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# Did the German Aviation Tax Affect Passenger Numbers? New Evidence Employing Difference-in-differences

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## ABSTRACT

The taxation of aviation has emerged as a key component of the European Union's efforts to mitigate greenhouse gas emissions. This study examines the impact of the German Aviation Tax, levied on a per-passenger basis, since its implementation in 2011. Eurostat data on annual numbers of departing passengers for 27 German and 198 non-German EU airports between 2005 and 2019 is used in a dynamic differences-in-differences analysis approach. Special consideration is given to the passenger composition at hub airports, potential spillover effects to neighboring airports, and correlation of air fare price development and tax implementation and its consequences for estimation. Our main models show that among those passengers subject to the tax, its implementation reduced passengers by 6.1% to 11.8% in the first year, after which passenger numbers recover completely, rendering the tax virtually ineffective as a climate change mitigation policy. As sensitivity analysis we present the results of 150 regressions by means of Specification Curve Analysis. This shows a slightly wider range of passenger reductions for the first year and supports the finding that the impact of the tax is zero thereafter. The Specification Curve Analysis confirms the robustness of the main results to the choice of data subset and ticket variable, while also revealing some sensitivity to the inclusion of a lagged dependent variable

**Keywords:** Difference-in-differences, specification curve analysis, dynamic panel model, aviation policy, transport economics

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## 1. Introduction

Greenhouse gas emissions from the aviation sector are rising and of growing concern to scientists and policy makers. Over the period 2014-2017, passenger-kilometres flown by commercial flights departing from the 28 countries forming the European Union (EU) and from the European Free Trade Area have increased by 20% while resulting CO<sub>2</sub> emissions increased by 10% (EASA et al., 2019). By comparison, EU CO<sub>2</sub> emissions from fossil fuel use and cement production declined by 5% over the same period. Although the share of the aviation in EU-wide emissions is currently modest at roughly 3.6 % (EASA et al. 2019), it is expected to grow rapidly. The total number of flights is expected to increase by 42% from 2017 to 2040, while CO<sub>2</sub> emissions and NO<sub>x</sub> emissions are expected to grow by at least 21% and 16%, respectively (EASA et al., 2019). Importantly, the climate change impacts from aviation do not only come from CO<sub>2</sub> emissions. When including NO<sub>x</sub> and aviation-induced cirrus clouds, Azar and Johansson (2012) find that the 100-year global warming potential (GWP-100) of CO<sub>2</sub> emissions from aviation is 1.3 to 2.9 times higher than for emissions close to the ground. It is unclear how the COVID-19 pandemic will affect the future of aviation, but earlier economic crises led only to a temporarily, not structurally lower growth rate of passenger numbers (World Bank, 2020). Developments of passenger numbers in 2021 indicate a similar tendency (Eurocontrol 2021).

Air passenger taxes can mitigate aviation's contribution to global warming by increasing the relative price of flight tickets, while also increasing efficiency of the tax system by broadening a country's tax base (Krenek and Schratzenstaller 2017). After decades of avoiding taxation altogether due to the outcomes of the 1944 Chicago Convention, various tax schemes began appearing in the mid-nineties. Taxation of jet fuel is currently being discussed at the EU level, but unilateral implementation continues to be complicated, thereby shifting focus to taxing the consumer. Currently, aviation taxes exist *inter alia* in the United Kingdom, which introduced an air passenger duty in 1994, France, which introduced a civil aviation tax in 1999, and Germany which introduced an air passenger tax in 2011. At the EU level, the aviation sector has been included in the Emission Trading Scheme EU-(ETS) since 2012 for emissions of intra-EU flights. The merits of aviation taxes are hotly debated, with environmental groups arguing that existing policies are insufficient to adequately reduce the sector's emissions and industry representatives arguing that aviation taxes lead to job and GDP losses (BUND 2013, Transport and Environment 2021, IATA 2010, PwC 2017). To inform debates, it is necessary to assess the impacts of aviation policies rigorously.

In this study, we investigate the impact of the German Aviation Tax on the number of air passengers who start their journey in Germany. The tax was introduced in 2011 and applies to tickets of passengers who start their journey at a German airport. We use a difference-in-differences approach

(DID) in which our control group consists of EU countries without an air passenger tax and the treated group is made up of German airports. Importantly, we assess the robustness of our results by presenting a Specification Curve Analysis (see Simonsohn et al. 2020) based on the results of 196 different model specifications.

## **2. Background**

### **2.1 Aviation Taxation in the literature**

General taxation theory (and common sense) teaches that when a tax is implemented, the supplier price falls, the consumer price rises, leading to an overall reduction in quantity. The size of this reduction depends on the pass-through rate on the specific market, which in turn depends on the elasticities of demand and supply, which depends on the market structure of the good in question. In practice, price elasticities and pass-through rates are challenging to evaluate on the aviation market, since detailed price data can be difficult to come by (Koopmans and Lieshout 2016). Nevertheless, work has been done to pin down the character of the aviation market and the pass-through behavior of airlines. Koopmans and Lieshout (2016) found, that cost changes which affect only a particular company or airport are passed through by less than 50%, but cost changes which affect the entire sector are passed through to customers by more than 50 %. For the German Air Transport Tax, the latter is the case, as it applies to all airlines and flights, as long as the passengers are departing from a German airport. The authors also label the aviation market as a Cournot oligopoly – where the producers (airlines) move first in setting their supply (i.e. flight schedules) and then vary the prices according to demand (Koopmans and Lieshout 2016). Other applied studies come to similar conclusions – that in aviation, cost changes are not passed through in their entirety, but still to a significant extent (Wadud 2015, Forsyth and Gillen 2007, Forsyth 2008). Important in the context of taxation is also a finding by Rivers and Schaufele (2014), that carbon taxes can have a larger salience than a comparable price change brought about by other causes. This was demonstrated similarly for a gasoline excise tax by Li et al. (2014). For the German Aviation Tax, we therefore expect a rise in fare prices in response to the implementation, with reductions in passenger numbers that are not exclusively determined by the price developments.

Few econometric impact assessments of aviation taxes exist to date. Seetaram et al. (2014) analyze the effects of changes in the UK Air Passenger Duty on the total number of outbound passengers to ten countries using country-specific time series models. They conclude that the Duty reduced demand for travel to five out of the ten analyzed destinations, with taxation elasticities smaller than one. Markham et al. (2018) use time series analysis to analyze the effects of the levy on CO2 emissions from Australia's 2012-2014 Clean Energy Future policy on domestic aviation and found no effect from the levy. Mumbower et al. (2014) investigate the price elasticity of aviation demand in general,

but do not connect it to any policy in particular. González and Hosoda (2016) use time series analysis to analyze the impact of the 30% rate cut introduced in 2011 in Japan, which had been taxing fuel since 1972. In 2013, after the tax cut, emissions from domestic flights had increased by 9.23% compared to the case of no tax change. The first study to analyze the impacts of the German Aviation Tax was the one by Gurr and Moser (2017). They find that a one Euro increase in the tax rate reduces the number of departing passengers by 0.2%, however, their analysis is based on data from German airports only and hence does not include a control group. Falk and Hagsten (2019) use a dynamic panel DID approach and data for total annual numbers of passengers (sum of arriving, departing and transfer passengers) at the airport level and include Austrian airports in their treatment group. They find that the tax induced an 8.7% and 5% reduction in the total number of passengers in 2011 and 2012 respectively. In several cases they also find passenger reductions in 2013, 2015, and 2016, concluding that these reductions were driven by airports that are predominantly visited by low-cost carriers. Borbely (2019) analyses the German tax using a synthetic control approach. The author finds that deviations from counterfactual passenger numbers are positive for the main hub airports such as Frankfurt Main but negative for most regional airports. He further concludes that annual passenger numbers were reduced by 4 million passengers in 2011-2015, or about 2%. Like Falk and Hagsten (2019), his analysis is based on total annual numbers of passengers (sum of arriving, departing and transfer passengers), although the tax applies only to departing passengers. Most recently, Oesingmann (2022) included the German aviation tax as a comparison policy in her analysis of the EU ETS' impact on aviation, using a gravity model approach. She finds a statistically significant reduction of 6% to 12%, but does not specify in which year (Oesingmann 2022). We build upon these studies by using data for departing passengers only, stricter criteria for the control group, and complemented by a rigorous robustness testing approach through Specification Curve Analysis.

## **2.2 The German Aviation Tax**

The German “Luftverkehrsteuer”, or Aviation Tax, was adopted into law in October 2010, and entered into force on January 1<sup>st</sup>, 2011. The tax applies to all outbound passengers and is payable by the carrier airline, on each seat sold for each flight departing from Germany (Generalzolldirektion 2019). The tax does not apply to passengers who started their journey outside Germany. Those excluded are transit passengers, who started their journey outside Germany and continue their journey in Germany on the same aircraft, usually with the same flight number, and transfer passengers, who started their journey outside Germany and switch flights in Germany during their journey. The tax is split into three rates, based on the distance flown, an image of the three distance zones can be found in Appendix B, Figure 6.

The aim of the tax is threefold: to generate tax income of about 1 billion Euro annually, to end the exemption of air travel from mobility taxes, and to create incentives for environmentally friendly behaviour (Generalzolldirektion 2022). The annual revenue so far has indeed been about 1 billion Euro per year (Destatis 2019). The tax rates introduced in 2011 were €8,00, €25,00 and €45,00 for Zones 1, 2 and 3, respectively. The rates were reduced by 6.25% in 2012 and have been adjusted every year since, with usually small changes (Generalzolldirektion 2021). From personal experience, the tax does not appear explicitly when purchasing a ticket but is listed on the more detailed receipt issued at the end.

The basis for taxation is the full journey purchased by a passenger. Transfer passengers of airport X are passengers who transfer from one flight to another at the airport in question, which means their journey did not start here. Unlike transit passengers, their two connecting flights do not have the same flight numbers, which means they are always counted double at the transfer airport: once as arrival, and once as departure, as for example indicated in Frankfurt airport's yearly statistical report (Fraport 2019, p.11).

Journeys that include layovers are usually purchased in a single booking, and not in several instalments. This is a crucial detail when considering taxation under the German Aviation Tax. "Departures" under the German Aviation Tax are passengers, who start their journey at a German airport (Generalzolldirektion 2020b). For example, a passenger who starts their journey in Prague, switches planes at Frankfurt airport, and then continues to New York City does not "depart" from Germany in the eyes of this particular legislation. They are, however, counted amongst the Frankfurt departures in the available data. Departure numbers for Frankfurt airport will therefore have an upward bias, when viewed under the lens of the Aviation Tax, which in turn will bias estimations relying on this data.

Hub airports like Frankfurt, Düsseldorf, or Munich have large proportions of transfer passengers. Data on this is unfortunately not recorded in detail, however, both Frankfurt and Munich do regular passenger surveys with subsequent estimates of transfer passengers. The annual report of Munich airport states a transfer passengers share of 38% in 2019 (Munich Airport 2021, p. 10). A 2019 estimate for Frankfurt airport puts the share of transfer passengers at 53.7% (Fraport 2019, p. 11). It is very likely that Düsseldorf, another German hub, and non-German hub airports will also have large shares of transport passengers, and the conclusion must be that transfer passengers are a data caveat that should be taken seriously. As a consequence, hub airports are eliminated from the dataset used for this study. A list of the excluded hubs can be found in the Appendix of this paper.

### 3. Methods and Data

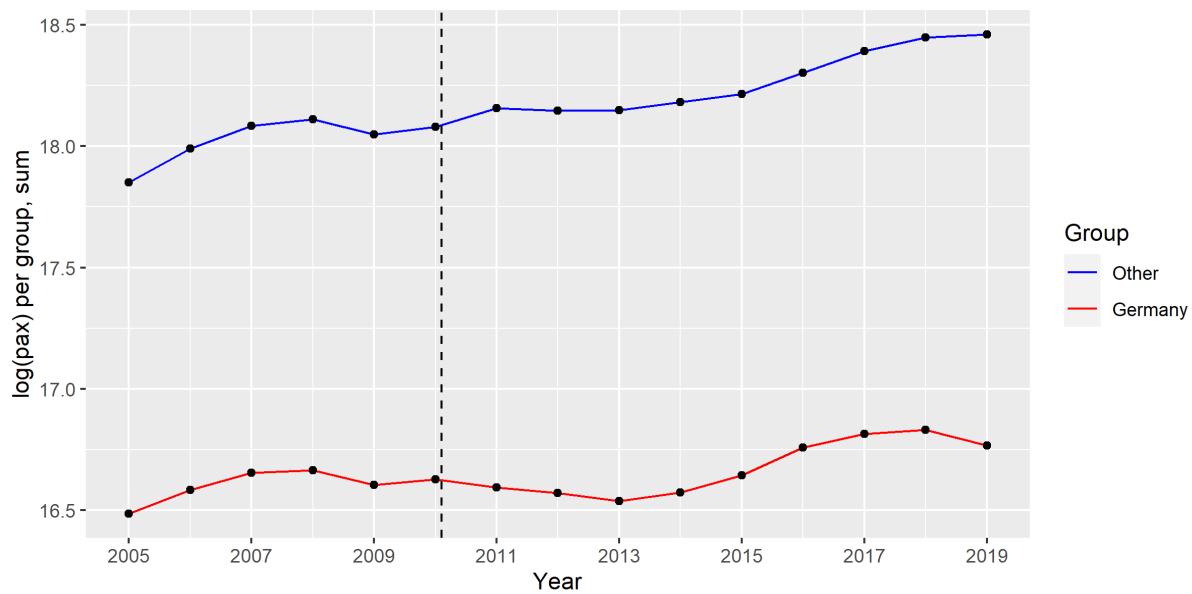
#### 3.1 Identification

A difference-in-differences (DiD) approach is implemented, using Eurostat panel data on annual departures at 140 European airports between 2005 and 2019 (Eurostat 2021a). The 13 airports located in Germany make up the treatment group, and the years 2011 to 2019 make up the treatment period.

There are several countries in Europe which have or had implemented taxes that are similar to the German Aviation Tax, in the sense that they also levy per-passenger taxes on aviation, namely Austria, France, Ireland, Italy, the Netherlands, and the United Kingdom. Since the hypothesis is that a passenger tax does affect passenger numbers, an analysis of the German tax should not use airports or countries as controls, where a similar policy was enacted around the same time (i.e. between 2009-2013), or where an existing policy was changed significantly. As a consequence, airports located in Austria, France, Ireland, and the Netherlands were excluded from the dataset for the main regressions. However, as part of the sensitivity analysis we also ran models where these countries' airports were not excluded.

Difference-in-differences study design has been widely applied in policy analysis, prominent examples are the studies by Card and Krueger (1994) and Dube et al. (2010). The validity of difference-in-differences is predicated on the assumption of parallel trends (see Angrist and Pischke 2008, Bertrand 2004, Meyer 1995, Callaway and Sant'Anna 2021). Parallel trends are given, if the two groups' average passenger numbers were to develop in parallel over the course of the observation period under the assumption of no treatment. Naturally, since treatment did take place, we can only rely on observations during the pre-treatment period to gauge the validity of parallel trends. Pre-treatment here means pre-tax. As can be seen in Figure 1, the development of the average German and non-German airport's passenger numbers follows quite similar patterns providing some support to the assumption of parallel trends. In addition to the visual inspection of the data for presence of parallel trends an econometric approach is used as well, oriented on the Event Study approach commonly used with staggered treatment implementation (Bertrand 2004, Abadie 2005, Callaway and Sant'Anna 2021). In addition to the dummies indicating treatment – in this study, this means one binary treatment dummy for each year 2011-2019 – to record the treatment effect, the models also contain pre-treatment dummies except for the year 2010, which is the reference period. These yearly pre-treatment dummies allow us to test whether the number of passengers at airports in the treated group (i.e. the German airports) significantly differed from those the control group already before treatment took place. If the pre-treatment dummies' coefficients are not significantly different from zero, it is reasonable to assume parallel trends.





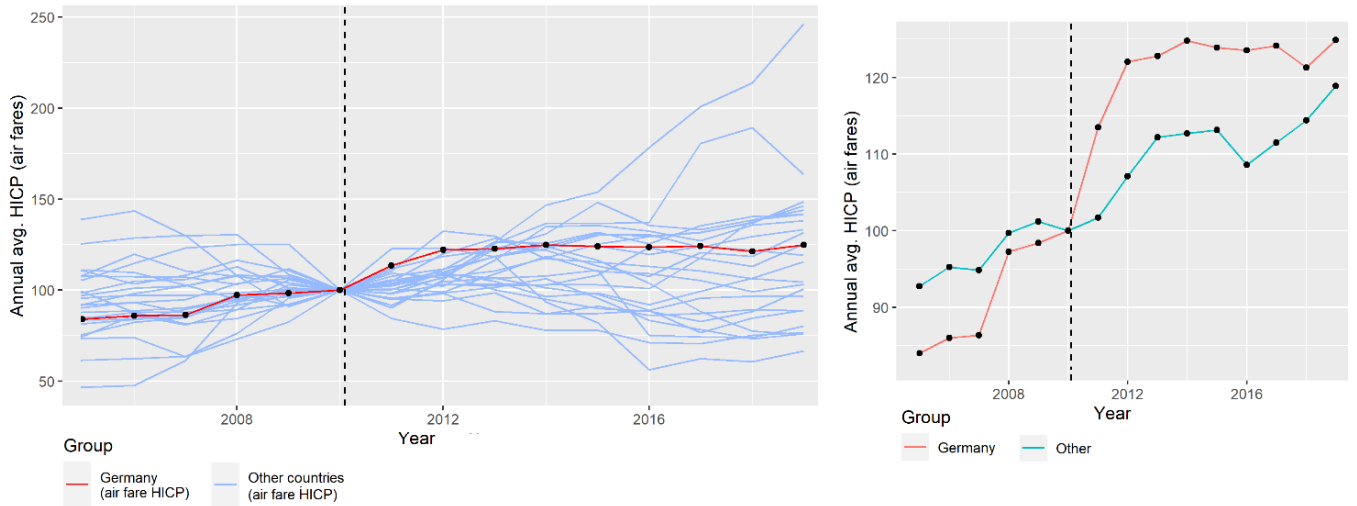
**Figure 1:** Visual analysis of parallel trends - development of the log of annual number of passengers (PAX) in Germany (red) and the group of controls (blue). Data: Eurostat 2021a

Including pre-treatment dummies in the model has another advantage. Including pre-treatment dummies and leaving 2010 out as the reference period means the effect size represents specifically the difference between treated and controls, when compared to the last year before tax implementation. Without them, the interpretation of the estimated effect size would represent a comparison to the average of the entire pre-treatment period.

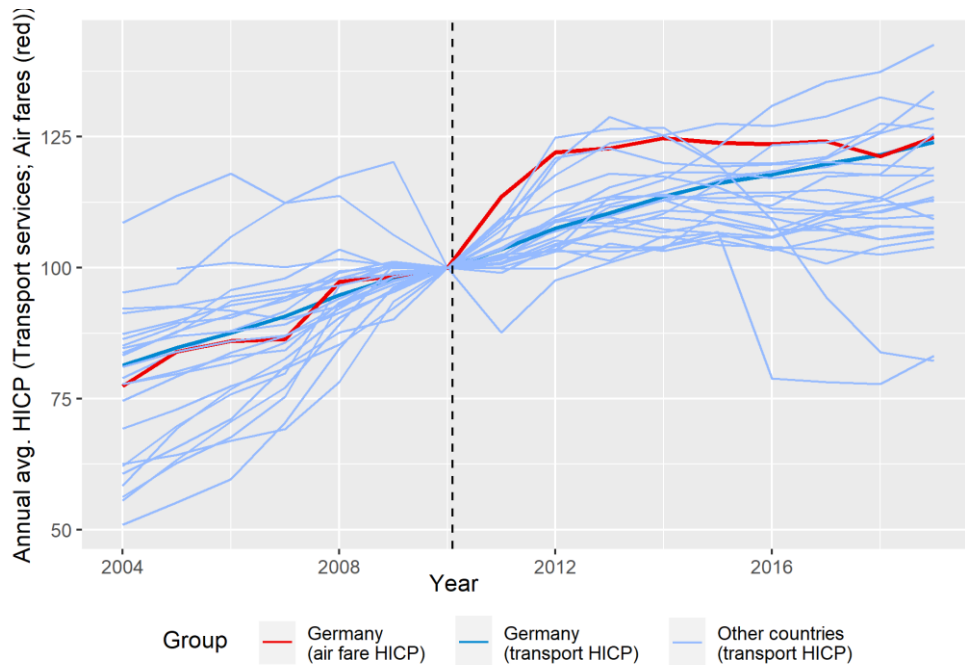
While it is important to include a ticket price variable as a control variable in our analysis, this could lead to biased estimates of the effect size of the tax due to endogeneity (Mumbower et al. 2014). The most detailed price data available, a by-country annual Harmonized Index of Consumer Price (HICP) of passenger transport by air, would absorb a portion of the effect which a researcher would like to be attributed to the treatment, and therefore bias the absolute value of the estimate downward. Figure 2 depicts this visually, showing a below-average price for Germany before tax implementation and an above average price after.

Instead of air fare, the HICP of transport service in general is used. Figure 3 shows that, unlike the price variable in Figure 2, the transport services price index for Germany stays in the same relation to the controls' prices before and after the tax implementation in 2011 while, importantly, it also develops closely to the German air fare HICP in the pre-treatment period.

Another point of concern are potential spillover effects. In case of the German Aviation Tax, these would manifest as surges in passenger numbers at non-German airports close to the German border, as direct response to the tax implementation. Such spillovers, if present, will bias analysis results if these neighbouring airports are included as control observations. An overestimation of the tax's effect



**Figure 2:** HICP of passenger transport by air (Eurostat 2021b), Left panel: development by country, Right panel: development by treatment group (Treated: Germany)



**Figure 3:** HICP of passenger transport by air for Germany (red), transport services (overall) for Germany (dark blue) and transport services (overall) for control countries (light blue) (Eurostat 2021b).

would be the result, since German airports with – as hypothesized – decreased passenger numbers would be compared with inflated passenger numbers at those neighbouring airports. Previous studies have found evidence for spillover effects at several of such neighbouring airports (Borbely 2018). Consequently, airports within 350 km or less of the border were excluded for the main estimations, for a list see Appendix A. Selection was oriented on the studies by Borbely (2018) and Falk and Hagsten (2019). We explicitly test for the role of including/excluding neighboring airports in the control group in our specification curve analysis.

### 3.2 Estimation

We estimate the DID with dynamic treatment effects (Callaway and Sant'Anna 2020, Jacobsen et al. 1993), specification given by Equation (1)

$$\ln(pax_{it}) = \beta_0 + \sum_{t=2006}^{2009} \beta_{pre}^t D_{it}^{treat} + \sum_{t=2011}^{2019} \beta_{post}^t D_{it}^{treat} + \beta_x' X_{it} + \tau_t + \mu_i + v_{it} \quad (1)$$

where  $pax_{it}$  is departure passengers at airport  $i$  in year  $t$ ,  $D_{it}^{treat}$  a treatment dummy for year  $t$ ,  $X_{it}$  is a vector of time-varying explanatory variables,  $\tau_t$  are the year fixed effects,  $\mu_i$  are the time-invariant airport fixed effects, and  $\varepsilon_{it}$  the estimation error.  $D_{it}^{treat}$  is a set of thirteen dummies, four pre-treatment and nine post-treatment dummies, leaving out 2010, that equal 1 if the airport of observation lies in Germany and the period is year  $t$ , and 0 otherwise.

Our coefficients of interest are those in  $D_{it}^{treat}$  for  $t \geq 2011$ . Each coefficient in this vector represents the average difference in passenger numbers between German and non-German airports, for the year  $t$ , keeping all else constant, compared to the base year 2010.

First estimations were done using Pooled OLS (POLS) and Fixed Effects (FE) estimators. However, a static model like this implies that demand and supply of airplane seats is adjusted instantaneously and no consideration of previous periods takes place. However, an assumption of a certain level of persistence in the dependent variable of passenger numbers is reasonable, and calls for the addition of a lagged dependent variable (LDV),  $\ln(pax)_{i,t-1}$ :

$$\ln(pax_{it}) = \beta_0 + \beta_{lag} \ln(pax)_{i,t-1} + \sum_{t=2006}^{2009} \beta_{pre}^t D_{it}^{treat} + \sum_{t=2011}^{2019} \beta_{post}^t D_{it}^{treat} + \beta_x' X_{it} + \tau_t + \mu_i + v_{it} \quad (2)$$

Estimating Model (2) using OLS results in inconsistent estimates since it disregards the dependence between the LDV and the composite error  $\mu_i + v_{it}$ . Estimation with FE is subject to the Nickell bias, especially if the panel is comparably short, as is the case here (Nickell 1981, Baltagi 2005 p.136f.) The dynamic model given in Equation 2 was therefore implemented in four ways. First, an estimation with FE and lagged dependent variable was run, despite its suspected bias when applied to dynamic models. It will serve as a bridge from the simplistic static model to the dynamic model. Second, after first-differencing the model to get rid of some of the bias, the Arellano-Bond (AB) difference GMM estimator is implemented which uses farther differences as instruments (Arellano and Bond 1991). Third, following Blundell and Bond's concerns about poor precision and finite sample bias of the Arellano-Bond estimator, Model (2) was then estimated using the Blundell-Bond estimator which makes use of lags of both the dependent variable and its first-differenced version to produce a more

precise estimator (Blundell and Bond 1998). Lastly, the model was also estimated using a Quasi-maximum likelihood (QML) estimator as proposed by Phillips (2015) and implemented by Kripfganz (2016). Models were estimated using Stata version 16 with robust standard errors or errors clustered at the country level, depending on the model.

### 3.3 Data

The dependent variable – the annual number of departing passengers per airport – was retrieved from Eurostat (Eurostat 2021a). Covariates are annual GDP per capita (World Bank 2021), annual Harmonized Index of Consumer Prices (HICP) of air fare prices, annual HICP of accommodation prices (Eurostat 2021b), and a dummy for the occurrence of a terror attack each year (University of Maryland 2021). Additionally, since the air fare price was likely influenced by the implementation of the tax, no air fare variable was used as covariate in the main estimations. All variables are observed and obtained at the country level, except for the dependent variable where the unit of observation is the individual airport.

The data is pruned along several dimensions. Only airports without missing datapoints in the years 2009 to 2012 were used for estimation. In addition to excluding hub airports, airports located in countries where a similar per-passenger tax was or had been implemented were excluded, as well as several additional German and non-German airports that had major policy changes in the period of interest leading to strongly irregular data, following the approach by Borbely (2018). Additionally, neighboring airports near the German border were dropped as well. A list of all excluded airports (hubs, irregular airports, neighboring airports) can be found in the Appendix. We are left with 21 treated airports, 4 of those being hubs, and 268 control airports, 22 of those hubs. Table 1 shows some summary statistics for the final data.

Table 1: Summary statistics of final data, own calculations

|                                 | <b>Treated (Germany)</b> |       | <b>Control</b> |       |
|---------------------------------|--------------------------|-------|----------------|-------|
|                                 | mean.                    | St.D. | Mean           | St.D. |
| N° airports (non-hubs)          | 17                       | -     | 246            | -     |
| N° hubs                         | 4                        | -     | 22             | -     |
| Non-hub passengers total (Mio.) | 2.00                     | 2.11  | 1.02           | 1.66  |
| Hub passengers total (Mio.)     | 16.74                    | 8.44  | 11.20          | 8.06  |
| GDP/capita (1000 US\$)          | 43.17                    | 3.83  | 39.75          | 18.11 |
| General transport HICP          | 95.94                    | 6     | 95.74          | 7.34  |
| Accomodation price              | 88.61                    | 13.28 | 99.03          | 10.53 |
| N° obs                          | 405                      |       | 5070           |       |

## 4. Results

### 4.1 Estimation Results

Employing all four specifications laid out in the previous section leads to the estimates presented in Table 2. Ignoring problems of bias through addition of the LDV for now, an estimation employing a Fixed Effects Estimator results in effect estimates of -12 %<sup>2</sup> in 2011 and -7.5 % in 2012, and four additional coefficient estimates for 2016 to 2019 – the relevance of which is questionable due to the estimator not being well-suited for the dynamic model. The Arellano-Bond estimator finds an effect estimate of -11% for 2011, the Blundell-Bond of -6.1%, and the Quasi-maximum Likelihood estimator of -11.8%. None of these estimations find an effect after 2011. Another observation is that implementing the Blundell-Bond estimator means significantly smaller effect estimates than when using any of the three other estimators.

**Table 2:** Estimation results based on Equation (2) of the dynamic model to investigate the effect of the German Aviation Tax on passenger numbers in Germany, in the years 2011-2019, using the data from all non-hub airports.

|                | (1) FE+LDV |         | (2) AB   |         | (3) Blundell-Bond |         | (4) QML  |         |
|----------------|------------|---------|----------|---------|-------------------|---------|----------|---------|
|                | Coeff.     | St.E.   | Coeff.   | St.E.   | Coeff.            | St.E.   | Coeff.   | St.E.   |
| L.log_pax      | 0.772**    | (0.016) | 0.616**  | (0.078) | 0.999**           | (0.003) | 0.964**  | (0.042) |
| Treated 2011   | -0.128**   | (0.015) | -0.116** | (0.030) | -0.063*           | (0.023) | -0.126** | (0.033) |
| Treated 2012   | -0.078**   | (0.021) | -0.090   | (0.049) | -0.002            | (0.040) | -0.054   | (0.045) |
| Treated 2013   | -0.038     | (0.030) | -0.022   | (0.051) | -0.023            | (0.024) | -0.021   | (0.030) |
| Treated 2014   | -0.021     | (0.020) | 0.011    | (0.056) | 0.018             | (0.019) | 0.010    | (0.032) |
| Treated 2015   | 0.006      | (0.033) | 0.044    | (0.058) | 0.015             | (0.024) | 0.034    | (0.041) |
| Treated 2016   | -0.066*    | (0.026) | -0.030   | (0.061) | -0.044            | (0.034) | -0.038   | (0.035) |
| Treated 2017   | -0.050*    | (0.024) | -0.031   | (0.056) | -0.000            | (0.024) | -0.014   | (0.033) |
| Treated 2018   | -0.063*    | (0.024) | -0.046   | (0.060) | 0.010             | (0.022) | -0.024   | (0.033) |
| Treated 2019   | -0.090**   | (0.015) | -0.071   | (0.080) | 0.005             | (0.042) | -0.048   | (0.055) |
| GDP/cap        | 0.178      | (0.067) | 0.350**  | (0.088) | -0.023*           | (0.009) | 0.081    | (0.053) |
| Accomod. Price | -0.003     | (0.001) | -0.005*  | (0.002) | -0.000            | (0.001) | -0.002   | (0.001) |
| Terror attack  | 0.013      | (0.010) | -0.005   | (0.011) | -0.006            | (0.007) | 0.009    | (0.012) |
| Fixed effects: |            |         |          |         |                   |         |          |         |
| Airport        | Yes        |         | Yes      |         | Yes               |         | Yes      |         |
| Year           | Yes        |         | Yes      |         | Yes               |         | Yes      |         |
| N° obs         | 3555       |         | 3288     |         | 3555              |         | 3528     |         |

Note: Standard errors were clustered at country level and are in parentheses, all models also included yearly pre-treatment dummies for 2006-2009 following an Event Study Approach, \*\* and \* indicate statistical significance at the 1% and 5% level respectively.

<sup>2</sup> For deriving effect from a coefficient  $\beta$  in a log-level model:  $effect = (e^\beta - 1) * 100$

Now turning towards the data for all airports, Table 3 shows the results of the main four regressions when using data that does not exclude hub airports. Effect estimates are smaller than when using only data from non-hub airports, but not significantly so, and their magnitudes are in a similar order as those in Table 2 – with Blundell-Bond resulting in the smallest estimates, no significant coefficients after 2011 for AB, BB, and QML estimation, and the FE + LDV estimation resulting in additional significant estimates for 2016 to 2019. Disregarding the latter model, the effect of the tax on passenger numbers is estimated to be between -4.2% and -10.7% in 2011, when including hub airports in the analysis.

**Table 3:** Estimation results based on Equation (2) of the dynamic model to investigate the effect of the German Aviation Tax on passenger numbers in Germany, in the years 2011-2019, using data from all airports including the hubs.

|                | (1) FE+LDV |         | (2) AB   |         | (3) Blundell-Bond |         | (4) QML  |         |
|----------------|------------|---------|----------|---------|-------------------|---------|----------|---------|
|                | Coeff.     | St.E.   | Coeff.   | St.E.   | Coeff.            | St.E.   | Coeff.   | St.E.   |
| L.log_pax      | 0.778**    | (0.015) | 0.619**  | (0.086) | 1.000**           | (0.002) | 0.970**  | (0.037) |
| Treated 2011   | -0.109**   | (0.014) | -0.096** | (0.027) | -0.043*           | (0.021) | -0.107** | (0.030) |
| Treated 2012   | -0.063**   | (0.020) | -0.071   | (0.043) | 0.008             | (0.032) | -0.042   | (0.039) |
| Treated 2013   | -0.035     | (0.029) | -0.011   | (0.046) | -0.018            | (0.021) | -0.020   | (0.026) |
| Treated 2014   | -0.026     | (0.021) | 0.015    | (0.050) | 0.011             | (0.016) | 0.000    | (0.029) |
| Treated 2015   | -0.005     | (0.032) | 0.042    | (0.051) | 0.012             | (0.020) | 0.018    | (0.036) |
| Treated 2016   | -0.070**   | (0.025) | -0.027   | (0.054) | -0.041            | (0.027) | -0.046   | (0.030) |
| Treated 2017   | -0.060*    | (0.023) | -0.034   | (0.049) | -0.012            | (0.020) | -0.029   | (0.029) |
| Treated 2018   | -0.064*    | (0.023) | -0.042   | (0.053) | 0.005             | (0.018) | -0.028   | (0.028) |
| Treated 2019   | -0.075**   | (0.016) | -0.050   | (0.071) | 0.014             | (0.035) | -0.037   | (0.047) |
| GDP/cap        | 0.161      | (0.086) | 0.415    | (0.221) | -0.067            | (0.028) | -0.032   | (0.139) |
| Accomod. Price | -0.003     | (0.002) | -0.006*  | (0.002) | -0.001            | (0.001) | -0.001   | (0.001) |
| Terror attack  | 0.023      | (0.016) | 0.016    | (0.015) | -0.003            | (0.011) | 0.019    | (0.012) |
| Fixed effects: |            |         |          |         |                   |         |          |         |
| Airport        | Yes        |         | Yes      |         | Yes               |         | Yes      |         |
| Year           | Yes        |         | Yes      |         | Yes               |         | Yes      |         |
| N° obs         | 3919       |         | 3626     |         | 3919              |         | 3892     |         |

Note: Standard errors were clustered at country level and are in parentheses, all models also included yearly pre-treatment dummies for 2006-2009 following an Event Study Approach, \*\* and \* indicate statistical significance at the 1% and 5% level respectively.

## 4.2 Sensitivity Analysis

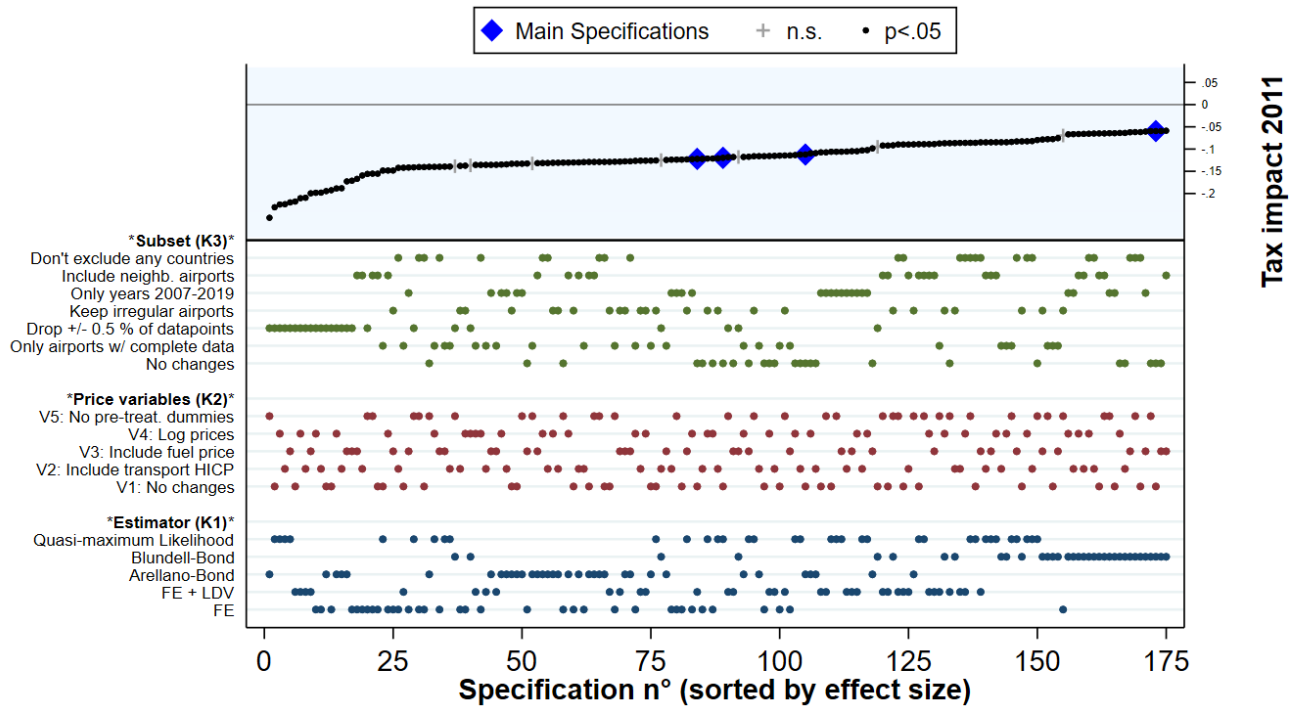
A specification curve analysis (SCA) was implemented to test the robustness of the above results. Since all of the above specified estimators have merit, and there are several additional specifications – regarding estimator, subsample, and variable composition – which could be explored, an SCA is a

straightforward way of comparing the effects of different specifications and to get an overview of their relationships. SCA as implemented in this study was developed and discussed by Simonsohn et al. (2020). Their intent was to add transparency to studies by recognizing that specification decisions are often subjective and at times encourage cherry-picking if the researcher elects to present only those estimations, whose results are favorable to the primary hypothesis. It is common practice to test alternative specifications as well and report them in the robustness test section of a paper, but even then, researchers can be inclined to report tests that are favorable. Even if that is not the intention, given that there is limited room in a publication, researchers at all times have to make limiting decisions on what model results they present. Simonsohn et al.'s solution was to look at all the specification decisions that were made for the main models, collect all other alternative, plausible, and non-redundant specifications, and then run these estimations and useful combinations of them.

For all such estimations, the coefficient size and significance of the effect of interest are extracted and presented in a plot, accompanied by indications for each estimate's underlying specification decisions. This visual representation makes it substantially easier to find specification characteristics that lead to variation in the estimates. It also reduces opportunities for selective reporting, even if it will not eliminate the influence of a researcher's beliefs entirely (Simonsohn et al. 2020).

For this study, the specification characteristics to be analyzed can be grouped into three categories: variations over the type of estimator (K1), variations over the way the price variables were incorporated (K2), and variations on the specific data subset which was used for estimation (K3).

K1 included, in addition to the estimators used in the main results table above, also the static FE estimator, for reference. K2 includes the original specification with no air fare variable, a specification using the general transport price HICP, a specification using kerosene prices, and specifications where the pre-treatment dummies (2006-2009) were left out. Lastly, K3 includes several options for restricting or relaxing the data set used for estimation. Amongst them are a subset with only complete data, a subset of only the years 2008-2019 since a few countries only started collecting data in 2008, and a subset where the neighboring airports that were suspected of being the receivers of spillover effects were allowed back in and controlled for with appropriate dummies. All in all, 175 different specifications were evaluated and are presented below.



**Figure 4:** SCA of estimated German Aviation Tax’s effect on passenger numbers at German airports in 2011, extracted from 175 specifications, using data on non-hub airports

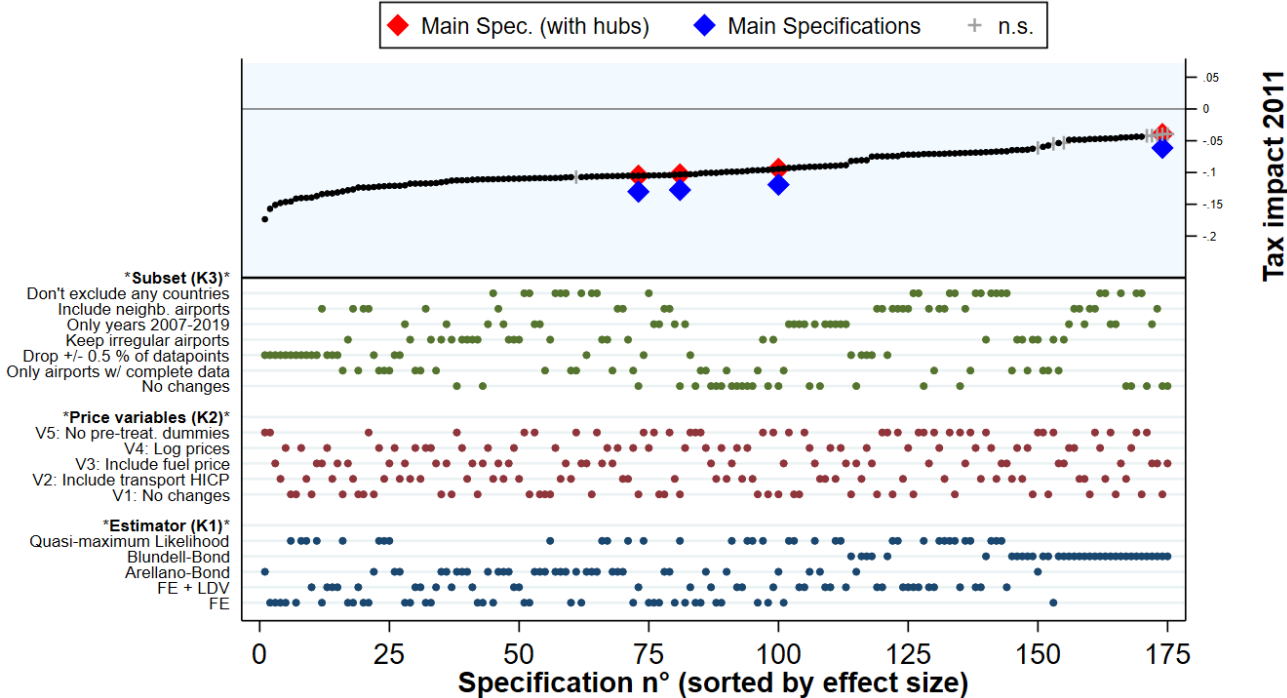
Figure 4 shows the resulting full Specification Curve Analysis (SCA) plot. All regressions run for this SCA used the data that does not include hub airports. The top panel shows the estimated coefficients of the 2011 treatment dummy, sorted by magnitude, and whether they are statistically significant at the 5 % level. Blue diamonds indicate the results reported in Table 1. The particular producing each estimate is indicated in the bottom panel – the specification’s data subset (K3) as a green dot, the variation on covariates (K2) in red, and the estimator (K1) in blue.

First, looking at the distribution of estimates in general, the figure shows that all effect estimates have a negative value. Furthermore, it shows that using a Blundell-Bond estimator almost always results in effect estimates that are much smaller – i.e. further to the right of the plot – than those using other estimators. For other estimators, the spread of effect estimates is more even – the dots indicating that a particular estimator was used are not as clustered together as those of the Blundell-Bond estimator. Still, with most estimators one can observe a definitive tendency towards a certain range of estimates. This shows that the choice of estimator is not trivial. In this case, since AB, BB, and QML are all valid estimators for the model at hand, it means that looking at all three is vital, and the “true” effect likely lies somewhere in the middle.



Third, the SCA seems to indicate that the choice of price variable and the choice of data subset does not have as strong of an influence on the estimation results as the choice of estimator. None of the variable choice options in K2, show any clustering around a certain coefficient value. For the data subset options in K3 options there is slightly more grouping together, however, all options show estimation results across the full spectrum, with the exception of those estimations with datasets where the highest/lowest 0.5% of all data points were dropped. The reason for this clustering could potentially lie in the specific characteristics of those airports that exhibit the highest/lowest passenger numbers.

**Figure 5** shows the specification curve for the same specifications as Figure 4, but this time run with data on all airports, including the previously dopped hubs. One can see, that the main specifications appear in the same order on the curve and at the same spots, but the estimates including hub data are visibly smaller. Here again, as in the results shown in Table 2, this difference is not statistically significant, but the prevalence of it showing up for all specifications is noteworthy, and supports the notion of hubs being a significantly different type of airport.



**Figure 5:** SCA of estimated German Aviation Tax’s effect on passenger numbers at German airports in 2011, extracted from 175 specifications, using data on all airports including hubs

## 5. Conclusions

We find that the German Aviation Tax, implemented in 2011, had a significant but not persistent effect on the number of passengers departing from German non-hub airports. In the year 2011, immediately after implementation, passenger numbers were reduced by between 6.1% and 11.8%, when compared to passenger numbers at airports in other, tax-less, European countries. This range and the statistical significance of the difference was found to be robust through extensive Specification Curve Analysis. After 2011, however, the tax's effect declines and ceases being statistically significant. Previous studies have found reductions in passenger numbers prevailing after 2011, sometimes into 2015, a finding that could not be confirmed here (Falk and Hagsten 2019). After eliminating candidates for spillover effects, excluding airports ineligible as controls due to similar taxes, and excluding all hub airports from analysis due to incorrigible data collection idiosyncrasies regarding transfer passengers, the effect of the tax was found to be limited to 2011. A Specification Curve Analysis comprising 175 plausible and non-redundant specifications confirms this conclusion.

As detailed above, hubs currently should not be included in analyses of per-passenger taxes in aviation without significant scrutiny, since the necessary journey-level data is not available. Extant datasets make no distinction between transfer passengers, who did not begin their journey at the respective airport, and other departure passengers who did. Since the object of analysis, the German Aviation Tax, does not apply to transfer passengers, such data will not be able to accurately reflect the response of all passengers flying out of Germany to the tax. It mixes treated and untreated groups of passengers, and therefore any result for hub airports based on such data will be biased. This is not an unimportant shortcoming, since hub airports make up a significant proportion of aviation traffic in any country. Until reliable and long-run data on transfer passengers at hubs is available, studies intending to depict per-passenger tax effects in their entirety will continue to fall short.

According to publicly available data, the tax continues to fulfill its original purpose of raising additional annual income for the state of Germany. The tax did not, however, contribute to a persistent reduction of greenhouse gas emissions, even though motivating more environmentally friendly behavior was one of its other explicit goals. To curb emissions from aviation, a clear and sustainable reduction of flight volume is vital until low-emission technologies become economically viable and widely implemented. A per-passenger tax could, in theory, bring about such a behavioral change if it is appropriately high, internationally applied, and adjusted continuously to match stricter carbon emission goals. As evidenced by the analyses above, this does not currently apply to the German Aviation Tax. Passenger numbers at German airports evidently bounced back to levels that would be expected without the tax, only one year after its implementation, making the German Aviation Tax in its current form a toothless tiger in the face of greenhouse gas emission goals.

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## **Appendix A - Lists of airports excluded from main models**

### **List of airports that were dropped due to irregular data (for approach, see Borbely 2018):**

LAAGE airport, LUEBECK-BLANKENSEE airport, MEMMINGEN airport, NIEDERRHEIN airport, SYLT airport, ZWEIBRUECKEN airport, VAASA airport, VARKAUS airport, GOTEBORG/SAVE airport, BUCURESTI/HENRI COANDA airport, THISTED airport, VITORIA airport, MOSS/RYGGE airport, FOGGIA/GINO LISA airport, BRESCIA/MONTICHIARI airport, BOLZANO airport, CHALONS/VATRY airport, GLOUCESTERSHIRE airport, LYDD airport, OXFORD/KLINGTON airport, CAMBRIDGE airport

### **List of airports that were dropped due to being close to the German border, to account for potential spillover effects (Borbely 2018, Falk and Hagsten 2019):**

AMSTERDAM/SCHIPHOL airport, BASEL airport, BILLUND airport, BRUSSELS airport, CHARLEROI/BRUSSELS SOUTH airport, EINDHOVEN airport, LIEGE airport, LUXEMBOURG airport, MAASTRICHT/AACHEN airport, METZ NANCY-LORRAINE airport, ROTTERDAM airport, STRASBOURG-ENTZHEIM airport, ZURICH airport

### **List of hub airports that were dropped due to transfer passenger bias:**

ADOLFO SUAREZ MADRID-BARAJAS airport

AMSTERDAM/SCHIPHOL airport

ATHINAI/ELEFThERIOS VENIZELOS airport

BARCELONA/EL PRAT airport

BEOGRAD/NIKOLA TESLA airport

BERLIN-TEGEL airport

BRUSSELS airport

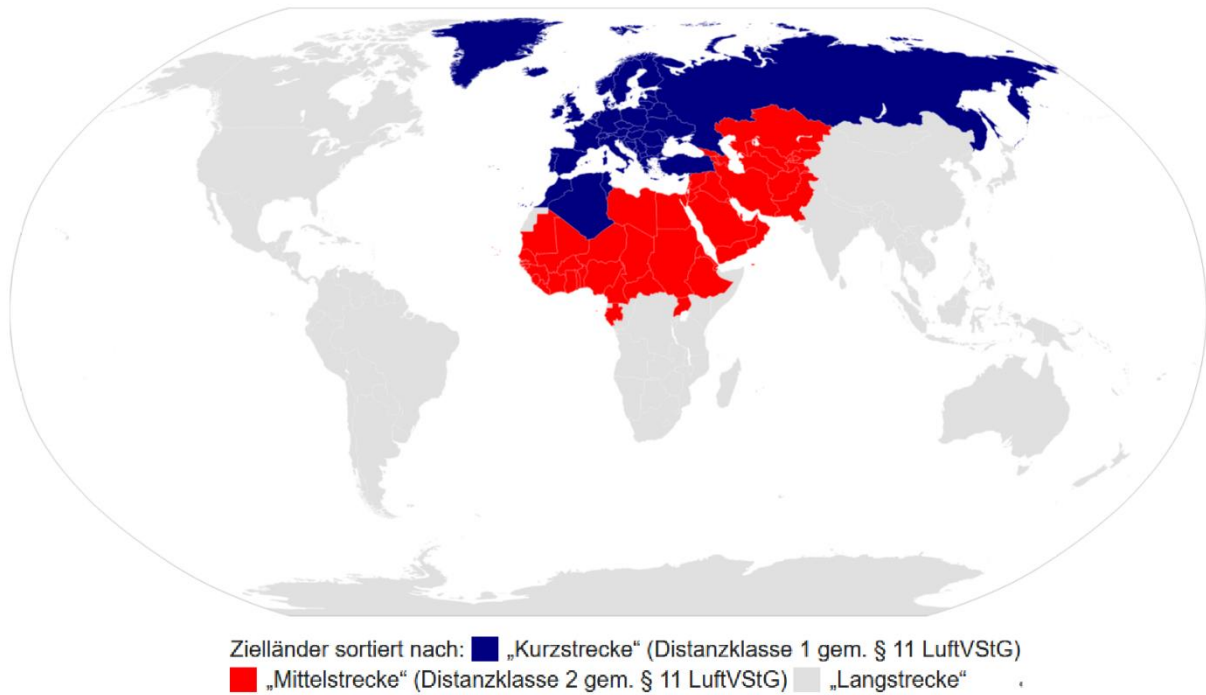
DUBLIN airport

DUESSELDORF airport

FRANKFURT/MAIN airport  
GENEVA airport  
GLASGOW airport  
HELSINKI-VANTAA airport  
KEFLAVIK airport  
LISBOA airport  
LONDON GATWICK airport  
LONDON HEATHROW airport  
LUXEMBOURG airport  
LYON SAINT-EXUPERY airport  
MANCHESTER airport  
MILANO/MALPENSA airport  
MUENCHEN airport  
OSLO/GARDERMOEN airport  
PALMA DE MALLORCA airport  
PARIS-CHARLES DE GAULLE airport  
PRAHA/RUZYNE airport  
RIGA airport  
ROMA/FIUMICINO airport  
STOCKHOLM/ARLANDA airport  
WARSZAWA/CHOPINA airport  
WIEN-SCHWECHAT airport  
ZURICH airport



## Appendix B – Supplementary Figures



**Figure 6:** Distance zones for the German Aviation Tax, short distance (blue), middle distance (red) and long distance (grey). Source: Unknown author (2019), retrieved at: <https://de.wikipedia.org/wiki/Luftverkehrsabgabe#/media/Datei:Luftverkehrsabgabe.svg>