips. In fact, there is a centre-periphery model as in Europe if one considers separately the western and eastern parts of the US. In addition, Florida is over-serviced, likely as both a domestic tourist spot and a remote area (exactly like the Canarias and Balearics islands for Spain, or Sicilia and Sardinia for Italy).

[16] Especially by road, and even by rail in the Northeast.

Japan, which is served by an extensive HSR network like in core Europe, also shows a centre-periphery model, although the Tokyo area is somewhat over-serviced compared to the model. This is likely due to the role of Tokyo as an airline hub where domestic and international markets are interlinked.

China also fits with a centre-periphery model, the centre being more or less the space served by north-south core high-speed railways (Yang et al., 2018). However, Shanghai and Guangdong (Shenzhen and Guangzhou) are exceptions. Their positive residuals could relate to their gateway position within the Chinese urban system and their openness to the world. In contrast, India follows an inverted centre-periphery model, with more air traffic than expected in its core (namely, Mumbai and Delhi). This could be explained by the lack of high-speed railways and efficient motorways.

As for Russia, the lack of domestic air services compared to the model may suggest rail has remained significantly used despite the very long distances.

5. Conclusions and avenues for research

In contrast with previous research works focused on the determinants of air traffic, this paper has innovated in considering the whole world while also (1) seeking factors for international and domestic air services separately, and (2) comparing models fed by national and sub-national data.

The key findings and consequences are as follows. This research does not contradict factors of air traffic found by previous authors. However, it has demonstrated that domestic and international markets should not be considered jointly, since the factors of air traffic are not entirely the same for both markets, or are of different magnitude. Second, a limited set of factors is enough to describe a significant part of the spatial pattern of air services worldwide. Finally, and even more importantly, it appears that it is more valuable to consider sub-national spatial units than countries, notwithstanding MdAPE values and the fact that more independent variables would be relevant for sub-national models. Indeed, an in-depth analysis of the geography of residuals at the sub-national level offers an opportunity to highlight some extra factors that likely contribute to the spatial patterns of air services. In addition, national units clearly mask centre-periphery patterns and/or significant disparities within large countries. In sum, geography matters beyond econometrics.

In this context, this paper could serve as a warning for the airline industry. Indeed, planning costly airport facilities and fleet developments should be conducted carefully, considering the appropriate factors at the appropriate scale.

Finally, this attempt to capture the determinants of passenger air services paves the way for further investigations. First, some more factors could be considered (e.g., employment type, industry mix, income distribution, international openness of the economy, airfares and surface transport options), even though this is challenging, if not impossible, at the sub-national level. Climate conditions could be considered more easily too since they influence to some extent the propensity to fly for holiday purposes (outbound traffic) and the ability of places to attract tourists (inbound traffic). And of course, regulatory regimes should be added, since protectionist regulations would move key air volumes away from the market's needs, while public service obligations could conversely involve more air services than expected if only market rules prevailed (Fageda et al., 2018). In addition, more dependent variables could be investigated. For instance, the same analysis could be conducted based on intercontinental air services only, which are geographically probably even more selective than international services. Considering the demand (i.e. the number of passengers) would be more relevant, but at the price of weaker spatial coverage. Furthermore, one may also think about a relational analysis; that is, an analysis by country- or region-pairs instead of departing air services. But once again, this would be challenging because most relational data (e.g., foreign trade or migration) are known by country-pair at best. Also, one could also consider time series, and then the investigation of the direction of causalities as well as short-term vs. long-term effects. However, gathering data at sub-national levels for the cross-sectional analysis here was already a hugely time-consuming task. Doing the same for several years would require even greater human resources. Finally, it would be relevant to replicate our analysis for air cargo. But likely more challenging, one should not forget a large part of air cargo is carried in the belly of passenger flights, whose profitability is thus sometimes due to the related extra revenues (Morrell, 2011; Popescu et al., 2010). This means that in a perfect world, in evaluating the factors of air passenger traffic, researchers should try to disentangle them from cargo activities.

Acknowledgements

This research owes a lot to several colleagues from the Université libre de Bruxelles. We would like to warmly thank Catherine Dehon for her invaluable support related to the statistical methods. Christian Dessouroux prepared an earlier release of shapefiles with sub-national spatial units worldwide. Thank you as well to Taïs Grippa, Didier Peeters and Hugo P´erilleux for their technical help related to GIS issues. Any remaining errors are our sole responsibility.

Appendix

Source	**Spatial coverage**	**Spatial units**	**Market**	**Dependent variable**	**Method***	**Time**
Abed et al. (2001)	Saudi Arabia	Country as a whole	International	Pax	MLR	1971-1992
Adler and Hashai (2005)	Europe (36 countries)	Country-pairs	International	Pax	MLR-G	May 2000
Albayrak et al. (2020)	Turkey	Provinces	Total	Pax	PDR-FE, PDR-RE	2004-2014
Alperovich and Machnes (1994)	Israel	Country as a whole	International	Pax/capita	TSR	1970-1989
Ba-Fail et al. (2000)	Saudi Arabia	Country as a whole	Domestic	Pax	MLR	1971-1994
Battersky and Oczkowski (2001)	Australia	4 city-pairs	Domestic	Pax-km	MLR	1992-1998
Bhadra (2006)	USA	Metropolitan areas by pairs (30,703 O&D markets)	Domestic	Pax	MLR-G	1999
Bhadra and Kee (2008)	USA	Larger metropolitan areas (235) by pairs (up to 35,761 O&D markets)	Domestic	Pax	MLR-G	1996-2006

Boonekamp et al. (2018)	Europe	Airport-pairs with at least 500 passengers/year (11,619)	Total (but domestic dummy among factors)	Pax	MLR-G	2010
Carson et al. (2011)	USA	Traffic from 179 airports	Total	Pax/capita	AIM (aggregating individual markets) and quasi-AIM approaches	1990-2002
Cattan (1995)	Europe (11 countries)	Larger cities (90) by pairs	International	Passengers flights	MLR-G	1988
Chang (2012)	APEC	Country-pairs (383)	International	Pax	Non-parametric regression tree (gravity model)	2006-2007
Chen et al. (2020)	Taiwan	Country as a whole	Total	Pax	MLR	2001-2014
Chi (2014)	USA vs. 12 other countries	Country pairs	International	Pax	MLR	1996-2012
Chi and Baek (2012)	USA	Country as a whole	Domestic	Pax-miles	Johansen cointegration analysis and vector error-correction model	1995-2010
Chi and Baek (2013)	USA	Country as a whole	Domestic	ΔPax	Autoregressive distributed lag approach	1996-2011
Choo (2018)	Canada vs. 68 countries	Country-pairs (68)	International	Pax	PDR-FE, PDR-RE	1990-2015
Coshall (2006)	UK	International traffic to 20 countries (country-pairs)	International	Pax	TSR	1976-2003
Dargay and Clark (2012)	UK	Domestic traffic within the country as a whole	Domestic	Pax/capita	MLR	2002-2006
Dargay and Hanly (2001)	UK to 20 OECD countries	Country-pairs	International	Pax/capita	Fixed effect model (pooled time-series cross-sectional approach)	1989-1998
Discazeaux and Polèse (2007)	USA and Canada	Urban area (89)	Total	Pax	MLR	2000
Dobruszkes et al. (2011)	Europe (30 countries)	Larger functional urban areas (113)	Total vs. international	Seats	MLR	2008

Dziedzic et al. (2020)	Europe	Regional airports (146 across 21 countries)	Total	Pax	MLR	2016
Fleming and Ghobrial (1994)	South-eastern USA (7 states)	States (7)	Total	Pax	MLR	1975-1987
Fridström and Thune-Larsen (1989)	Norway	City pairs (95/year on average)	Domestic	Pax	MLR-G	1972-1983
Goetz (1992)	USA	Largest metropolitan areas (50)	Total	Pax/capita Pax/job	SLR + analysis of the outliers	1950-1987
Goff (2005)	USA	Smaller metropolitan areas and cities (233)	Total	Passengers air services (binary/ flights/ links)	Logistic, censored and truncated regressions	2003
Grosche et al. (2007)	Germany vs. other European countries	1,228 city pairs	International	Pax	MLR-G	Jan-Aug 2004
Hakim and Merkert (2019)	South Asia (8 countries)	Countries	Total	Pax	PDR-FE	1973-2015
Hazledine (2009)	Australia	Airport-pairs (from 5 airports to 212 non-resort airports)	Domestic vs. international	Seats	MLR-G	March 21, 2007
Hofer et al. (2018)	USA	Traffic from 926 airports	Domestic	Pax	MLR	2012
Hutchinson (1993)	Canada	Airport-pairs	Domestic	Pax	MLR-G	1987
Iyer and Thomas (2021)	India	Regional airports (57)	Domestic	Pax	MLR	2018/9
Jankiewicz and Huderek-Glapska (2016)	Central and Eastern Europe (8 countries)	Countries	Total	Pax	PDR-FE (single equation one-way model)	2004-2011
Jorge-Calderón (1997)	European Union (12 countries)	International city-pairs (339)	International	Pax	MLR-G	1989
Kaemmerle (1991)	USA	Enplanements at 260 small-community airports	Total	Pax	MLR	1985
Kiraci (2018)	Turkey	Country as a whole	Domestic vs. international	Pax	Unit root tests	1980-2015
Klodt (2004)	Frankfurt, Hamburg and Munich (Germany)	City-pairs to 14 German cities and 101 foreign cities	Domestic vs. international (border barrier effects)	Passengers flights	MLR-G	1999

Kluge et al. (2017)	Europe (28 countries)	Countries	Total	Pax/capita	MLR	2014
Kopsch (2012)	Sweden	Domestic traffic within the country as a whole	Domestic	Pax	MLR	1980-2017
Lim (2004)	Korea to Australia	Country-pair	International	Pax	Time series model	1980-1999
Liu et al. (2006)	USA	Metropolitan areas (145)	Total	Pax	Logistic regression	2000
Liu et al. (2013)	World	City-pair (91 cities)	Total	Direct passenger flights	Stochastic actor-based modelling	2010 vs. 2000
Mao et al. (2015)	World (3,416 airports)	Airport-pairs	Total	Pax	MLR-G (with normal, Poisson and binomial normal distributions)	2010
Matsumoto (2007)	World	International traffic between world cities.	International	Pax	MLR-G	2000
Profillidis and Botzoris (2015)	World	Countries	Total	Pax/capita	SLR	1980-2013
Seetaram (2012)	Australia	International traffic from 15 countries (country-pairs)	International	Pax	Dynamic PDR	1980-2008
Sivrikaya and Tunç (2013)	Turkey	Domestic traffic by city-pair	Domestic	Pax	MLR-G	2011
Suau-Sanchez and Voltes-Dorta (2019)	Europe	Airports that serve ski resorts	Total vs. international	Passengers flights	Zero-inflated Poisson regression	2018/19
Tsekeris (2009)	Greece	Domestic travel to tourist islands (zone-pairs)	Domestic	Pax	Dynamic PDR	1968-2000
Tsui and Fung (2016)	Hong Kong	City-pairs (top 45 routes)	International	Pax	MLR-G	2001-2012
Valdes (2015)	Middle-income countries (32)	Countries	Total	Pax	Static and dynamic PDRs	2002-2008
Yao and Yang (2012)	China	Provinces	Total	Pax	PDR (generalized error correction method)	1995-2006

* MLR: multiple linear regression. MLR-G: multiple linear regression with gravity specification. PDR: panel data regression. PDR-FE: panel data regression, fixed effects. PDR-RE: panel data regression, random effects. SLR: simple linear regression. TSR: time series regression.

Table A1. Research on the determinants of passenger air traffic by space and time (past three decades

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