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Air passenger movements and innovation

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Abstract

This paper looks at the relationship between the different types of air passenger movements and innovation in each NUTS3 region within Great Britain, between the years 1998 and 2012. This paper examines how the amenities and the respective positive externalities urban areas provide are thought to be important contributors to processes such as innovation. In addition, this paper seeks to conduct a heterogeneity analysis between the impact of different types of air travel, specifically looking at the difference in innovation created by movements between homogenous and heterogenous areas, in this case represented domestically by the distance of routes, and overall by the type of route, whether it be domestic, European, or international. By doing so, a case can be made for the abundance (or lack) of social bridging and bonding capital within the UK. Using instrumental variable analysis, alongside the necessary diagnostics, tests, and checks, a distinct positive causal relationship was found between domestic air movements and the different measures of innovation, therefore indicating that these types of movements within the UK directly contribute to innovation in certain areas. In addition, the relationship was found to be dominated by short-distance routes, possibly indicating that within Great Britain bridging social capital is lacking.

Contents

1. Introduction

Historically, cities began as meeting points between farmers, in order to exchange goods and services. Because of the aggregation of businesses in specific areas, cities have therefore always been at the forefront of innovation and the exchange of ideas. Most inventors, artists and philosophers in the past also resided within cities to benefit from the agglomeration of amenities that could be found there. Nowadays, although the jobs have greatly diversified, we find the same relationship, and with much of the world population now living in cities (UN, 2018), the relationship between them and innovation is ever more important. What has changed compared to the past, however, is the connectivity of cities and their residents, through developments such as the train and aeroplane.

The introduction of these new modes of transport has greatly reduced the cost of communication and transportation, and thus has led to ever more frequent and large exchanges in not only goods, but at the same time also knowledge and human capital, a metric often used in measuring the degree of globalisation (and by proxy, often development) a nation has (Darrat, 1986; Damijan & Kostevc, 2015**).** There is little doubt that such large changes in transportation have brought distant communities closer together, and there is even less doubt that in the prior two centuries, the rate of innovation was higher than it had ever been before.

However, with the introduction and mass adoption of the internet, as well as the increased transport alternatives offered to connect regions and cities, it is important to re-examine the relationship between innovation and the modes of transports themselves. The scope of this paper is specifically therefore to look at how, within Great Britain (hereafter: GB), changes in passenger numbers and flights have impacted innovation in its constituent regions. This leads to the central research question, provided below.

How do different types of air passenger movements influence innovation in a city?

This research question is currently extremely socially relevant given not only the aversion to flying seen in the past few years, often encapsulated under the term *flygskam*, which translates to “flight shame” (Söderberg & Wormbs, 2019), but also given the recent COVID-19 pandemic, which has greatly damaged the airline industry and has cast doubts on the future of aviation, especially in the domestic setting. Therefore, by examining intra-and-inter-GB air movements, it should be possible to paint a picture of the current losses (or lack thereof) in terms of innovation for England, Wales and Scotland, and thus help guide future policy decisions relating to air transportation. Scientifically, the question is equally valid, as there is not a large amount of recent research re-examining the relation between airplanes and innovation within the Western world, and thus while this paper does not specifically look at substitutes to air transportation, it does help gain a better understanding of the role air movements still have in the communication-innovation dynamic.

The main results were created using fixed effect and instrumental variable regressions and showed a distinct causal relationship between domestic movements and innovation in the form of patent applications across Great Britain. These findings indicate that bonding social capital plays a noteworthy role in Great Britain, at least within the context of stimulating patent-related applications and innovation. This is supported by a stronger association between innovation and movements in shorter routes, compared to longer ones. Therefore, policymakers focused on innovation should ensure that domestic routes are protected and even encouraged, specifically between more homogenous areas, as bonding social capital was shown to play a much stronger role than bridging social capital in the context of stimulating innovation.

The paper will now continue with a theoretical framework in which the theoretical foundation of the paper is set, followed by a data section describing the sources and modifications to the data, and then by a methodology which describes the analytical methods used to try and answer the research question. After this, a results section will illustrate and describe the most important results, followed by an implications section, which will evaluate the results in the context of real-world policy making, finally followed by a conclusion which will summarise the main findings and recommendations.

2. Theoretical Framework

In this section, a literature review will be performed of the most relevant academic research and concepts on the subject area to introduce all necessary background knowledge. This review will be split into two subsections based on common themes and background literature, followed by an explanation and description of the respective hypotheses used to help answer the central research question.

2.1 Air movements, urban interactions, and externalities

Referring back to the introduction, the idea that cities foster and promote development is often based on the concept of agglomeration, which traditionally consist in the growing economies of scale and the easier and cheaper availability of production inputs and outputs (Markusen, 1996). Therefore, because of the higher concentration of businesses operating in a given area, there are external economies of scale which allow for lower production costs, thus forcing competitors to relocate or change their type of business (in a perfectly competitive market).

However, as Porter describes in his 1996 paper, these factors are lately becoming less relevant, as reduced transport costs and increased globalisation would reduce the relative benefits that economies of scale and agglomeration can bring in a developed economy(Porter, 1996). What are instead becoming much more relevant are *dynamic efficiencies*, where changes in production methods and types yield unilateral gains in an economy (Abel et al., 1989). Putnam proposed in 1993 that social capital consists of three factors, being morals, societal values, and societal networks, all factors which are outside the scope of economies of scale and classical urban economic theory (Putnam, 1993).

Putnam argues that willing interactions between different social groups contribute to the growth of social capital, which directly contributes to dynamic efficiency (Putnam, 1993). This is because as groups interact and intermingle more, not only do social networks expand between entrepreneurs and other key stakeholders in the economy, but trust also increases as a whole as the heterogeneity of the population is decreased and cultural integration increases (Putnam, 1993).

Concurrently, Porter suggests that these efficiencies are a leading reason for regional cluster growth, where specialised knowledge, inputs, or demand push businesses to locate to urban areas, which offer agglomeration benefits (Porter, 1996). Therefore, geographical and cultural proximities play a large role in modern agglomeration economies, being the basis of these transfers in skill and knowledge (Porter, 1996). Even with the advent of telecommunication and internet technologies in the past few decades, previous literature that examines the relation between population density and economic growth itself, while controlling for technological changes, transportation cost changes and congestion externalities, strongly shows that agglomeration externalities such as knowledge spill overs still play a quintessential role in the determination of innovation, here measured by the number of patent applications (Sedgley & Elmslie, 2011; Agrawal et al., 2017). Based on the literature examined so far, two hypotheses are proposed to help examine the central research question:

H1: Regions with higher passenger volumes have higher levels of innovation

It is necessary to first establish this relationship within the dataset to be able to use the theoretical framework. By examining how changes in passenger volumes impact the number of patents or EUTM filed, it is possible to establish a basic link within GB between transport and basic agglomeration theory, where places that have more amenities and attract more people should also have more innovation, both scientific and entrepreneurial (Porter, 1996). It also offers some insight on the fact that part of the above-average flows may be indeed caused by knowledge flows between different areas, leading to more networking and knowledge sharing (Agrawal et al., 2017). The search of higher-quality education that also leads to innovation may also be contributing to the matter, leading to larger passenger flows (Baumol, 2005; Catalini et al., 2020).

H2: Movements between larger cities have a greater relative impact on innovation

One would expect businesses and individuals to travel more to other cities to collaborate and share knowledge, as these agglomeration externalities are expected to attract not only more specialized individuals and businesses, but also academics and other entities that are less economically represented (Porter, 1996; Dong et al., 2020; Gibbons and Wu, 2019). Therefore, one expects that for the same change in passenger travel domestically, cities would benefit more in terms of innovation, as the cost of transportation is lower between cities is lower, and there are more amenities and agglomeration externalities to encourage the travel.

2.2 Bonding and bridging social capital

Focusing more specifically on the findings of Porter and Putnam however, recent papers indicate that the increase in availability and quality of transport networks such as roads and railroads show a significant positive relationship between this development and regional innovation, although the input and output costs when not located in an urban area are dropping (Agrawal et al, 2017). A possible explanation for this is that knowledge flows from more distant neighbours are facilitated by the reduced transport cost, and therefore the economic performance in areas such as these is higher than would be predicted by a standard agglomeration model (Agrawal et al, 2017).

A recent paper by Dong et al. supports the idea, as it looks at knowledge creation differences across China and their relation to the new High-Speed Rails being built to connect the large country (Dong et al., 2020). By reducing the cost of transport (both financially and in terms of time), teamwork is facilitated across cities and their respective areas, allowing for knowledge spill overs not predicted by agglomeration theories (Dong et al., 2020). Similar findings in the context of productivity in the manufacturing industry can be also found in China, in a recent paper by Gibbons and Wu; reductions in travel times and distances by land were found to have a positive effect on productivity, probably due to the same mechanisms as mentioned by Dong et al. (Gibbons and Wu, 2019).

These rail networks are real possible substitutes to air travel; however, most countries do not have the infrastructure required for such high-speed rail lines. Thus, transferring this idea specifically to aeronautical travel in a more British style environment (with antiquated rail networks), namely in the USA, a paper by Catalini et al. looks at a quasi-experiment scenario with the introduction of low-cost airlines, which reduce geographic frictions that limit teamwork and collaboration (Catalini et al., 2020). Their findings show that reductions in limitations to travel increase collaboration, especially between high-quality scientists that otherwise would have been limited by their local environments (Catalini et al., 2020). This relationship however is not limited to scientific collaboration: face-to-face contacts can also simply attract new businesses or partnerships to cities, also leaving their areas of poorer economic opportunity, and thus reaffirming the importance of travel frictions in the urban-regional development and innovation dynamic (Brueckner, 2003).

The previously described research into how cities and regions react to changes in transportation strongly ties into and is a partial foundation to the concepts of bonding and bridging social capital. Bonding social capital refers to internal links within communities or similar peoples e.g., the cooperation between people of the same ethnicity, language, or in relatively homogenous areas, nationality (Patulny & Svendsen, 2007). Bridging social capital on the other hand refers to links between dissimilar communities or peoples (Patulny & Svendsen, 2007). It is no coincidence that the two trains of thought emerged relatively close to each other; in essence, depending on the distances and similarities between communities, it is possible to narrow down the mechanism by which changes in transportation infrastructure and ease-of-use lead to changes in innovation and productivity, and thus allow for more specific research that yields greater real-life policy-making utility.

This is because social capital can not only include individuals or communities, but also exclude them, although this is very difficult to measure (Leonard, 2004). As suggested by Leonard, the conditions for creating bridging social capital also can stifle bonding social capital, as seen by the border division in Northern Ireland, and within their own communities (Leonard, 2004). For this reason, GB is a good place to look at these two types of social capital, as it features the highest geographical inequalities in Europe (Bounds, 2019) and also strong historical, financial, and economic ties between major cities.

Keeping these concepts in mind, the following two additional hypotheses are proposed to guide the structure of the analysis:

H3: Domestic movements have a larger impact on innovation than foreign movements

Although GB is relatively unequal on an income scale across the country, it is still a relatively homogenous nation, and thus one would expect that for the same given change in passenger numbers, domestic movements would have a larger impact than the foreign ones. This is in line with the idea of bonding social capital, but also would shed some light on the relationship between bridging social capital and UK urban economies (Patulny & Svendsen, 2007).

H4: Air movements between more distant regions are associated with a larger change in innovation than nearer ones

This hypothesis is made to look at the intra-GB movements, and to see if bridging social capital plays an important role within the economy of Great Britain. If the aforementioned differences play too large a role, one expects little benefit in long-distance travel, as this fact would indicate that a large majority of the passengers on these flights chose flying due to the cost of the only substitutes, road or rail travel. In addition, if the cost reductions in travel brought by commercial flights are large enough, one would expect the more distant knowledge flows to positively contribute to innovation in an area (Agrawal et al., 2017; Porter, 1996).

In the following section, the datasets used for the hypotheses and their respective manipulations will be discussed, followed by a methodology section which will explain in detail the analytical methods used to answer these hypotheses.

3. Data

The data obtained for the proposed analysis spans from 1992 to 2012, although most of the analysis is performed 1998-2012 (with the route or pair-movement data ranging from 2000-2012) due to the greater availability of suitable control variables. All the data regarding air movements, passenger numbers, and route movement variables was obtained from the UK Civil Aviation Authority (Civil Aviation Authority, 2020). A table matching corresponding airports to their respective NUTS3 regions and cities can be found in **Appendix A**. The air movement data consists of airport-centric data and route data for intra-GB routes. The route data differs from the main dataset because it looks at the sum of in-and-outbound movements to a specific airport (and its respective region), while the airport-centric (and main) dataset looks at the sum of *all* the in-and-outbound movements to the respective region and airport.

The type of data obtained was relating to the total number of passengers, the number of terminal and transferring passengers for both scheduled and chartered flights, the number of domestic, international, and European Community (EC) flights that were both scheduled and chartered, and finally the scheduled and chartered route movements between airports; these variables will all feature as independent variables in later regressions.

The ultimately chosen control variables at a NUTS3 level, which consist of the GDHI, resident population, as well as several GDP chained-volume indexes (with the reference year set in 2016) of the education, R&D, and production sectors, were obtained both from Eurostat and from the Office for National Statistics (Eurostat, 2020; OfNS, 2020), with Eurostat also being the source for the innovation data: in this case, the number of total patents filed for in a region, the number of high-tech patents filed in a region, and the number of EU trademarks filed within a region (Eurostat, 2020). The reason for the three different sources of innovation data is the possible different nature of the innovation created in an area (with e.g., EUTM proxying business-related innovations). Some additional data regarding education was obtained from the Office for Students Register (OfS, 2020). The descriptive statistics, alongside the code names for all used variables, can be found below.

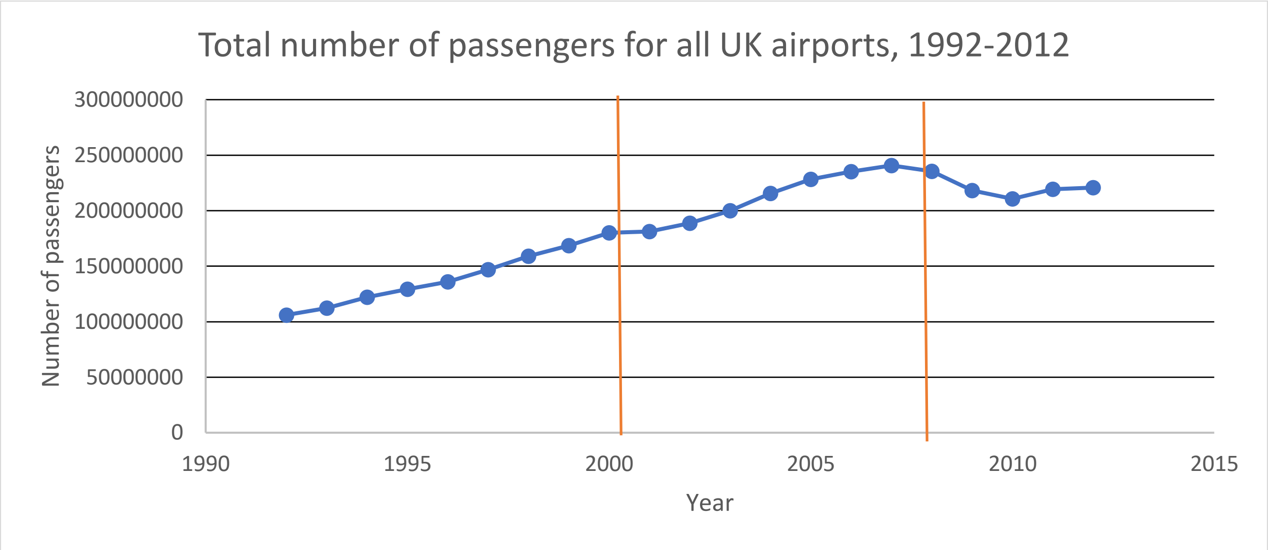
Table A – Descriptive Statistics and corresponding code names

Raw Variable	Full Variable Name	Obs	Mean	Std. Dev.	Min	Max
pax	Total passengers	1,222	3153356	9286435	0	7.00E+07
term_shd_pax	Terminal Scheduled Passengers	1,198	2659217	8776096	0	6.99E+07
term_cht_pax	Terminal Chartered Passengers	1,198	557310.9	1639812	0	1.11E+07
trans_shd_pax	Transfer Scheduled Passengers	1,198	13433.36	42213.8	0	351904
trans_cht_pax	Transfer Charter Passengers	1,198	5202.077	15483.84	0	170216
allpatent	All patents	1,096	46.89158	59.61636	0.08	378.28
hipatent	High-tech patents	910	14.5403	25.5553	0.11	219.72
gdhi	Gross disposable household income (GDHI)	919	4718.577	3135.934	155	13318
eutm	EU Trademarks	876	30.07078	29.96355	1	185
respop	Resident population	861	576116.4	664551.2	19220	2761887
educhain	Education chained-volume measure Index	861	153.7492	226.6701	9.2	3625.5
prodchain	Production chained-volume measure index	861	104.0866	31.03261	45.4	258.7
rdchain	R&D chained-volume measure index	861	90.87967	58.64984	6	429
ec_shd	European community scheduled passengers	826	14971.66	36084.69	0	224567
ec_cht	European community chartered passengers	826	2551.774	5931.013	0	38866
intl_shd	International scheduled passengers	826	5639.134	26203.58	0	218463
intl_cht	International chartered passengers	826	1916.345	5300.745	0	39530
dom_schd	Domestic scheduled passengers	826	12415.82	16996	0	82442
dom_cht	Domestic chartered passengers	826	918.3039	1742.131	0	9612
p2p_pax_s	Scheduled passengers per route	949	188110.7	283184.7	0	1696300
p2p_pax_c	Chartered passengers per route	949	214.922	775.2233	0	8846

As one can see, the mean of the scheduled flights is much greater than that of the chartered flights, which is to be expected as most commercial flights are scheduled. The range of airports is also quite large, with some airports having no passengers each year, and others having as many as 70 million (namely Heathrow). The resident populations of the NUTS3 areas vary largely as well, between 19,000 and 2.8 million people.

All the data is available from national and supernational organisations, and thus they are to be considered credible and accurate within reason. It is important to note that although the data provided is for all of the UK, the analysis will focus specifically on GB, in order to avoid transport substitution effects from biasing the results (as Northern Ireland only has maritime and aviation routes to the mainland). The time-span utilised features two exogenous shocks which allow for a better understanding, through the models that will be discussed in the methodology, of the relationship between air passenger movements and innovation. This can be seen below, with the two points marked with an orange line.

Figure A

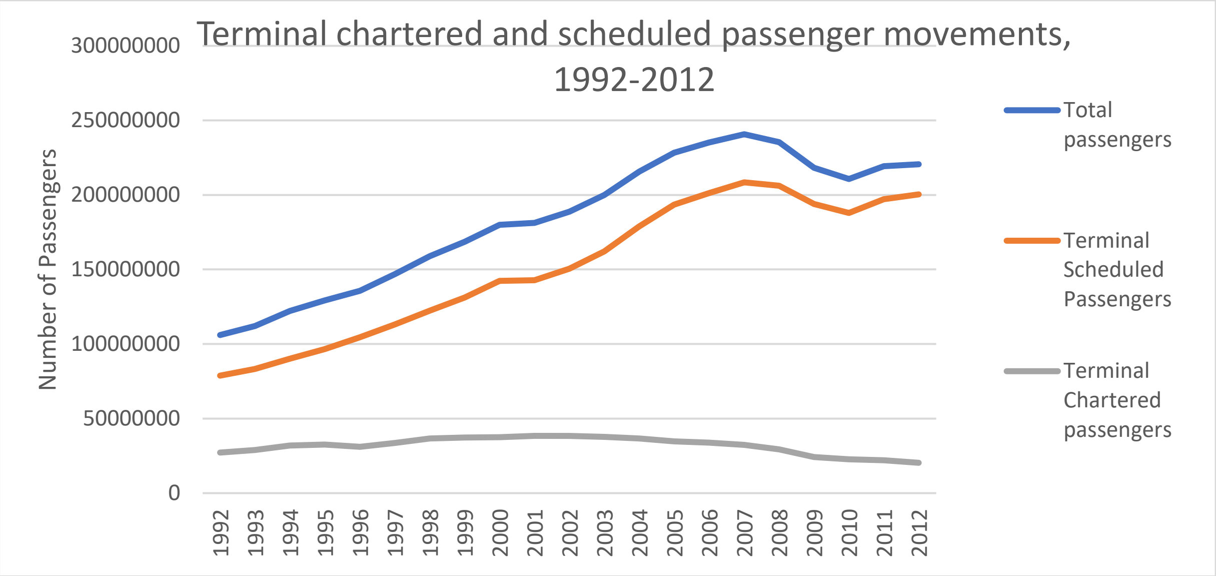


Source: (UK) Civil Aviation Authority, 2015

To condense all the data into a useable dataset, it was necessary to match each airport with its respective NUTS3 area, as this is the territorial unit used in the analysis. It is important to note the changes in NUTS3 nomenclature over the past few decades in order to match the datasets correctly, most notably with changes in 2008, 2012, and 2015, also known by their official nomenclature of NUTS2003, NUTS2006, NUTS2010 and NUTS2013 (Eurostat, n.d.). In addition, for the point-to-point movement analysis it was necessary to either sum or weigh-out averages for controls between two areas, as unidirectional movement information was not available; this was done using gross GDP, which is not contained within the models created, but well-proxies differences in the sizes of regional characteristics, which in turn used regionally balanced chained values (OfNS, 2019). Lags were also created for the independent variables to serve as robustness checks and to further examine the relationship between the dependent and independent variables.

When looking at the data itself, it could be seen in fig. A that overall, there has been a relatively constant increase in the number of people flying yearly, with reductions in 2008 (with the financial market crash) and 2001 (due to the September 11th attacks). The main variation in these passenger numbers was in the scheduled flights, with the charter flights seeing a much lesser response to exogenous shocks; it is partially for this reason that chartered flights are later used as an instrumental variable for the analysis. This relationship can be seen below.

Figure B

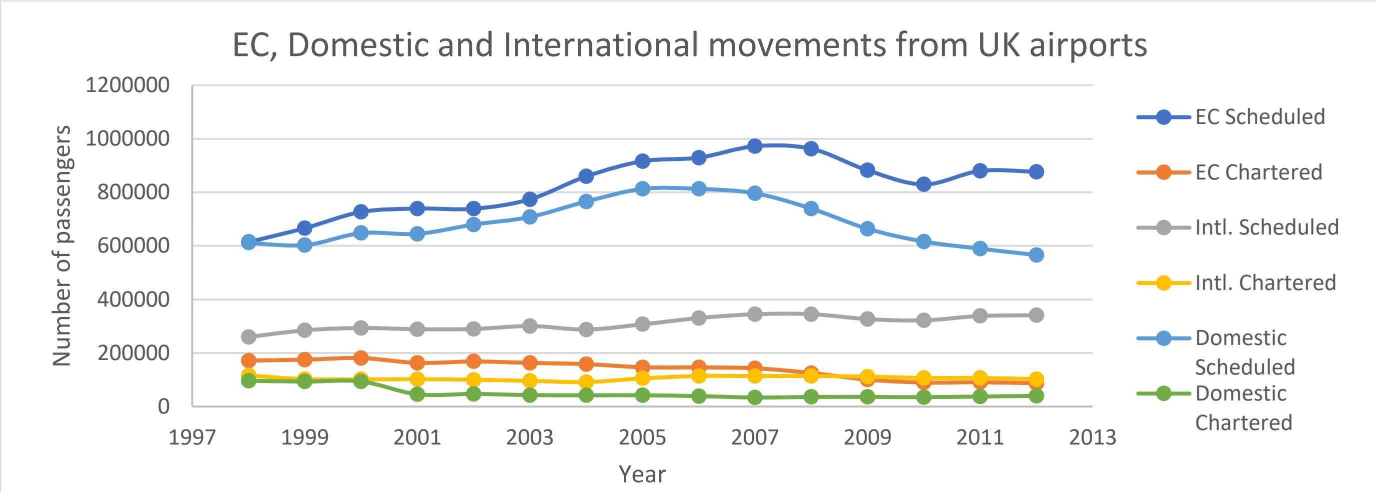


Source: (UK) Civil Aviation Authority, 2015

In addition, data regarding transfer passengers was also collected and used: the reason why is hinted by the fact that these numbers are generally decreasing, unlike the general passenger numbers, and not strongly responding to the aforementioned shocks. The reason for this is found in the change in air transport organisation, as airlines have moved from a hub-and-spoke transport model which requires many transfers, to point-to-point transport models, thanks to the advent of aircraft such as the A350 and B787 (Marsh, 2007). The trend for these variables is shown in **Appendix B**. Additionally, when looking at individual routes' movements between airports, it is useful to note that many of these movements are between large cities or capitals of respective regions, with few relative changes over the research's timeframe. A representative example of the passenger distribution table can be found in **Appendix C**.

When breaking down the passenger numbers by type of flight, it is seen that the amount of scheduled domestic flights has been decreasing over the years, as well as the number of European Community (hereafter: EC) flights; international flights have however remained relatively unaffected, and the chartered flights even less so. This is part of the reason that the analysis is domestically focused, as these changes in the data allow for a more significant outcome in the analysis. For the purposes of this paper, although the EC is in a common aviation market with the UK, the flights are considered separate. This is done to ensure that no exogenous factors (such as the increased difficulty of transporting people over water in substitute cases) bias the results of the analysis. The patterns described above are shown below.

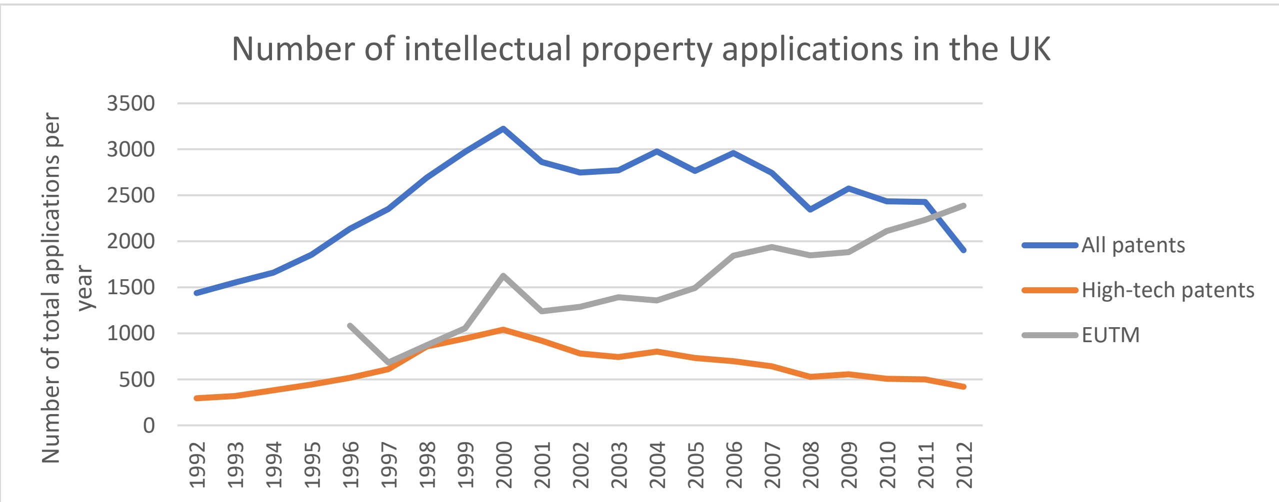
Figure C



Source: (UK) Civil Aviation Authority, 2015

Finally, it is noteworthy to look at changes in patent application patterns. As can be seen by the graph below, the yearly change in all types of patents filed for has not been constantly increasing, with all patents showing a clear reaction to market shocks. The EU trademarks however have been increasing relatively constantly over time, but this is probably since they are relatively recently introduced and being slowly adopted in favour of national trademark applications, due to the increased benefits of the common market. Ergo, there is good reason to try and isolate the distinct relationship between the air movements previously discussed and intellectual property applications, as no conclusions can be drawn from the descriptive statistics.

Figure D



Source: (UK) Civil Aviation Authority, 2015

4. Methodology

To answer the hypotheses postulated in the theoretical framework, several types of analysis are needed to paint a wholistic picture. All regressions are performed with a 5% significance level and a 95% confidence interval. The analyses are all conducted in STATA; for the results, the robust option is used whenever possible. The types of analysis used consist of fixed and random effect (FE and RE respectively, depending on the outcome of the Durbin–Wu–Hausman test), and instrumental variable (IV) regressions, as well as propensity score matching (PSM) a as robustness check where suitable (where a quasi-experiment is run, assuming airports as treated, should their respective passenger flow be above the mean of all airports in a given year), which can be found in **Appendix E**.

For the IV regressions, it was necessary to find relevant and exogenous instruments for the independent variables used in the analysis. The independent variables consist of the scheduled terminal, European Community, International and Domestic passenger movements. The instruments used (respectively) are the chartered terminal, transfer, EC, International and Domestic movements.

These instruments cannot make use of the overidentification test; however, they can be assumed to be exogenous because chartered and scheduled flights respond to very different factors, and the common factors that they both respond to are included as control variables (which are listed in the next paragraph). This is quite a reasonable assumption, as chartered flights are tendentially planned far longer in advance, for example by travel agencies or government institutions, and therefore will be almost unaffected by changes in the non-examined factors, which will fall under the models' error term. The relevance of the instruments is instead tested via the first stage regressions performed for each IV model, which will be described in the **Results** section. An F-statistic over 10 was considered as a cut-off for instrument relevance, indicating that the instrument predicts the independent variable. In addition, the Kleibergen-Paap F-statistic is reported for each of the IV models, which when compared to a table of critical values by Stock and Yogo, shows the percent bias the IV models yield (Stock & Yogo, 2005); this serves as an extra weak identification test for when the independent and identically distributed random variables assumption is dropped. However, given that each model only uses one instrument, the first-stage F-statistics serve as an acceptable overall metric of instrument weakness. For reference, the rule of thumb Stock-Yogo weak instrument critical values are 16.38 at 10% of the maximal IV size, 8.96 at 15% of the maximal IV size, and 6.66 at 20% of the maximal IV size (Stock and Yogo, 2005).

Correlation and Variance inflation factor (VIF) tables were created to aid in control variable selection. The controls account for changes in education and production output, as well as changes in local wealth and population, which are some of the main known factors that associate with higher levels of innovation. All non-random missing data locations were also removed to balance the panel. Additional regressions based on city size-divisions and city-pair distances are also included, to better isolate specific relationships and thus allow a better comparison of the results to the theory. For the single-airport data, a category *big* is created if the airport is in a region with over a million residents; for the route data, a category is created for distance (set at 425 km as this distance is roughly the point where air travel is speedier than automotive transport) and the type of route (whether it is between two large or small area, or between a large and small area, with a large area having a resident population over one million).

Below one will find a list of the models' general forms for fixed effects (which is almost identical to the random effects model save for some differences in notation). The dependent variable is represented by the letter *y*, and can take the form of all patents, high-tech patents, or EU trademarks. The letter *x* is also used to represent all the independent variables. All the independent variables are respectively used with each dependent variable.

- FE:

$$y_{region,it} = \beta_1 x_{region,it} + \beta_2 res\_pop_{region,it} + \beta_3 GHDI_{region,it} + \beta_4 rdchain_{region,it} + \beta_5 educhain_{region,it} + \beta_6 prodchain_{region,it} + \alpha_i + u_{it}$$

- RE:

$$y_{region,ij} = \mu + \beta_1 x_{region,ij} + \beta_2 res\_pop_{region,ij} + \beta_3 GHDI_{region,ij} + \beta_4 rdchain_{region,ij} + \beta_5 educhain_{region,ij} + \beta_6 prodchain_{region,ij} + U_i + W_{ij}$$

A wholistic description of the results, and subsequently their relation and impact on the hypotheses, can be found in the following section.

5. Results

The regressions that will be shown below will be ordered from the simpler to the more complex models, and therefore the answers to each hypothesis will be found at the end of the section, after a comprehensive evaluation of all the models and results. As previously mentioned, regressions were run for all patents, the high-tech patents, and EU Trademarks. For all models that will be presented, fixed effects were more appropriate than random effects, according to Hausman tests performed at a 5% significance level, and therefore these will be presented over the random effect models. The two datasets used, the general one and the one containing route-specific data (hereafter: route dataset) will be split into two separate sections and will be followed by a re-evaluation of the hypotheses.

5.1 The general dataset

This dataset looks at movements divided by type (transfer or terminal), arrangement (chartered or scheduled flights) and the general type of flight (domestic, international, European, and total).

Table 2: Fixed effect models with all patents as the dependent variable

	(1) Terminal Scheduled Passengers	(2) Scheduled European Community Passengers	(3) Scheduled Domestic Passengers	(4) Scheduled International Passengers	(5) Terminal Scheduled Passengers	(6) Scheduled European Community Passengers	(7) Scheduled Domestic Passengers	(8) Scheduled International Passengers
Independent Variable	-1.85e-06*	-0.00004	0.00121***	-.000914***	-1.05e-06	0.00014	0.00129***	-0.00063**
	(1.10e-06)	(.0001665)	(0.004)	(.0002592)	(1.34e-06)	(0.000219)	(0.000381)	(0.000255)
Controls					X	X	X	X
Constant	66.66***	59.0505***	39.5106***	66.0062***	21.52	26.04	-1.854	28.25
	(4.91)	(3.58)	(6.18)	(2.20)	(24.90)	(22.42)	(18.92)	(21.91)
Observations	543	542	542	542	543	542	542	542
R-squared	0.0202	0.0002	0.0568	0.0257	0.091	0.094	0.152	0.103
Number IDs	39	39	39	39	39	39	39	39

Controls consist of: Resident population, GDHI, and the chained-value index for the respective R&D, Education and Production sectors of the region; Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Beginning with a simple fixed effect model for all patents, we see that for all patents filed in a region, the relationship between patents and passenger movements heavily depends on the type of movement. For example, terminal scheduled passenger movements only yielded significant negative results at a 10% significance level with the absence of control variables. The results were insignificant also for all EC passengers, however with positive coefficients. The relationship between domestic passengers' movements and all patents however shows a strongly significant (at 1%) positive relationship with and without controls, with a coefficient of 0.00129 and 0.00121 respectively, indicating that for every additional passenger under the model, another 0.00129 patents are filed in the airport's region. On the other hand, the model for international passengers shows a negative significant relationship (at 5%), albeit with a smaller absolute coefficient than that of the domestic movements.

Table 3: Fixed effect models with high-tech patents as the dependent variable

	(1) Terminal Scheduled Passengers	(2) Scheduled European Community Passengers	(3) Scheduled Domestic Passengers	(4) Scheduled International Passengers	(5) Terminal Scheduled Passengers	(6) Scheduled European Community Passengers	(7) Scheduled Domestic Passengers	(8) Scheduled International Passengers
Independent Variable	-1.99e-06***	-.0003123**	.0001865	-.0005381***	-7.80e-07	-5.37e-05	0.000328	-0.000343**
	(5.34e-07)	(.0001304)	(.0003105)	(.0001045)	(9.76e-07)	(0.000205)	(0.000211)	(0.000162)
Controls					X	X	X	X
Constant	29.11***	26.62***	15.74***	24.23***	21.52	26.04	-1.854	28.25
	(2.73)	(3.20)	(5.36)	(1.02)	(24.90)	(22.42)	(18.92)	(21.91)
Observations	543	542	542	542	543	542	542	542
R-squared	0.0606	0.0266	0.0034	0.0234	0.091	0.094	0.152	0.103
Number IDs	39	39	39	39	39	39	39	39

Controls consist of: Resident population, GDHI, and the chained-value index for the respective R&D, Education and Production sectors of the region; Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For high-tech patents, we see a much more negative overall trend in the coefficients of the independent variables, with the only model with controls (being the international passenger movements) showing a significant negative result at a 5% significance level. It is interesting to note that even of the coefficients that are not significant, the domestic movements have the only positive coefficients.

Table 4: Fixed effect models with EU Trademarks as the dependent variable

	(1) Terminal Scheduled Passengers	(2) Scheduled European Community Passengers	(3) Scheduled Domestic Passengers	(4) Scheduled International Passengers	(5) Terminal Scheduled Passengers	(6) Scheduled European Community Passengers	(7) Scheduled Domestic Passengers	(8) Scheduled International Passengers
Independent Variable	2.76e-06***	.0005509**	-.0001694	.0006172**	3.76e-07	0.000142	3.53e-05	-0.000175*
	(1.01e-06)	(.0002093)	(.0002992)	(.0002721)	(3.25e-07)	(0.000108)	(0.000265)	(9.28e-05)
Controls					X	X	X	X
Constant	22.39***	22.84***	37.73***	29.65***	-33.61	-34.95	-37.29*	-35.50
	(4.66)	(4.64)	(4.72)	(2.38)	(21.24)	(22.16)	(20.94)	(21.31)
Observations	527	526	526	526	527	526	526	526
R-squared	0.0745	0.0544	0.0018	0.0194	0.376	0.376	0.373	0.374
Number IDs	39	39	39	39	39	39	39	39

Controls consist of: Resident population, GDHI, and the chained-value index for the respective R&D, Education and Production sectors of the region; Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

On the other hand, for EU Trademark applications, one sees a much more positive result in the coefficients, although no model with controls is significant at 5%. The base models of the scheduled terminal, EC and international passengers yield significant and positive results at 5% (and 1% for the terminal scheduled passengers), which is more in line with the results of the fixed effect regressions of all patent applications, and almost the opposite of the high-tech patent applications, except for the negative (but insignificant at 5%) trend of the international passenger movements.

In view of these results, not much can be said about the general relationship between passenger movements and patent or trademark applications, never mind a causal link. Therefore, the regressions seen above will be rerun with instruments, as previously described in the methodology section. In addition, the separation of the large areas from the small ones will be created to examine the possible impact of the access more closely to larger markets that was discussed in the *Theoretical Framework* section. A similar but more detailed division will also be later performed for the route dataset, which will also allow one to examine the importance of social bonding and bridging.

To perform instrumental variable regressions however, the instruments must be tested to ensure they are not too weak and are relevant. The first-stage results for all considered instruments can be found below.

Table 5: First-Stage results for IV

	(1) Terminal Scheduled passengers	(2) Terminal Scheduled passengers	(3) European Community Scheduled Passengers	(4) Domestic Scheduled Passengers	(5) International Scheduled passengers
Instrument Tested	Terminal Chartered Passengers	Transfer Scheduled Passengers	European Community Chartered Passengers	Domestic Chartered Passengers	International Chartered passengers
Independent variable	1.560***	177.6***	2.656***	4.338***	0.280
	(0.229)	(7.284)	(0.233)	(0.421)	(0.192)
Constant	-4.131e+06**	-4.259e+06***	-21,692***	-3,139	-7,045
	(1.646e+06)	(1.200e+06)	(5,659)	(2,804)	(4,871)
Controls	X	X	`X	X	X
First-stage F-Statistics	46.42	594.35	130.05	106.05	2.12
Observations	581	581	580	580	580
R-squared	0.262	0.608	0.384	0.251	0.185

Controls consist of: Resident population, GDHI, and the chained-value index for the respective R&D, Education and Production sectors of the region; Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As one can see, all the instruments listed above save for the international chartered passengers are not weak and are therefore suitable for use in a second stage. Because international movements lack a suitable instrument, they will not be present in the IV regressions. On the next page one will find these IV analyses.

Table 6: IV models with all patents as the dependent variable

	(1)	(2)	(3)	(4)
Independent Variable	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers
Instrument	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers
Independent Variable	-8.34e-06**	-1.27e-06	-0.000403	0.00244**
	(3.95e-06)	(1.36e-06)	(0.000407)	(0.000976)
Controls	X	X	X	X
Kleibergen-Paap Wald F Statistic	7.4	62.25	18.82	17.66
Observations	543	543	542	542
R-squared	-0.150	0.091	0.067	0.104
Number of panelid	39	39	39	39

Controls consist of: Resident population, GDHI, and the chained-value index for the respective R&D, Education and Production sectors of the region; Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Starting with the relationship between all patents and the independent variables, one can see a negative and significant (at 5%) relationship between terminal scheduled passengers and all patent applications. However, one can also see that the domestic movements have a significant (at 5%) and positive coefficient of relatively high magnitude in comparison to the other independent variables' coefficients. While the Kleibergen-Paap F-statistic indicates *Domestic Chartered Passengers* as a strong instrument, it is important to note that the instrument *Transfer Scheduled Passengers* is significant only at the 15% Stock-Yogo threshold, and therefore the magnitude of the coefficient should be considered with care when attempting to attribute economic value to the results.

Table 7: IV models with high-tech patents as the dependent variable

	(1)	(2)	(3)	(4)
Independent Variable	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers
Instrument	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers
Independent Variable	-2.19e-06*	7.84e-07	0.000155	0.00139**
	(1.33e-06)	(7.65e-07)	(0.000235)	(0.000550)
Controls	X	X	X	X
Kleibergen-Paap Wald F Statistic	7.90	59.61	17.68	14.83
Observations	465	465	464	464
R-squared	0.177	0.172	0.184	0.102
Number of panelid	34	34	34	34

Controls consist of: Resident population, GDHI, and the chained-value index for the respective R&D, Education and Production sectors of the region; Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The regressions for the high-tech patents have a similar outcome, with a negative and significant (however only at 10%) coefficient, and a strong positive significant (at 5%) relationship between domestic movements and high-tech patent applications. The Kleibergen-Paap F-statistic results here indicate that both the *Domestic Chartered Passengers* and *Transfer Scheduled Passengers* instruments are significant only at the 15% Stock-Yogo threshold, and therefore the magnitude of the coefficients should again be considered with care.

Table 8: IV models with EU Trademarks as the dependent variable

	(1)	(2)	(3)	(4)
Independent Variable	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers
Instrument	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers
Independent Variable	-6.75e-07 (1.92e-06)	1.47e-06 (1.12e-06)	0.000236 (0.000330)	0.000748 (0.000732)
Controls	X	X	X	X
Kleibergen-Paap Wald F Statistic	9.34	61.48	18.48	14.95
Observations	527	527	526	526
R-squared	0.375	0.367	0.374	0.343
Number of panelid	39	39	39	39

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Looking at the EU Trademark models, one can see that there are no significant results. Overall, one can say that there is relatively good evidence for the causal link between domestic flights and positive patent applications. In addition, there is some weaker evidence for a negative causal relationship between terminal passenger movements and all patent applications; the possible causes and implications of this are discussed in the conclusion and implications section. The propensity score matching that can be found in **Appendix D** as a robustness check corroborates these results, with a positive difference between treated and untreated groups (respectively, above and below Great Britain's passenger flow mean) found for domestic movements for EU Trademarks and all patent applications.

5.2 Route-Dataset Analysis

To better be able to link the results with the theoretical framework and answer the two sets of hypotheses, it is also useful to divide the regressions between larger and smaller areas, in order to see how the availability of amenities and externalities impacts the causal relationships seen before. Below are the respective IV regressions for these areas, with the larger ones having a population of above a million residents.

Table 9: IV models with all patent applications as the dependent variable, divided by area size

	(1) Large areas	(2)	(3)	(4)	(5) Small areas	(6)	(7)	(8)
Independent Variable	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers
Instrument	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers
Independent Variable	7.50e-06	-8.61e-06	0.00235	-0.000274	-3.61e-06*	5.00e-07	-1.58e-05	0.00238**
	(4.66e-06)	(6.22e-06)	(0.00270)	(0.00158)	(2.19e-06)	(1.25e-06)	(0.000302)	(0.00114)
Controls	X	X	X	X	X	X	X	X
Kleibergen-Paap Wald F Statistic	9.33	4.23	0.97	3.35	11.41	4.23	59.92	18.05
Observations	104	104	104	104	439	439	438	438
R-squared	-0.416	-0.684	-1.994	0.031	0.087	0.099	0.111	0.147
Number of panelid	7	7	7	7	32	32	32	32

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Although nothing can be said about the larger areas given the lack of significant results, possibly due to the low number of regions that fall in the larger category (namely 7, as represented by the number of panelid), one can see that the domestic movements in smaller areas are significant at 5%, and given the that the overall coefficient previously calculated was 0.00244, it is likely that the smaller regions make up for most of the positive causal relationship seen between domestic passenger movements and all patent applications. In addition, the R^2 value has risen from 0.104 to 0.147, indicating a very large increase in the fit of the model. The Kleibergen-Paap F-statistics for the significant results here reflect those found in the main model.

Table 10: IV models with high-tech patent applications as the dependent variable, divided by area size

	(1) Large areas	(2)	(3)	(4)	(5) Small areas	(6)	(7)	(8)
Independent Variable	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers
Instrument	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers
Independent Variable	-2.28e-08	-1.12e-06	0.000311	-0.000848	-1.22e-06	1.21e-06*	0.000232	0.00217***
	(1.98e-06)	(2.49e-06)	(0.000667)	(0.000856)	(1.00e-06)	(7.11e-07)	(0.000180)	(0.000807)
Controls	X	X	X	X	X	X	X	X
Kleibergen-Paap Wald F Statistic	7.82	3.88	1.16	3.32	45.81	80.27	59.97	12.05
Observations	99	99	99	99	366	366	365	365
R-squared	0.156	0.144	-0.018	-0.349	0.213	0.171	0.191	0.026
Number of panelid	7	7	7	7	27	27	27	27

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For the high-tech patent we also see a strong positive and significant (at 1%) relationship between domestic movements in small regions and patent applications, with a coefficient almost doubling that found in the general model (namely, of 0.00139). Therefore, there is evidence for a strong causal relationship between the movements in smaller regions and high-tech patent applications; the implications of this will be discussed in the **Conclusion** section. The Kleibergen-Paap F-statistic for significant domestic movements reflects what is found in the main model, however the instrument *Terminal Chartered Passengers* appears to be strong in the context of this model.

Table 11: IV models with EU Trademark applications as the dependent variable, divided by area size

	(1) Large areas	(2)	(3)	(4)	(5) Small areas	(6)	(7)	(8)
Independent Variable	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers	Terminal Scheduled Passengers	Terminal Scheduled Passengers	European Community Scheduled Passengers	Domestic Scheduled Passengers
Instrument	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers	Transfer Scheduled Passengers	Terminal Chartered Passengers	European Community Chartered Passengers	Domestic Chartered Passengers
Independent Variable	-2.00e-06	5.00e-06	-0.00115	-0.000433	-1.24e-06	6.32e-07	0.000104	0.000679
	(4.11e-06)	(5.10e-06)	(0.00149)	(0.00143)	(1.15e-06)	(8.92e-07)	(0.000202)	(0.000857)
Controls	X	X	X	X	X	X	X	X
Kleibergen-Paap Wald F Statistic	12.09	4.23	0.97	3.30	48.42	81.47	60.00	12.53
Observations	104	104	104	104	423	423	422	422
R-squared	0.605	0.542	0.483	0.613	0.285	0.317	0.316	0.288
Number of panelid	7	7	7	7	32	32	32	32

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The regressions for the EU trademarks yielded once again no significant results, and thus not much can be said about them. However, the models do have relatively high R^2 values, indicating that the data fits quite well with the regression lines created.

To add another dimension to the analysis and to better evaluate the previous results, route data was also processed, whose models can be seen below. This movement data allows one to see the total (incoming plus outgoing) scheduled and chartered flights between to airports (and thus their respective regions). This more focused analysis will also allow for more to be said regarding the presence of bonding and bridging social capital, whose analysis and implications are contained in the results and implications section. First the base models will be examined, followed by the first-stage IV results, and finally group-separated FE regressions (whose groups are described in the **theoretical framework** section) due to the absence of a suitable instrument and the Hausman test preferring fixed over random effects. Propensity score matching was also performed for this dataset as a robustness check, and can be found in **Appendix E.**

Table 12: OLS, FE, and RE models with all patent applications as the dependent variable

VARIABLES	(1) OLS - Total passenger flow	(2) FE - Total passenger flow	(3) RE - Total passenger flow
Total Passenger Flow	4.99e-05***	8.22e-05***	8.47e-05***
	(6.55e-06)	(1.42e-05)	(1.17e-05)
Constant	19.31*	-51.56	32.67
	(11.69)	(52.19)	(20.14)
Controls	X	**X**	X
Observations	949	949	949
R-squared	0.322	0.154	0.141
Number of panelid	73	73	73

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: OLS, FE, and RE models with high-tech patent applications as the dependent variable

VARIABLES	(1) OLS - Total passenger flow	(2) FE - Total passenger flow	(3) RE - Total passenger flow
Total Passenger Flow	2.49e-05***	1.28e-05**	2.19e-05***
	(2.43e-06)	(6.23e-06)	(5.23e-06)
Constant	-5.254	1.134	35.30***
	(4.730)	(25.26)	(10.49)
Controls	**X**	**X**	**X**
Observations	949	949	949
R-squared	0.158	0.312	0.2989
Number of panelid	73	73	73

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14: OLS, FE, and RE models with EU Trademark applications as the dependent variable

VARIABLES	(1) OLS - Total passenger flow	(2) FE - Total passenger flow	(3) RE - Total passenger flow
Total Passenger Flow	3.98e-05***	-7.71e-06	5.43e-06
	(3.66e-06)	(1.00e-05)	(9.46e-06)
Constant	-0.203	-140.5***	-34.81***
	(7.223)	(28.21)	(9.984)
Controls	**X**	**X**	**X**
Observations	949	949	949
R-squared	0.528	0.369	0.3459
Number of panelid	73	73	73

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For all and high-tech patent applications, one sees a distinctly positive and significant (at 5% and 1%) relationship with domestic route movements, with the EU Trademarks showing insignificant results save for the basic OLS model. This is in line with the general results that were shown before. Thus, as before, an instrument will now be tested to see whether an IV regression is possible. The results of the first stage can be found below.

Table 15: Route dataset - IV First stage

	(1) Sum of scheduled domestic passengers per route
Instrument Tested	Sum of chartered domestic passengers per route
Independent variable	19.071 *
	(10.89)
Constant	- 162702.9 ***
	(59452.67)
Controls	**X**
Cragg-Donald Wald F Critical Value	3.06
Observations	949
R-squared	0.170

As one can see, both the relationship between the instrument and the dependent variable (the sum of the scheduled passengers per route) is only significant at 10%, and in addition yields a critical F value of only 3.06 when tested, which falls short of the rule of thumb of 10. Therefore, there is no suitable instrument that can be used for the purposes of this analysis.

Working only with fixed effect, the previous models were also split into distance radii, and the relationship between the origin and destination area (in terms of size). This is very important because it allows not only for the spatial aspect to be taken into account when looking at the relationship between patent applications and regional movements, but it also allows one to get an indication of which types of flows associate more strongly with innovation, also partially indicating their nature. For example, flows between large regions may indicate that entities that innovate prevalently look for large resource pools and amenities. These models can be seen below (the RE models are dropped as FE is chosen for all the models due to the outcome of the Hausman tests performed on all previous regressions).

Table 16: Fixed Effect models with all patent applications as the dependent variable, divided by route distance and route relations

	(1)	(2)	(3)	(4)	(5)
	Route Distances		Route Relations		
VARIABLES	FE – Short Distance Routes	FE – Long Distance Routes	FE – Large-Large Region Pairs	FE - Small-Large Region Pairs	FE - Small-Small Region Pairs
Total Passenger Flow	0.000106***	6.93e-05***	5.71e-05***	9.91e-05**	0.000136***
	(1.81e-05)	(2.36e-05)	(1.45e-05)	(4.68e-05)	(1.58e-05)
Controls	X	X	X	X	X
Constant	-36.23	-56.89	-34.72	-63.28	-232.3**
	(74.78)	(72.15)	(70.82)	(171.2)	(95.81)
Observations	494	455	208	338	403
R-squared	0.175	0.166	0.173	0.099	0.277
Number of panelid	38	35	16	26	31

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For all patent applications, one can see significant positive effects for all the types of domestic movements at 1% for all except the small-large route grouping, which is accepted at 5%. The strongest association appears to be between small regions (meaning each has a population below one million people). In addition, shorter routes appear to have a more strongly positive relationship than longer distance routes, although this may be caused by the availability of substitutes for short-distance travel and therefore the relatively higher cost (as demographics that would promote innovation, such as entrepreneurs and academics, are more likely to have funds allocated to only travel, and are likely to value their time more highly than the average individual).

Table 17: Fixed Effect models with high-tech patent applications as the dependent variable, divided by route distance and route relations

	(1)	(2)	(3)	(4)	(5)
	Route Distances		Route Relations		
VARIABLES	FE – Short Distance Routes	FE – Long Distance Routes	FE – Large-Large Region Pairs	FE - Small-Large Region Pairs	FE - Small-Small Region Pairs
Total Passenger Flow	1.74e-05**	2.30e-05	1.30e-05**	1.45e-05	1.61e-05
	(8.04e-06)	(1.37e-05)	(4.88e-06)	(1.95e-05)	(9.60e-06)
Controls	X	X	X	X	X
Constant	21.31	8.683	43.22*	66.60	-18.49
	(34.01)	(33.78)	(21.25)	(59.01)	(83.27)
Observations	494	455	208	338	403
R-squared	0.257	0.379	0.375	0.257	0.388
Number of panelid	38	35	16	26	31

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For high-tech patents, only the short-distance group and the large-large route grouping are significant at 5%, with positive coefficients. These are however smaller than those found for all patents, which indicates (as one would expect) that these movements have a lower impact on high-tech patents than all patent applications.

Table 18: Fixed Effect models with EU Trademark applications as the dependent variable, divided by route distance and route relations

	(1)	(2)	(3)	(4)	(5)
	Route Distances		Route Relations		
VARIABLES	FE – Short Distance Routes	FE – Long Distance Routes	FE – Large-Large Region Pairs	FE - Small-Large Region Pairs	FE - Small-Small Region Pairs
Total Passenger Flow	-7.46e-06	2.19e-07	-8.77e-06	-4.57e-05*	1.79e-05
	(1.16e-05)	(1.66e-05)	(1.45e-05)	(2.59e-05)	(1.82e-05)
Controls	**X**	**X**	**X**	**X**	**X**
Constant	-153.1***	-117.3***	-159.2***	-235.6***	28.83
	(33.16)	(41.66)	(51.04)	(71.47)	(42.38)
Observations	494	455	208	338	403
R-squared	0.367	0.387	0.459	0.369	0.343
Number of panelid	38	35	16	26	31

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

None of the models constructed for EU Trademarks returned significant results, save for the small-large route grouping, and even then, only at 10%. This is however not unexpected, as UK trademarks are much more likely to be used by domestic-focused businesses than EU ones.

Looking at the robustness checks computed under **Appendix E**, of what is significant at 5%, one sees the outcome of a quasi-experiment where for high-tech patent applications, long distance routes have a stronger impact than short distance routes; although the results for the long-distance FE model are insignificant, the difference in coefficients would appear to confirm this. Other than that, the sign of the results follows what is to be expected based on the fixed effects results, aside from a negative trend in the small-small route groups, although this is to be expected due to the bias in selecting the treatment group, which strongly favours larger areas. One should however note that this discrepancy in the small-small region relations for the dependent variables between the robustness check and the main model does cast some doubt on the inter-city relations seen in the previous models as they are not causal. To have a proper causal relationship to examine, a proper experiment should be performed, and therefore the results that were just presented should be taken with a tentative view.

5.3 Re-examining the Hypotheses

Based on what has been shown in this section, a breakdown of the hypotheses and their validity will now be conducted, grouped in the same way as they were presented in the theoretical framework.

Air movements, urban interactions, and externalities

H1: There is evidence for and against this hypothesis. When looking at the simpler models made for all three types of innovation proxies, it appears that whether or not an increase in passenger flows is associated with an increase in innovation is highly dependent on the type of passenger movement, with both positive and negative outcomes. However, there is strong evidence for a causal relationship between increases in domestic movements and increases in both all and high-tech patent applications in Great Britain, as seen in the instrumental variable regressions, indicating that domestic air travel directly contributes to innovation within the island. This is especially true for smaller regions, which probably require these fast and direct connections to be able to provide what is needed by entrepreneurs and academics. Therefore, this hypothesis is considered valid for all and high-tech patent applications.

H2: It is difficult to say anything on movements between larger areas based on the IV regressions, however it appears based on the route dataset that changes in domestic passenger movements have a smaller impact than those between smaller regions (or even between larger and smaller regions). This indicates that the nature of the travel in larger cities is most likely more diverse and therefore more leisure oriented. This follows reason, as smaller regions will have fewer amenities and attractions, and therefore most travellers will be locals or business oriented. This hypothesis is therefore rejected for all the dependent variables. It is important to note that this relationship is not causal.

Social bridging and bonding

H3: There is substantial causal and correlational evidence from the models created that domestic movements within Great Britain have a greater impact than foreign ones, or even than the total number of air movements. The hypothesis is considered valid at least for all and high-tech patent applications.

H4: It can be said that for nearer cities, air movements and all patent applications move more closely together, however for the two other dependent variables it is not possible to accept this hypothesis. The robustness check reflected these results save for the high-tech patent applications. Therefore, this hypothesis is rejected for high-tech and EU Trademarks.

The implications of these findings and their relation to the expected outcome and theoretical framework, alongside shortcomings and improvements, are discussed in the next section.

6. Conclusion and Implications

The results showed a significant causal relationship between domestic flights and innovation (in the form of high-tech and all patent applications) in Great Britain, alongside a positive correlation between short-distance flights and innovation. Overall, the most significant results were those regarding the domestic movements, showing a clear causal positive impact on patent applications. Some of the previous section's results indicated a negative trend between patent applications and general passenger movements, however this could be caused by the fact that international movements contain a larger relative amount of leisure travellers who contribute to tourism and other sectors besides innovation. In addition, both the significance and coefficients of these results were not as high as for the domestic movements' results. It therefore would appear likely that GB should focus on its domestic air connections, as they appear to have a positive significant causal relationship with patents. This does not mean that non-domestic flights are to be ignored, however further research is necessary to determine the causal direction between their passenger movements and patent applications, as the causal results for these types of flights are not strong enough to make solid conclusions or recommendations.

In fact, in terms of policy recommendations, it appears that focusing on short distance has the largest total payoff in terms of additional average patent and trademark applications. This could indicate that many of the passenger on these shorter air routes are business travellers, and therefore changes in these types of domestic flights are to be considered more important in the framework of promoting innovation. Because of the higher relative price to transport substitutes for short routes, one would also expect more of this type of traveller. Interestingly however, when looking independently at small areas and not their routes, increased domestic movements show a strong positive causal relationship with patent applications. Therefore, it is also important for policymakers to try to stimulate the general number of domestic flights for small airports as well, for similar reasons as those given for stimulating short distance routes: the demographic of these movements is more likely to generate innovation.

What these results support very strongly however is the importance of social bonding capital within Great Britain, and the important role social bonding plays within the innovation-related sectors within the country. When considering the damage the aviation sector has taken during the COVID-19 pandemic, and the even greater damage to the economy of Great Britain, it therefore is very important for the government to not stop supporting domestic travel within the country should the government have the goal of promoting domestic innovation, which often leads to increased economic growth and employment. These findings also show that if the policy goals of aviation within Great Britain are to connect communities and foster innovation, there is good reason to increase funding and/or research for electric aircraft vehicle research, as these domestic routes are the only realistic uses of these aircraft for the near future. This would also allow for a good part of the aviation-related pollution to be decreased, leaving carbon 'margins' for international flights.

The fact that high-tech patents did not respond as heavily to changes in distance (compared to all patent and trademark applications) may also indicate the nature of the travellers encouraging this kind of innovation, which tends to be academia-related, and therefore relies more heavily on connections between universities and research centres than other factors. This relationship could imply that, as one would expect, for more frequent and common activities leading to innovation (referring here to all patents and EUTM), the transition between what is bonding and bridging social capital occurs quite quickly, as the degree of homogeneity in the respective fields decreases more rapidly than in fields such as academia, although more research on the matter is needed to yield conclusive answers.

Nevertheless, by reducing the difficulty in transport (and therefore connecting) larger cities, bonding social capital should allow both cities to make use of the others' physical and soft resources, therefore encouraging innovation. This goes in line with the theory that was discussed in the theoretical framework, however it is important to note that this part of the results is not causal. Movements between smaller regions yielded for all patent applications a higher correlation than between the larger ones, but seeing as the robustness check yielded contradictory results, more research on the matter is needed to give a definitive answer. It is necessary to incorporate the demographics of the passengers to determine the nature of their travel, and therefore have a better idea of the mechanism at play between these movements and innovation.

While this paper was able to find some causal relationships between the key variables, there are improvements that can be made. Firstly, adding the ethnical or even municipal background of residents in an area would allow to have a much better picture of social bonding and bridging capital, rather than trying to proxy homogeneity through distance. Secondly, having direction-specific route data would allow one to see the direction of the "flows" in innovation, which would be very useful for policy recommendations as it would allow for a more specific government focus (e.g., aiding remote SME, or instead upgrading large-city amenities to attract the aforementioned SMEs). Thirdly, as previously mentioned, having demographic information about the types of air travellers would also allow for more specific analyses and recommendations. Finally, expanding the analysis to include other similar European countries would allow not only for a larger dataset which increases predictive power, but also reduce the biases and errors seen in the models.

In conclusion, there is evidence for encouraging air movements in a domestic setting when trying to directly foster innovation. Seeing as the UK is leaving the EU in 2021, the focus should specifically be on domestic movements between closer regions of interest if the government wishes to increase innovation and to stimulate the local economy, as it is likely the little impact seen by non-domestic flights will decrease even further in the future as the cost of travel increases. This all indicates that the domestic aviation market should be aided to continue allowing for the social bonding externalities that are helping the economy, and that therefore the bailout packages given during the COVID-19 caused recession serve more than preserving an unnecessary transport modality. It is to be seen in the future whether advances in ICT will reduce the benefit to physical interactions in the business and science community, however for the moment they remain an important means of promoting innovation.

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Appendix A

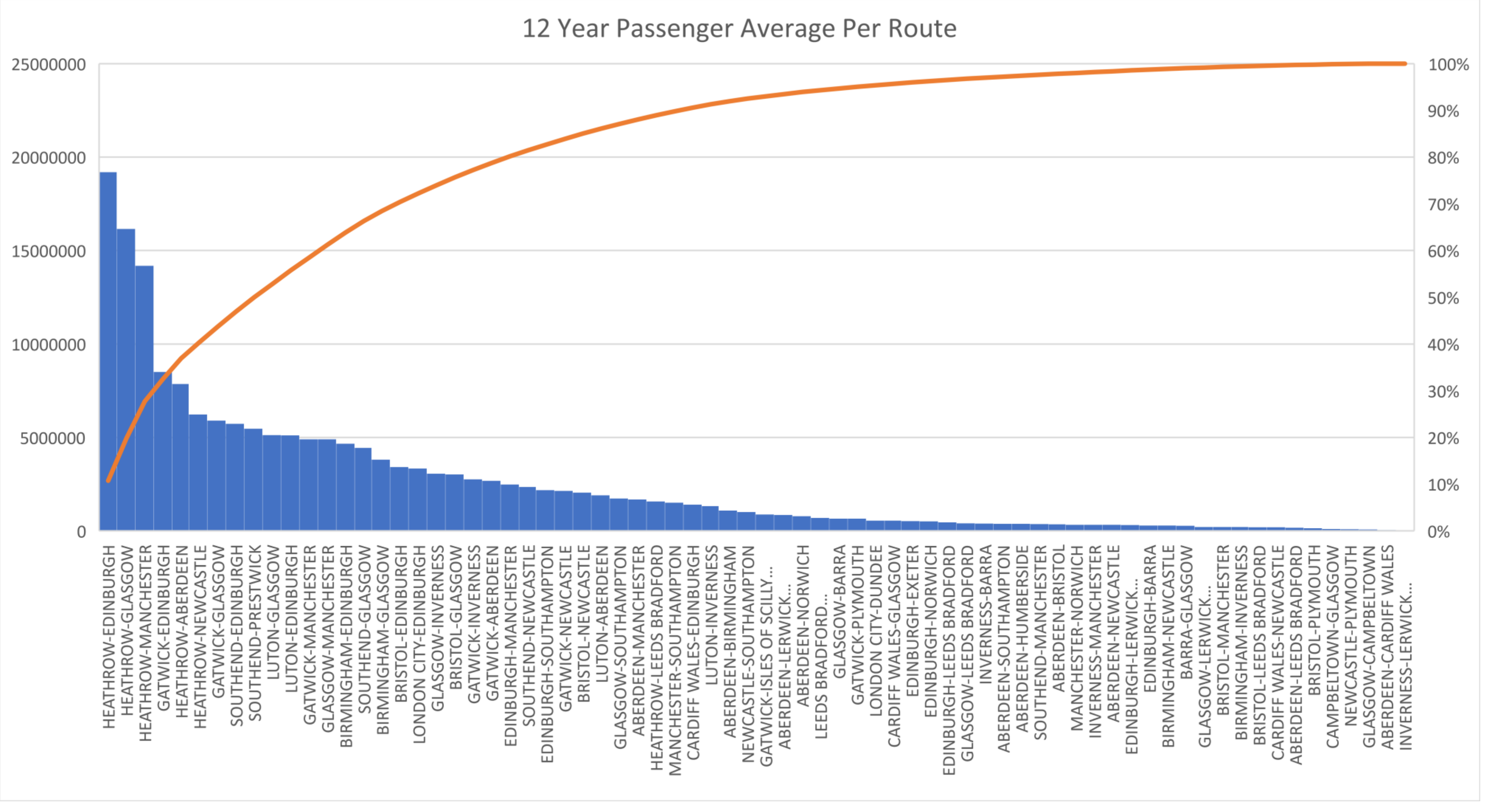
Table 19: NUTS3 and their corresponding airports/cities

NUTS3	Airport	NUTS3	Airport
UKM50	ABERDEEN	UKM65	KIRKWALL
UKM64	BARRA	UKE42	LEEDS BRADFORD
UKG31	BIRMINGHAM	UKD72	LIVERPOOL
UKD42	BLACKPOOL	UKI41	LONDON CITY
UKK21	BOURNEMOUTH	UKH21	LUTON
UKK11	BRISTOL	UKJ44	LYDD
UKH12	CAMBRIDGE	UKD33	MANCHESTER
UKM63	CAMPBELTOWN	UKC22	NEWCASTLE
UKL22	CARDIFF WALES	UKH15	NORWICH
UKM75	EDINBURGH	UKK30	PENZANCE HELIPORT
UKK43	EXETER	UKK41	PLYMOUTH
UKJ28	GATWICK	UKM66	SCATSTA
UKM82	GLASGOW	UKJ28	SHOREHAM
UKI74	HEATHROW	UKJ35	SOUTHAMPTON
UKE13	HUMBERSIDE	UKH37	SOUTHEND
UKM62	INVERNESS	UKH37	STANSTED
UKM62	ISLAY	UKM64	STORNOWAY
UKK30	ISLES OF SCILLY (ST. MARYS & TRESCO)	UKM66	SUMBURGH
		UKM63	TIREE

Source: Eurostat, 2020

Appendix B

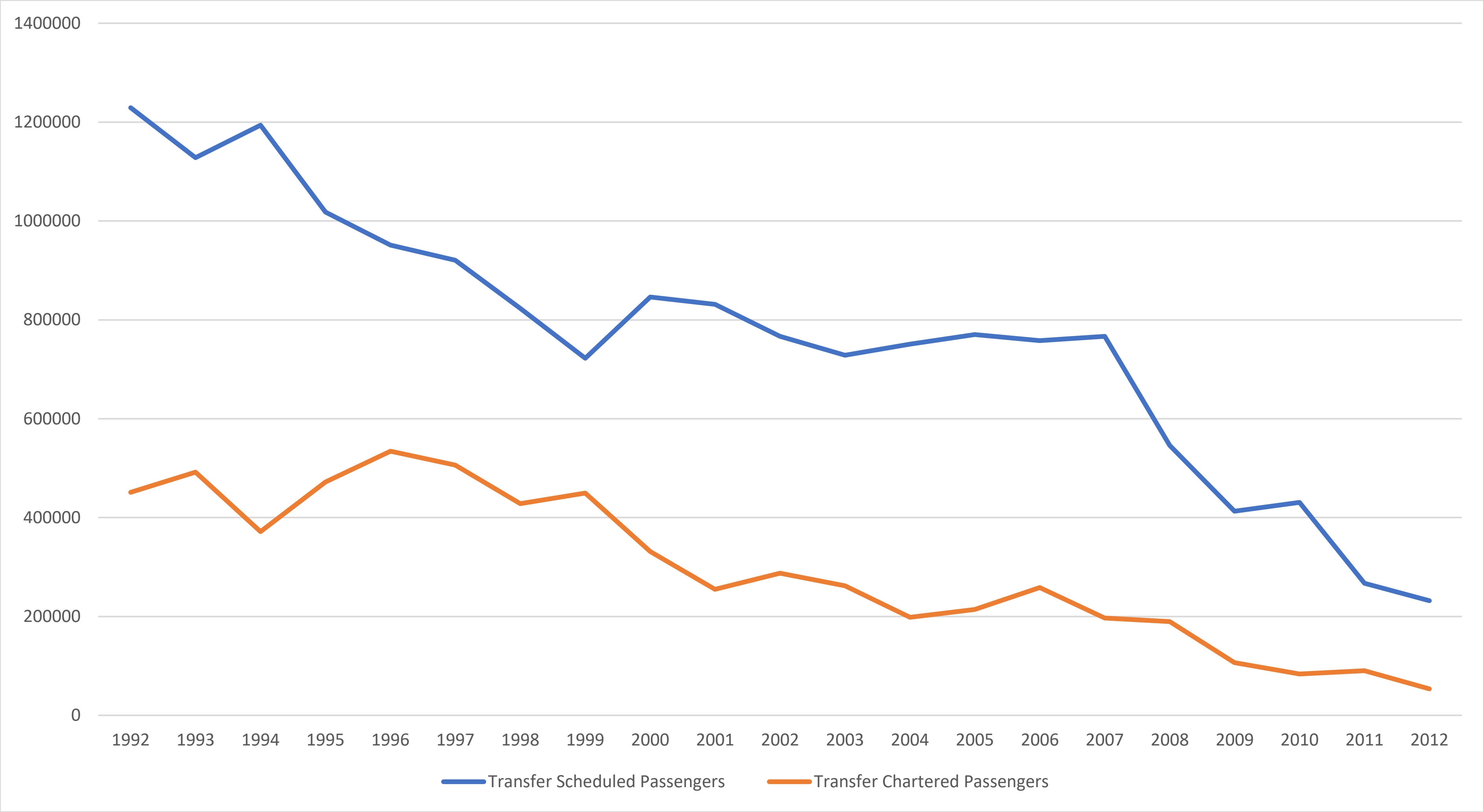
Figure E: Distribution of passengers over all intra-GB routes, 12-year average



Source: (UK) Civil Aviation Authority, 2015

Appendix C

Figure F: Plot of Transfer Scheduled and Charter passengers in Great Britain, 1992-2012



Source: (UK) Civil Aviation Authority, 2015

Appendix D

Table 20: Propensity score matching for all patent applications

	(1) PSM All passengers	(2) PSM Terminal Scheduled Passengers	(3) PSM Domestic Passengers	(4) PSM European Community Passengers	(5) PSM International Passengers
Difference between treatment and control group	6.828	1.802	13.11**	18.51	36.25***
	(5.001)	(5.995)	(6.191)	(12.67)	(10.20)
Observations	529	529	529	529	529

Table 21: Propensity score matching for high-tech patent applications

	(1) PSM All passengers	(2) PSM Terminal Scheduled Passengers	(3) PSM Domestic Passengers	(4) PSM European Community Passengers	(5) PSM International Passengers
Difference between treatment and control group	-8.040***	-7.457***	6.850	1.779	-3.273
	(2.220)	(2.681)	(4.432)	(2.701)	(2.310)
Observations	455	455	455	455	455

Table 22: Propensity score matching for EU Trademark applications

	(1) PSM All passengers	(2) PSM Terminal Scheduled Passengers	(3) PSM Domestic Passengers	(4) PSM European Community Passengers	(5) PSM International Passengers
Difference between treatment and control group	6.472**	7.811***	6.068**	19.64**	15.78*
	(2.830)	(2.578)	(2.527)	(8.932)	(8.776)
Observations	513	513	513	513	513

Appendix E

Table 23: Propensity score matching for all patent applications in the route dataset, divided by route distances and city relations

	(1)	(2)	(3)	(4)	(5)	(6)
		Route Distances		Route Relations		
VARIABLES	PSM - Overall	PSM – Short Distance Routes	PSM – Long Distance Routes	PSM – Large-Large Region Pairs	PSM - Small-Large Region Pairs	PSM - Small-Small Region Pairs
Difference between treatment and control group	18.04*	36.24***	4.747	16.98	-14.80	-25.87***
	(9.917)	(6.591)	(8.051)	(19.65)	(10.65)	(10.03)
Controls	X	X	X	X	X	X
Observations	947	494	453	208	336	403

Table 24: Propensity score matching for high-tech patent applications in the route dataset, divided by route distances and city relations

	(1)	(2)	(3)	(4)	(5)	(6)
		Route Distances		Route Relations		
VARIABLES	PSM - Overall	PSM – Short Distance Routes	PSM – Long Distance Routes	PSM – Large-Large Region Pairs	PSM - Small-Large Region Pairs	PSM - Small-Small Region Pairs
Difference between treatment and control group	11.99***	13.26**	15.97***	18.70***	2.359	-4.308
	(3.229)	(6.084)	(3.216)	(4.232)	(4.088)	(3.515)
Controls	X	X	X	X	X	X
Observations	947	494	453	208	336	403

Table 25: Propensity score matching for EU Trademark applications in the route dataset, divided by route distances and city relations

	(1)	(2)	(3)	(4)	(5)	(6)
		Route Distances		Route Relations		
VARIABLES	PSM - Overall	PSM – Short Distance Routes	PSM – Long Distance Routes	PSM – Large-Large Region Pairs	PSM - Small-Large Region Pairs	PSM - Small-Small Region Pairs
Difference between treatment and control group	12.05	21.60*	14.58***	43.59***	18.01***	-25.16***
	(7.429)	(11.14)	(5.544)	(14.64)	(4.408)	(4.353)
Controls	X	X	X	X	X	X
Observations	947	494	453	208	336	403