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THE IMPACT OF ECONOMIC AGREEMENTS AND ENVIRONMENTAL INSTRUMENTS ON AIR TRANSPORT DEMAND:

EMPIRICAL POLICY ANALYSIS WITH STRUCTURAL GRAVITY MODELS

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Abstract

Over the past decades, European air transport has experienced an immense growth in passenger numbers and air freight volumes. The number of air passengers has tripled and air cargo volumes are 2.5 times higher than in 1990. Apart from the basic drivers of air transport growth such as GDP, GDP per capita or population size, multinational economic and aviation specific agreements aim to promote air transport supply and demand. On the other hand, greenhouse gas (GHG) emissions from aviation have increased by 125% since 1990, while total GHG emissions in the European Union (EU) have decreased by more than 20% since then. The growing environmental impacts of flying are putting more pressure on policy makers to implement environmental policy instruments that incentivize emissions reductions.

This thesis empirically analyzes the impacts of different economic agreements and environmental policies on air transport demand: First, the effect of the Euro, the European Union, the Schengen membership and of other regional trade agreements (RTAs) and air services agreements (ASAs) on air cargo flows are analyzed and compared with their impact on trade flows and air passenger flows. This thesis shows that EU membership positively affects trade and air passenger flows, but mostly has only a small positive but non-significant effect on air cargo flows. Other RTAs have an impact on all trade, but not on air transport. So far, air freight has not been able to benefit from these economic trade agreements. In contrast, the Euro and the Schengen Agreement have a positive impact on air freight and air passenger flows. However, these agreements have no influence on the overall trade flows. Since 50% of air cargo volumes are transported by passenger aircrafts, air cargo flows are particularly driven by passenger demand patterns.

Second, this thesis aims to verify whether the expected impacts on the aviation sector due to different environmental policies can be confirmed. The European Emissions Trading Scheme (EU ETS) aims to internalize the externalities of flying by assigning a price to CO_2 emissions. The effect of the EU ETS on intra-European aviation demand is compared to the effect of an aviation tax. The regressions show that until 2018 the EU ETS has had no significant demand-reducing effect on air passenger flows. The aviation tax (Luftverkehrabgabe) shows a clear and

robust negative effect on passenger flows in the analyzed time range. Thus, this does not mean that the tax is the more effective policy measure, as air passenger taxes do not relate to the actual amount of CO_2 emitted per passenger.

And lastly, this thesis applies recent econometric advances in international trade economics to an analysis of air passenger and air cargo flows. This involves formulating different structural gravity models with fixed-effects and estimating them using the Poisson pseudo-maximum likelihood (PPML) estimator. Previous gravity model estimations in the field of aviation economics were predominantly based on basic, atheoretical gravity models and linear estimators such as OLS. Since air cargo and air passenger data may share the feature of heteroskedasticity with trade flow datasets, a Poisson-based estimator should be used instead of a linear estimator. Currently, the most comprehensive and up-to-date structural gravity model includes international *and* intranational trade or aviation flows, time-varying international border dummies, and origin-year, destination-year, and country-pair fixed effects. Such a model thus controls for multilateral resistance, endogeneity, and globalization effects. As shown in the first empirical study of this thesis, including intranational flows and international border dummies may reverse the estimated effects of some of the policy variables. With respect to the second empirical study in this thesis, the estimates show that a different fixed effects setting may be used in the analysis of a homogeneous area such as the European Economic Area (EEA). This includes the inclusion of a time-varying cost index rather than time-varying country-specific fixed effects. In addition, the estimates support previous research showing that dummy variables may overestimate the effects of policy variables. More precise policy measures should be used in place of dummies whenever possible.

Zusammenfassung

In den letzten Jahrzehnten verzeichnete der europäische Luftverkehrssektor ein immenses Wachstum der Fluggastzahlen und des Luftfrachtaufkommens. Die Zahl der Fluggäste hat sich verdreifacht und das Luftfrachtaufkommen ist im Vergleich zu 1990 um das 2,5-fache gestiegen. Neben den grundlegenden Treibern des Luftverkehrswachstums wie dem Bruttoinlandsprodukt (BIP), dem Pro-Kopf-BIP oder der Bevölkerungszahl zielen multinationale wirtschaftliche und luftverkehrsspezifische Abkommen darauf ab, Angebot und Nachfrage im Luftverkehr zu fördern. Auf der anderen Seite sind die Treibhausgasemissionen (THG) des Luftverkehrs seit 1990 um 125 % gestiegen, während die gesamten THG-Emissionen in der Europäischen Union (EU) seither um mehr als 20 % zurückgegangen sind. Die zunehmende Umweltbelastung durch den Flugverkehr erhöht den Druck auf die politischen Entscheidungsträger, umweltpolitische Instrumente einzusetzen, die Emissionsreduzierungen herbeiführen.

In dieser Arbeit werden die Auswirkungen verschiedener wirtschafts- und umweltpolitischer Maßnahmen auf die Luftverkehrsnachfrage empirisch untersucht: Zunächst werden die Auswirkungen des Euro, der Europäischen Union, der Schengen-Mitgliedschaft und von weiteren regionalen Handelsabkommen (RTA) und Luftverkehrsabkommen (ASA) auf die Luftfrachtströme analysiert und mit den Auswirkungen dieser Abkommen auf die Handelsströme und die Flugpassagierströme verglichen. Die erste Studie dieser Arbeit zeigt demnach, dass sich die EU-Mitgliedschaft positiv auf den Handel und die Flugpassagierströme auswirkt, aber nur einen kleinen positiven und nicht signifikanten Effekt auf die Luftfrachtströme hat. Andere Freihandelsabkommen wirken sich auf den Gesamthandel positiv aus, nicht aber auf den Luftfrachtverkehr. Bislang konnte die Luftfracht nicht von diesen wirtschaftlichen Handelsabkommen profitieren. Hingegen wirken sich der Euro und das Schengen Abkommen positiv auf die Luftfracht- und Luftpassagierströme aus. Diese Abkommen haben jedoch keinen Einfluss auf die gesamten Handelsströme. Da 50 % des Luftfrachtvolumens mit Passagierflugzeugen befördert werden, werden die Luftfrachtströme in besonderem Maße durch das Nachfrageverhalten der Fluggäste bestimmt.

Zweitens zielt diese Arbeit darauf ab, zu überprüfen, ob die erwarteten Auswirkungen verschiedener umweltpolitischer Maßnahmen auf den Luftverkehrssektor bestätigt werden können. Der innereuropäische Luftverkehr wurde 2012 in das Europäische Emissionshandelssystem (EU ETS) integriert, um die externen Effekte des Fliegens zu internalisieren. Die Auswirkungen des EU ETS auf die innereuropäische Luftverkehrsnachfrage werden in der zweiten Studie mit den Auswirkungen einer Luftverkehrssteuer verglichen. Die verschiedenen Regressionen zeigen, dass das EU ETS bis einschließlich 2018 keine signifikante nachfragesenkende Wirkung auf die Fluggastströme hat. Die Luftverkehrssteuer zeigt einen signifikanten und robusten negativen Effekt auf die Passagierströme in dem betrachteten Zeitraum. Dies bedeutet jedoch nicht, dass die Steuer die effektivere politische Maßnahme ist, da sich die Fluggaststeuer nicht auf die tatsächliche Menge des pro Passagier ausgestoßenen CO_2 bezieht.

Drittens wendet diese Arbeit die neusten ökonometrischen Erkenntnisse aus der internationalen Handelsökonomie auf eine Analyse der Fluggast- und Luftfrachtströme an. Dazu werden strukturelle Gravitationsmodelle mit fixen Effekten aufgestellt und mit dem Poisson Pseudo-Maximum-Likelihood (PPML) Schätzer berechnet. Bisherige ökonometrische Berechnungen im Bereich der Luftfahrtökonomie basierten überwiegend auf einfachen Gravitationsmodellen und linearen Schätzern wie OLS. Da Luftfracht- und Fluggastdaten das Merkmal der Heteroskedastizität mit den Handelsdaten gemeinsam haben, sollte eine Poisson-basierte Berechnung anstelle einer linearen Berechnung der Regressionen erfolgen. Neue Gravitationsmodelle beinhalten internationale und inländische Verkehrs- bzw. Handelsströme, zeitvariable internationale „border dummies“ und unterschiedliche fixe Effekte. Ein solches Modell kontrolliert so für die „multilateral resistances“, für Endogenität und Globalisierungseffekte. Wie in der ersten empirischen Studie gezeigt wird, kann die Einbeziehung von inländischen Verkehrsströmen und internationalen border dummies die geschätzten Auswirkungen einiger der Politikvariablen umkehren. In Bezug auf die zweite empirische Studie in diesem Papier zeigen die Berechnungen, dass bei der Analyse eines homogenen Wirtschaftsgebiets wie dem Europäischen Wirtschaftsraum (EWR) unter Umständen besser ein anderes Fixed-Effects-Setting verwendet werden sollte. Dazu gehört die Einbeziehung eines zeitvariablen Kostenindexes anstelle von zeitvariablen länderspezifischen fixen Effekten. Darüber hinaus unterstützen die Ergebnisse frühere Untersuchungen, die zeigen, dass Dummy-Variablen die Auswirkungen politischer Preismaßnahmen überbewerten können. Wann immer möglich, sollten präzisere politische Maßnahmen anstelle von Dummies verwendet werden.

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List of abbreviations

ALI	Air Liberalization Index
APD	Air Passenger Duty
APEC	Asia-Pacific Economic Cooperation
ASA	Air service agreement
AvW	Anderson and van Wincoop
BASA	Bilateral air service agreement
BAU	Business as usual
CEPII	Centre d'Etudes Prospectives et d'Informations
CO	Carbon monoxide
CO_2	Carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
COVID-19	Coronavirus disease 2019
EASA	European Union Aviation Safety Agency
EEA	European Environment Agency
EIA	U.S. Energy Information Administration
EPRS	European Parliamentary Research Service
ETS	Emissions trading system
EU	European Union
EU ETS	European Union Emissions Trading System
EUA	European Emission Allowance
FDI	Foreign direct investment
FE	Fixed effects
FTA	Free trade agreement
GDP	Gross domestic product
GFC	Grand financial crisis
GHG	Greenhouse gas
H_2	Hydrogen
H_2O	Water vapor
HC	Hydrocarbons

IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICAP	International Carbon Action Partnership
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LCC	Low-cost carrier
MRT	Multilateral resistance term
NO_x	Nitrous oxides
O_3	Ozone
OLS	Ordinary least squares
OSA	Open skies agreement
PPML	Poisson pseudo-maximum likelihood
PtL	Power-to-liquid
RESET	Regression Equation Specification Error Test
RF	Radiative forcing
SAF	Sustainable aviation fuel
SARS	Severe acute respiratory syndrome
Sep11	September 11, 2001
SO_2	Sulfur dioxide
UAE	United Arab Emirates
UK	United Kingdom
US	United States
VAT	Value added taxes
WTO	World Trade Organization

1. Introduction

1.1. Aviation trends and drivers

In the past three decades, the aviation sector has experienced an immense growth in air passenger numbers and in air cargo volumes. Passenger numbers in the European Union (EU) have been rising since the deregulations of the European airline market that took place between 1987 and 1997. The EU's deregulation initiatives abandoned fare restrictions imposed on airlines in the EU and since then, any EU airlines can operate within the entire EU. This embraces the right to operate within another member state's national territory.[1] The deregulations have led to an increased supply and demand of air transport and to new airline companies, which in turn have fostered competition and decreased ticket prices. Since then, the number of air passengers has roughly tripled and air cargo volumes are 2.5 times higher compared to 1990 (EASA 2019; EEA 2018; EPRS 2016).

Figure 1.1 shows a more recent development of air passenger numbers and air cargo volumes (in tons) from and to the EU-27 countries plus the United Kingdom (UK). Since 2008, air passenger numbers have increased by 40% and air cargo volumes have increased by 20-25%. In the past decade, the number of passengers transported by air grew at an average rate of about 4% each year and total air cargo volumes of the EU countries rose at an average rate of about 2 % p.a. (Eurostat 2020a, 2021a).[2] Air passenger and air cargo volumes declined during the course of the financial and world economic crisis, but have been recovering again from 2013 on. Since 2015 however, air cargo growth has slowed again and air cargo volumes have been put under pressure due to a US-China trade conflict (IATA 2020).

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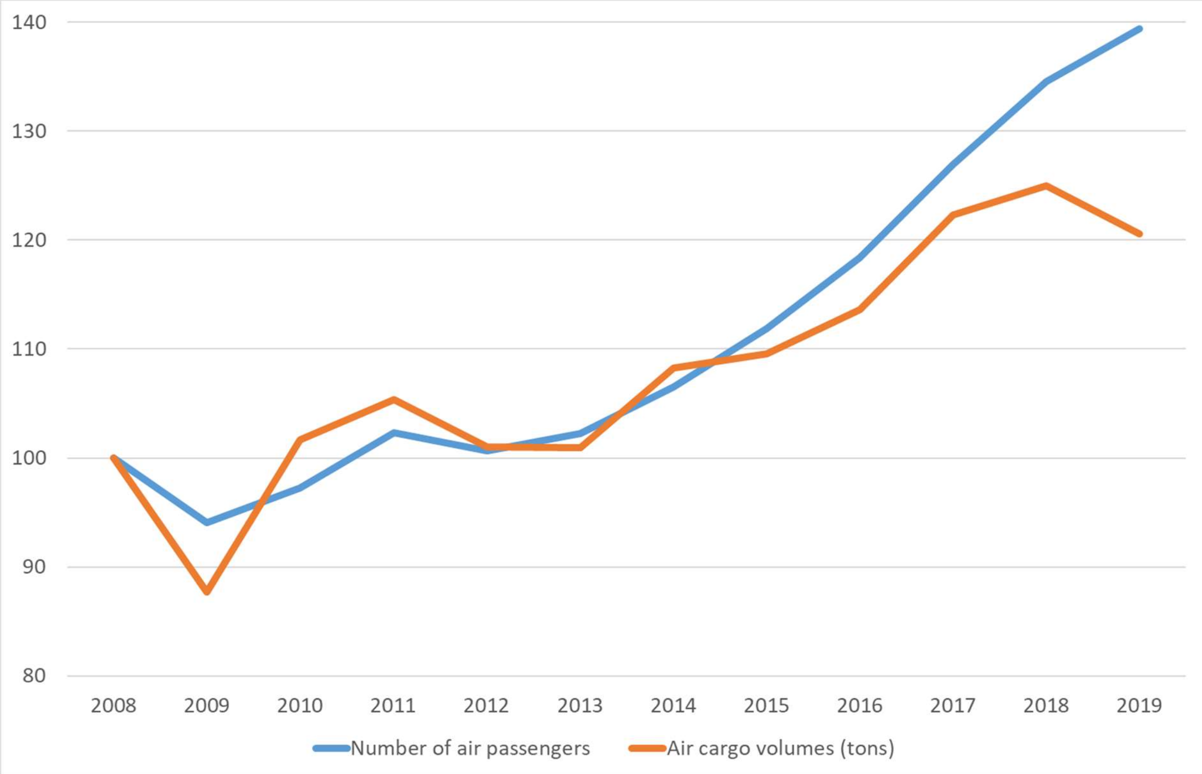
[1] The right to operate within another state's national territory is called "Ninth Freedom of The Air". For further details on the different *Freedoms of The Air* see ICAO 2018b.

[2] Growth rates are calculated with data derived from Eurostat on air passenger numbers and air cargo volumes (in tons) within and from/to the EU-27 countries plus the United Kingdom based on Eurostat 2020a, 2021a.

Figure 1.1: Aviation growth figures, EU-27 + UK (2008=100)



Source: Own figure with data from Eurostat 2020a, 2021a. Note: 2008=100.

In addition to the aforementioned deregulations in the aviation sector, multinational economic agreements (e.g. the formation and enlargement of the European Union, the Schengen agreement and the introduction of the Euro) reduce transaction costs for air passengers and for air cargo traffic. Multinational economic agreements generally reduce or completely abandon resistances that apply to the free movement of people or goods, and by this reduce transaction costs of traveling and of trading of goods and services (Rodrik 2018). Moreover, so called open skies agreements (OSA) or air service agreements (ASA) with non-EU countries reduce transaction costs since these agreements foster competition by abandoning frictions like deregulations of extra-EU aviation services.[3] The most important stimulus on aviation growth however, is a rising total gross domestic product (GDP) and a

[3] See for example Cristea et al. 2015; Micco and Serebrisky 2006; Yamaguchi 2008. For further details see chapter 2.2.

rising GDP per capita representing economic prosperity and rising wealth. Rising wealth increases one nation's demand of air transport services significantly, especially that of air passenger services.[4]

Exogenous shocks, on the other side, can affect aviation demand negatively. This includes exogenous shocks with a predominately regional impact such as local political riots, conflicts, wars or natural disasters. But also shocks with a broader or even global impact such as Sep11, SARS, the global financial crisis (GFC) and above all the COVID-19 pandemic.[5] In the case of COVID-19, apart from a demand-side effect, this shock event also has supply-side effects due to travel restrictions and forced aircraft groundings.

In addition to passengers, airplanes transport highly valuable or perishable goods such as pharmaceuticals, microelectronics, medical instruments and foods. The transport of these products relies on high quality and security standards, both in the air and when loading and unloading the goods at the airports. Moreover, transportation by air is a lot faster than ground transportation. When measured in value, airfreight accounts for about 35% of the total worldwide trade. Though when measured in volumes, air cargo makes up only less than 1% of the total trade volumes. As a consequence, almost all freight measured by volume is transported by ship, truck or train due to the lower transportation costs compared to air cargo. Whereas aviation does not compete with other modes of transport when transporting passengers over large distances, air cargo still competes with transportation by ship (IATA 2015; World Bank 2009; WTO 2013).

Table 1.1 gives an overview of the main aviation figures and their percentage changes between 2005 and 2017 for the European Economic Area (EEA). The number of commercial flights have for example increased by 8%, whereas passenger numbers have increased by 50%. This is due to the usage of airplanes that can transport a higher number of passengers and the rise in seat load factors. Only a fraction of flights are so called *all-cargo flights* and this number

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[4] See for example Grosche et al. 2007; Matsumoto 2004, 2007. For further details see chapter 2.1.

[5] See for example Ito and Lee 2005; Mitra et al. 2018 for the impact of terrorism on international air travel and Hotle and Mumbower2021 for the impact of SARS on domestic US air travel.

has even decreased in the past years. The rest of the air cargo volume is transported as so called *belly-cargo*. Pre-pandemic long-term traffic forecasts until 2045 for air passenger and air cargo volumes were about 2.6% and 2.5% p.a. for intra-European traffic (ICAO 2018a). Since air passenger planes transport half of their total airfreight in their bellies, air cargo capacity greatly depends on air passenger services and the network and routes they offer. This makes air cargo vulnerable to exogenous shocks that predominately affect air passenger flows. When air passenger planes where grounded due to the COVID-19 pandemic and its travel restrictions beginning in March 2020, air cargo capacity was greatly affected and therefore declined (IATA 2020; Suau-Sanchez et al. 2020).

Table 1.1: Intra-EEA aviation statistics

	Unit	2005	2017	% change
Number of flights	millions	8.89	9.56	8%
Average distance per flight	km	1,478	1,714	16%
Passengers on commercial flights	millions	592	890	50%
Passenger load factor	%	70.2	80.3	14%
Passengers per flight		86	124	44%
Number of all-cargo flights	thousands	319	312	-2%
Cargo	million tons	6.4	10.0	56%
Aircraft average age	years	9.6	10.8	13%

Source: EASA 2019.

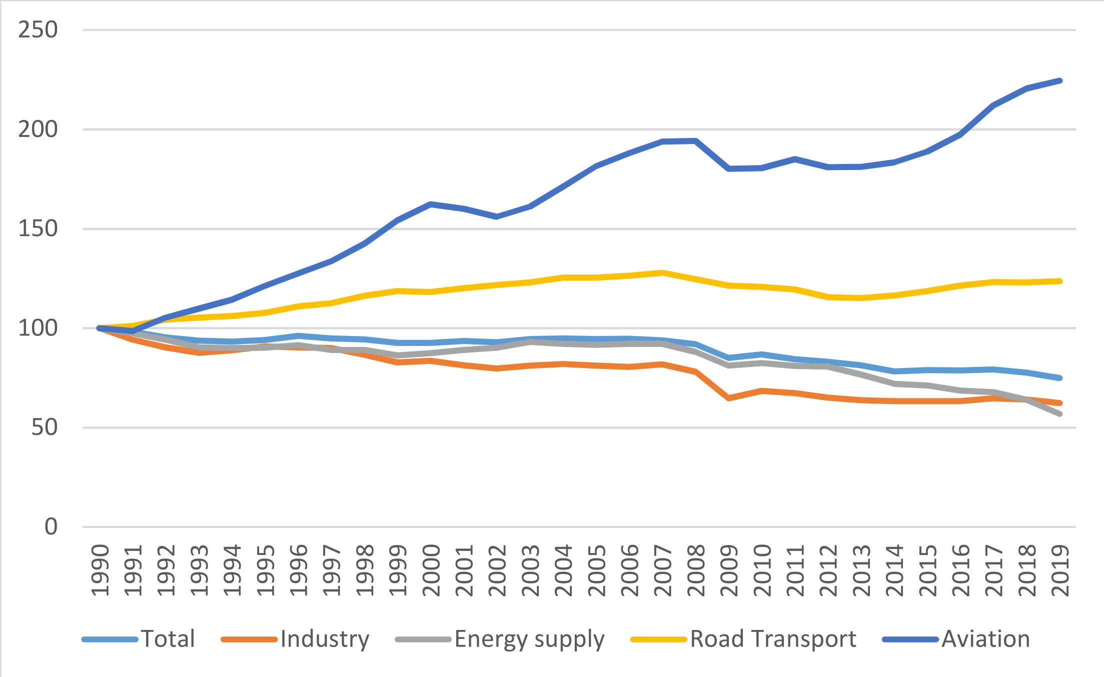
1.2. External effects of aviation

The growth of the aviation sector does however result in growing negative side effects for the surroundings. The most severe side effects of aviation are noise exposure and emissions in the form of various kinds of gases and particles. In economic theory, these side effects are considered external effects, or externalities. External effects occur if the consumption of a product or a production process imposes side effects on others. The concept of externalities traces back to Pigou (1920) who argued that externalities have an important impact on social welfare. The missing compensation for negative externalities is caused by the missing property-rights of the environment (e.g. air/atmosphere). Missing property rights lead to a market failure, since no price is allocated to the externalities. Hence, both positive and negative externalities may occur. Noise and emissions resulting from aviation are considered negative externalities. These side effects have negative impacts on others and no compensation is paid for the negative impact (Buchholz and Rübbelke 2019; Perman et al. 2011; Tietenberg 2020).[6]

Most of the emissions that originate from the burning of kerosene are emitted into the upper troposphere and lower stratosphere and contribute to climate change by increasing the concentration of greenhouse gases (GHG) (IPCC 1999). Whereas total GHG emissions in the EU have been decreasing since 1990, emissions from the transportation sector have steadily been increasing. GHG emissions from ground transportation have increased by 20% and emissions from domestic and international aviation have increased by 125% (see Figure 1.2) compared to 1990. GHG emissions from the transportation sector now account for 25% of the EU's total greenhouse gas emissions and 3.9% of total emissions come from the aviation sector alone (EEA 2021).[7] Though the total contribution of aviation to climate change is estimated to be almost 5% (Lee et al. 2009). In addition to the greenhouse gases carbon dioxide (CO_2) and water vapor (H_2O), planes emit nitrous oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons (HC) and direct particles such as soot. NO_x indirectly affects the concentration of GHG by raising the level of the greenhouse gas ozone (O_3) in the atmosphere. Particles directly emitted by airplanes react with the greenhouse gas H_2O, which leads to contrails and to the formation of cirrus clouds. (EASA 2019; IPCC 1999; Lee et al. 2009; Scheelhaase et al. 2016).

[6] This chapter focuses on the negative effects of emissions. For details on noise exposure from aviation see for example EASA 2016, 2019.
[7] Own calculations with data from the EEA greenhouse gases - data viewer, EEA 2021. Aviation and transportation figures include domestic and international aviation. See also chapter 4.2.1.

Figure 1.2: Growth of GHG emissions since 1990, EU-27 + UK (1990=100)



Source: Own figure with data derived from EEA 2021. Note: 1990=100.

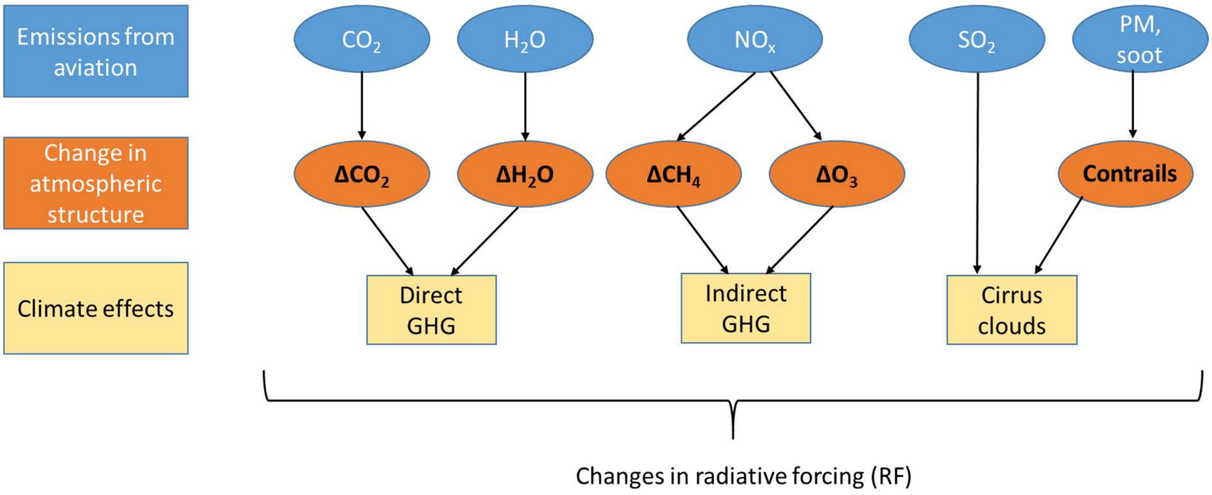
Emissions from planes, contrails and cirrus clouds contribute to climate change by changing and increasing radiative forcing (RF) of the atmosphere. Rising positive radiative forcing induces radiation from space (atmospheric radiation) to be absorbed and re-emitted back to the earth's surface instead of into space. This effect leads to rising atmospheric warming (EEA 2018). Table 1.2 shows an overview of the emissions produced by a 1-hour flight and Figure 1.3 shows the climate relevant emissions and climate effects produced by planes.

Table 1.2: Emissions from a one-hour flight

Green-house gases	Carbon dioxide (CO_2)	8,500 kg
	Water vapor (H_2O)	3,300 kg
Further emissions	Nitrogen oxides (NO_X)	31 kg
	Sulphur dioxide (SO_2)	2.5 kg
	Carbon monoxide (CO)	2.0 kg
	Hydrocarbons (HC)	0.4 kg
	Particulate matter (PM), soot	0.1 kg

Source: EASA 2016. Note: Figures relate to emissions from 2,700 kg kerosene (for a usual two engine jet aircraft during a 1-hour flight with 150 passengers).

Figure 1.3: Climate relevant emissions from aviation



Sources: Based on Bopst et al. 2019; Dessens et al. 2014; IPCC 1999; Lee et al. 2009.

The aviation sector's contribution to climate change is expected to continue to grow since both air passenger services and air cargo volumes are expected to continue to increase (about plus 2.5% p.a.). Fuel efficiency gains can be realized every year due to technologically improved planes and engines, but also due to an increase of seats per plane and higher seat load factors. Options for reducing the burn of fuel in aviation are: flight route optimization, navigation and surveillance systems optimization, flight management, engine optimization, improved capacity utilization, improvement in aerodynamics and early retirement of aircraft (Cames and Deuber 2004). The average kerosene consumption per 100 passenger-kilometers was 4.4 liters in 2005. By 2017, this figure had been reduced to 3.4 liters of kerosene per passenger resulting in a reduction of 22.7 %. But fuel efficiency gains are currently only at about 1.0% - 1.5% p.a. and therefore are not able to compensate for passenger and emission growth rates (EASA 2016, 2019; EEA 2018). Technological innovations that can compensate or neutralize emissions from aviation such as sustainable aviation fuels (SAF), power-to-liquid (PtL) fuels, electric aircrafts or alternative energy sources such as hydrogen (H_2) are being developed but are currently not able to completely substitute kerosene. The share of SAFs is less than 1% at present and their cost is about 3-5 times higher than the cost of kerosene

(EASA 2019; EPRS 2020). Airplanes that fly on a zero-emissions basis by using hydrogen are not expected to operate until 2035.[8]

1.3. Research gaps and objectives of this thesis

The determinants of aviation demand and of air passenger flows have been subject to various studies, though not nearly as frequently as there exist studies on the determinants of trade and trade flows between countries. Moreover, the analysis of air cargo flows is even less explored, although air cargo volumes account for about 35% of total trade on a value basis. As explained more in detail in the following Chapter 2.1, the related literature in the area of aviation economics distinguishes between two types of factors that determine aviation demand and passengers flows between countries and/or regions: Geo-economic factors and service-related factors. Apart from the basic determinants of demand such as population size and/or the gross domestic product (GDP) of a country, common geo-economic determinants also include economic, political or cultural ties between two countries. Economic or political ties are for example economic or aviation specific multinational agreements such as the European Union (EU), regional trade agreements (RTAs), the EURO, the Schengen agreement or bilateral air service agreements (ASA). These determinants are considered to foster demand by reducing transaction costs. As will be shown in Chapter 2.2, the impact of currency unions such as the Euro and of economic integration unions such as the EU or other RTAs on aviation demand is still unexplored. This is especially striking in regard to air cargo, since a vast amount of research has tackled these issues for trade in general up to now. As shown in Chapter 1.1, air cargo has not reached the same growth rates as trade in total in the past years.

Environmental policies also belong to the group of economic-political factors that determine aviation demand. Apart from technological solutions, environmental policy instruments may incentivize emission reductions. As will be explained in Chapter 2.3, these factors are supposed to reduce demand or to induce a shift to more CO_2-efficient technologies, since the

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[8] Airbus 2020 announced last year to put hydrogen aircrafts into service by 2035.

end price for the consumer is increased due to environmental policy measures. The most prominent and broadest environmental instrument applying to aviation is the European Union Emissions Trading System (EU ETS), which has covered aviation within the European Economic Area (EEA) since 2012. The impact of environmental policies on aviation demand has been explored by a few empirical studies in the case of air passenger taxes. Hence, studies that have been published on the effects of the EU ETS on aviation demand are purely simulation studies, and most of them were published before the integration of aviation into the EU ETS (see Chapter 2.3).

The commonly used tool for an empirical analysis of the volume of demand (trade, air services) between countries is the gravity model. The gravity model is considered the workhorse of empirical policy analysis in international trade economics (see Chapter 3.1). Since a seminal paper by Anderson and van Wincoop in 2003 and their structural specification of the gravity model of trade, so-called multilateral resistance terms (MRTs) have been included into the model to account for multilateral but unobservable barriers to trade. Moreover, as explained in more detail in Chapter 3.2, the trade economists Santos Silva and Tenreyro showed in 2006 that the estimation of gravity models with OLS brings inconsistent results when analyzing data that is heteroscedastic, such as trade data. The authors therefore advocate against a log-linearized estimation and for the poisson pseudo-maximum likelihood estimation (PPML). Applying this most recent methodology and estimation technique to the area of aviation economics has been limited to a few previous studies. Most of the related literature still applies the basic, atheoretical gravity model and estimates it with OLS. Therefore, accounting for multilateral resistance terms in the form of different fixed effects has so far not been considered frequently in aviation economics, and research misses contributions that analyze air cargo flows in a panel-data setting with a structural gravity model and fixed effects with PPML.

This thesis intends to fill the just explained research gaps concerning the effects of different economic agreements and environmental policy instruments on aviation demand and the correct gravity model specification. This thesis therefore aims to add the following different empirical and methodological contributions:

Firstly, apart from the analysis of the impact of the classical gravity model variables on air cargo flows, the first empirical study of this thesis analyses the impact of various multinational agreements on the volume of air cargo flows. These agreements are the Euro, the EU, the Schengen agreement, other RTAs and air service agreements. Additionally, the first study compares the effects of these variables on air cargo flows with their effect on trade flows and passenger flows.

Secondly, this thesis aims to verify whether the expected effects on the aviation sector due to the EU ETS can be approved. Previous simulation studies calculated demand reduction effects of the EU ETS on aviation demand of about -0.3 to -1.3%. But up to now, no empirical study analyzed the effects of the EU ETS on aviation demand. Moreover, the effect of the EU ETS on aviation demand is analyzed in comparison to the effects of a ticket tax – the German and Austrian Luftverkehrabgabe.

Finally, concerning the methodological contribution, the thesis applies the newest econometric advances from the field of international trade economics to an analysis of air passenger and air cargo flows. That implies the formulation and estimation of different structural gravity models that include different fixed effects. Moreover, the regressions are performed with the poisson pseudo-maximum likelihood (PPML) estimator.

To give these mentioned contributions to the research body, the remainder of this thesis is structured as follows: Chapter 2 reviews the theoretical assumptions and foundations of this thesis as well as a literature review on the determinants of aviation demand and the effects of policy variables (economic agreements and environmental instruments) on aviation. Chapter 3 introduces the methodology used in the empirical studies of this study, in other words, the structural gravity model and the poisson pseudo-maximum likelihood estimator. Chapter 4 of this thesis presents two empirical studies on the effects of policy variables on aviation demand. First, in Chapter 4.1 an empirical study on the effects of bi- and multinational economic agreements and air service agreements on air cargo flows in comparison with the effect of these policy measures on air passenger flows and total trade flows is presented. In chapter 4.2, a second empirical study on the effects of the EU ETS on aviation demand in comparison with the effects of an aviation ticket tax is given. The thesis closes with a conclusion and discussion section (Chapter 5).

2. Theoretical foundations and literature review

2.1. Determinants of aviation demand

The related literature distinguishes between two types of factors that determine air transport demand: Geo-economic factors or demand-side variables and service-related factors, also called supply-side variables (Boonekamp et al. 2018; Hsiao and Hansen 2011; Jorge-Calderón 1997). Population, GDP or GDP per capita and distance are common geo-economic factors, but so are other variables such as one nation's trade volume or the exchange rate between two currencies. Moreover, economic, political or cultural relationships and ties between two countries also belong to geo-economic variables. Examples for economic ties include economic agreements and currency unions such as the EU, the Euro and other trade or air service agreements. Cultural ties would include the same language or former colonial ties between two countries. Service-related factors consist of the cost of air transportation services, flight frequencies, travel time, aircraft type and other service related factors. Research that focuses only on the determinants of air cargo demand is scarce, but the determinants that are mentioned in the relevant literature are mainly those that determine air passenger demand. This includes distance, population, GDP, air cargo service costs and bi- or multinational air service agreements (Alexander and Merkert 2020; Geloso Grosso and Shepherd 2011; Kupfer et al. 2017; Matsumoto 2007). Hence one has to consider that airplanes predominantly transport special kinds of products, such as high value and perishable goods. It is therefore highly likely that other factors trigger air cargo demand and that some of the transported products can only be transported by air. To the best of my knowledge, this subject has not been explored up to now.

Most of the determinants just mentioned have a positive impact on air passenger demand and/or air cargo volumes. This includes the determinants population, GDP, economic, political and cultural ties, flight frequencies and the service levels. The relationship of distance and aviation demand is mainly non-linear, especially in the case of air passenger demand. On short distances, airplanes compete with other modes of transportation such as cars and trains, whereas these modes of transportation become obsolete on longer distances or on intracontinental routes. Hence, with increasing distances, air travel demand and supply is reduced due to long travel times or technological constraints. Air service costs and additional cost factors have a negative impact on aviation demand. The total cost or the ticket price resulting from the sum of the airline's price plus the various charges or taxes that apply to aviation are relevant to the customer. These would include airport charges but also environmental taxes and other charges on aviation. Table 2.1 presents the aforementioned basic determinants of aviation demand and their experienced direction of impact (positive/negative) on air passenger numbers and air cargo volumes in accordance with the surveyed literature. In addition to the basic determinants, exogenous shocks also influence the demand and supply of aviation services, and these are mostly negative. The strength of impact of exogenous shocks is very heterogeneous whether the exogenous shock has a predominately regional impact or a broader or even global impact such as Sep11, SARS, the GFC and the COVID-19 pandemic (Hotle and Mumbower 2021; Ito and Lee 2005; Mitra et al. 2018).

Table 2.1: Basic determinants of aviation demand

	Determinants of aviation demand	**Impact on aviation demand**
Geo-economic	Population	+
	GDP / GDP p. capita	+
	Distance[1]	+/-
	Political, economic, social ties	+
Service-related	Price	-
	Frequency	+
	Travel time[2]	-
	Service quality measures	+

Sources: Based on Alexander and Merkert 2020; Boonekamp et al. 2018; Geloso Grosso and Shepherd 2011; Hsiao and Hansen 2011; Jorge-Calderón 1997. Notes: (1) Non-linear (+ and -) in the case of air travel demand, mainly positive in the case of air cargo demand; (2) Relates to air travel demand.

The strength of the reaction of demand due to a change in the determinants is measured by elasticities. But no clear conclusion can be drawn with regard to the concrete amount of reaction and the aforementioned studies vary in their results. Though the impact of GDP for example mainly ranges between 0.2 and 0.3 (Cristea et al. 2015; Matsumoto 2004, 2007). In regard to the distance factor, previous studies have confirmed the non-linear impact on air travel demand, although with very differing results since the datasets used in the studies differ in regard to the tackled geographical scopes. The intensity of aviation demand response caused by price changes has been discussed in economics in great detail. Since the 1980s, various studies have calculated the price elasticity of demand for air travel services (InterVistas 2007; Molloy et al. 2012).[9] Price elasticity varies greatly depending on the type of customer, the region, or length of the route. Leisure and low cost customers (LCC) are more price sensitive (elasticity <-1.00) than business travelers (elasticity > -1.00) (Brons et al. 2002; IATA 2008; PWC 2005). Medium estimates of the overall price elasticity for the EU usually range between -0.8 (European Commission 2005) and -1.4 (InterVistas 2007). In a recent study by the European Commission, price elasticities for the European Market are differentiated by the route length. For the EU domestic market, the authors calculate the highest price elasticities (-1.23) due to the options of using other modes of transport other than flying, followed by intra-EU traffic (-1.12) and inter-continental flights (-0.89), which have the lowest price elasticities (European Commission 2019). Price reactions of first and business class travelers are about 0.5 points lower than those of leisure travelers. Studies also exist that suggest that the reaction of air travel demand to price changes is almost inelastic, assuming elasticities of only -0.29 in the short run and -0.44 in the longer run (Molloy et al. 2012) for the European Market.

2.2. The effect of economic agreements on aviation

Research on multinational economic agreements in the area of aviation economics covers mainly air transport liberalization issues and how these policies foster passenger numbers and/or air cargo volumes (Zhang et al. 2018). Papers that have studied the effect of bi- or multinational agreements on aviation demand mainly examine the impact of air liberalization

[9] The concept of price elasticity of air cargo demand has hardly been explored.

agreements such as open skies agreements (OSA) or air service agreements (ASA). Open skies agreements and air service agreements are bi- or multinational agreements with the intention to reduce or completely abandon frictions that apply to air travel or air transport services between the respective countries. The process of air liberalization started in the 1990's and the first international OSA was signed in 1992 between the US and the Netherlands (Alexander and Merkert 2020; Piermartini and Rousová 2013).[10]

Micco and Serebrisky (2006) found out that OSAs between the US and foreign countries increased air cargo imports to the US by 12%. Yamaguchi (2008) analyzed the amount of air cargo exports from the US. Due to the introduction of open skies agreements, US trade exports rose by 1.3%. Hwang and Shiao (2011) analyzed international air cargo flows between Taiwan and the US. Their results show that an OSA increased the amount of transported goods by air between the two countries by about 10%. Geloso Grosso and Shepherd (2011) utilized the Air Liberalization Index (ALI) on a dataset that includes trade flows between the countries of the Asia-Pacific Economic Cooperation (APEC). The ALI is a constructed and expert-based index provided by the World Trade Organization (WTO) that translates the openness of bi- or multilateral aviation markets into a continuous variable (WTO 2011a, 2011b). Overall, Geloso Grosso and Shepherd found positive but small effects of the ALI on air cargo flows. Hence, the effect of the ALI is positive and significant for manufacturing goods transported by air, with a coefficient that translates to an effect of 1.4%. Piermartini and Rousová (2013) and Cristea et al. (2015) analyzed the effect of the Air Liberalization Index on air passenger flows. Both studies found positive and significant effects, although to a relative small degree (between 1% and 3%). Gong et al. (2018) analyzed international air cargo flows from and to China and included a liberalization dummy into the model denoting the complete liberalization of air services from China to the US. The effect on exports from China to US is positive, relatively high (over 80%), and significant. Oum et al. (2019) analyzed the effect of ASAs between Canada and various partner countries. The effects are positive and significant for both air passengers and air cargo (12.5% and 9.4% to 19%). Abate and Christidis (2020) found in their

[10] See also chapter 4.1.2.

study on air traffic flows between the EU countries and external partner countries that the bilateral air service agreements (BASAs) negotiated by the EU en bloc increased air passenger demand by 27%. And lastly, Alexander and Merkert (2020) analyzed the effects of free trade agreements (FTA) on the US international air freight market and found a strong positive and significant effect of FTAs on high commodity goods.

As shown by the literature review, the magnitude of the demand effects due to air service agreements varies greatly among the mentioned studies. This is due to the usage of differing time frames and geographical scopes. Moreover, different product categories had often been analyzed. Table 2.2 displays a summary of previous studies that analyzed the effects of economic agreements on aviation demand. Almost all of these studies focus on different OSAs or ASAs; only one study analyzed the effect of an FTA on aviation demand (Alexander and Merkert 2020). Up to now – and to the best of my knowledge – no study has been published that analyses the effect of the EU or the EURO on aviation demand.[11] This is in contrast to the area of trade economics, where a vast number of papers has been published on the impact of the EU and the EURO on total trade flows.[12]

[11] Saayman et al. 2016 and Santana-Gallego et al. 2016 analyze the effect of the EURO and of trade and economic agreements on tourism flows.
[12] See for example - among others - Baier and Bergstrand 2007; Baldwin and Taglioni 2007; Benedictis, Luca De and Salvatici, Luca 2011; Bergstrand et al. 2015; Felbermayr and Steininger 2019; Glick 2017; Glick and Rose 2002, 2016; Larch et al. 2019b; Santos Silva and Tenreyro 2010.

Table 2.2: The effects of economic agreements on aviation demand

Studies: Authors (Year)	Bi- or multinational agreements	Scope	Impact on demand	
			Air passengers	Air cargo
Micco and Serebrisky (2006)	ASA / OSA	To the US		12%
Yamaguchi (2008)	ASA / OSA	From the US		1.3%
Hwang and Shiao (2011)	ASA / OSA	Taiwan-US		10%
Geloso Grosso and Shepherd (2011)	ASA / OSA (ALI)	APEC		1.4%
Piermartini and Rousová (2013)	ASA / OSA (ALI)	Worldwide	0.5%; 5%; 10%	
Cristea et al. (2015)	ASA / OSA (ALI)	Middle East[1]	2% - 3%	
Gong et al. (2018)	ASA / OSA	From/to China		80%
Oum et al. (2019)	ASA / OSA	From/to Canada	12.5%	9.4%; 19%
Abate and Christidis (2020)	BASA	From/to EU-28	28%	
Alexander and Merkert (2020)	FTA	From/to US		50%

Source: Own compilation. (1) = Including the countries Turkey, Egypt, Jordan, Saudi Arabia, Tunisia and UAE.

2.3. The effect of environmental instruments on aviation

Emissions from aviation are considered to be negative external effects, or negative externalities. From a political and economic perspective, two forms of policy instruments exist to control for negative external effects. These are different command and control instruments and market-based instruments.[13] Command and control instruments limit the amount of pollution or even prohibit the emission of a certain pollutant by setting either technology standards or performance standards (Buchholz and Rübbelke 2019; Perman et al. 2011; Tietenberg 2020). Technology and performance standards for airplanes and airplane engines are set for example by the International Civil Aviation Organization (ICAO) and the European Union's legislation. This may include standards for airplane designs that improve fuel efficiency or standards that cover the amount of emitted particulate matters by aircraft engines (EASA 2016, 2019). Hence in economics, command and control instruments are

[13] For the fundamentals on environmental economics and instruments to control for external effects like pollution and emissions, see for example - among others - Perman et al.2011 or Tietenberg 2020.

considered to be only second-best options. These instruments impose uniformity on companies and due to this lack the flexibility of choosing company-individual options to reduce emissions. Therefore, command and control instruments are usually not cost-efficient (Buchholz and Rübbelke 2019).

Market-based instruments are the favored instruments in economics to control for negative externalities. The two basic market-based instruments are emissions charges or taxes - named Pigouvian tax after Pigou (1920) - and cap-and-trade emissions trading systems (ETS). These instruments correct the market failure that arises due to missing-property rights of the environment and the missing monetary compensation for negative external effects. Market-based instruments therefore reduce or avoid pollution by placing a cost on the external effect. Moreover, the market mechanism should lead to the use of more energy efficient technologies. Therefore the price for the emissions - in form of taxes or emissions certificates - should be so high that firms have an incentive to invest in emissions avoiding technologies. This is true, if the marginal abatement costs equal the price that is given to the external effect (Perman et al. 2011; Tietenberg 2020). Criteria to evaluate the proficiency of market-based instruments are mostly their economic efficiency, the effectiveness of reducing emissions and the political feasibility. Since air passenger taxes or charges, for example, are usually not connected to the consumption of fuel or to the volume of emitted CO_2 emissions, a CO_2 or kerosene tax or an ETS is generally the better option with regards to the effectiveness of giving incentives to reduce emissions, for both customers and producers (Endres 2013; Perman et al. 2011; Sturm and Vogt 2018).

Regarding the aviation sector, the Convention on International Civil Aviation of 1944 limits charges on international aviation (ICAO 1944). As a result, international flights are generally exempted from value added taxes (VAT) or kerosene taxes. Some countries charge a VAT for domestic flights, but only a few countries tax kerosene at all. To account for the limited taxation on aviation, countries apply different national charges that are allowed under the

Chicago Convention.[14] These are mostly flight departure or air passenger taxes with a fixed amount per passenger. Table 2.3 shows an overview on taxes and charges covering aviation in the EU-27 countries and the United Kingdom. Only a few countries have installed national emissions trading systems, some of which cover the aviation sector such as the ETS in New Zealand, South Korea and in some Chinese provinces (ICAP 2020; World Bank 2019). However, since greenhouse gas emissions have a global impact no matter where emitted, there is a need for a multinational solution. Moreover, a global or at least multinational solution covers issues such as distortions of competition and carbon leakage. ”Carbon leakage refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints” (European Commission 2021b). This was the rationale behind the Kyoto Protocol and the implementation of the European Union Emissions Trading System (EU ETS) of 2005. The EU ETS currently represents the only existing multinational emissions trading system. Table 2.4 shows an overview of different ETSs worldwide that are currently in force and that include the aviation sector.

[14] The convention on International Civil Aviation of 1944 is also called *Chicago Convention* since the convention took place in Chicago.

Table 2.3: Taxes and charges covering aviation, EU-27 + UK

Type of tax	Explanation	Examples EU-27 + UK
Passenger ticket tax	Passenger ticket taxes are taxes imposed on **all air passengers** and levied per person. The national or regional government receives the revenues.	***Several countries*** UK: Air Passenger Duty (APD), France: Civil Aviation Tax, Germany: Air Transport Tax (Luftverkehrabgabe).
Value added tax (VAT)	European countries follow the ICAO's guidelines by not charging VAT on international air transport. Most European countries do charge VAT on **domestic flights**. The national or regional government receives the revenues.	***Most countries*** (on domestic flights) Germany: 19%, Netherlands: 21%. Reduced rates: Sweden 6%.
Taxation on aircraft fuel	Kerosene is **exempt** from taxation as per EU Energy Tax Directive for commercial operations, although it would be possible to tax intra-EU and domestic flights.	***No country*** (only effective in some non- EU countries such as Canada or the US for example)
Environmental tax	Mostly noise and emission charges **levied by airports**. The airports also receive the revenues.	***Several countries*** Austria, Germany, France for example
Taxes on air cargo	Taxes covering commercial passenger aviation that also apply to air cargo.	***One country*** French civil aviation tax is levied also on air freight

Sources: Based on European Commission 2019; Faber and Huigen 2018; Faber and O'Leary 2018.

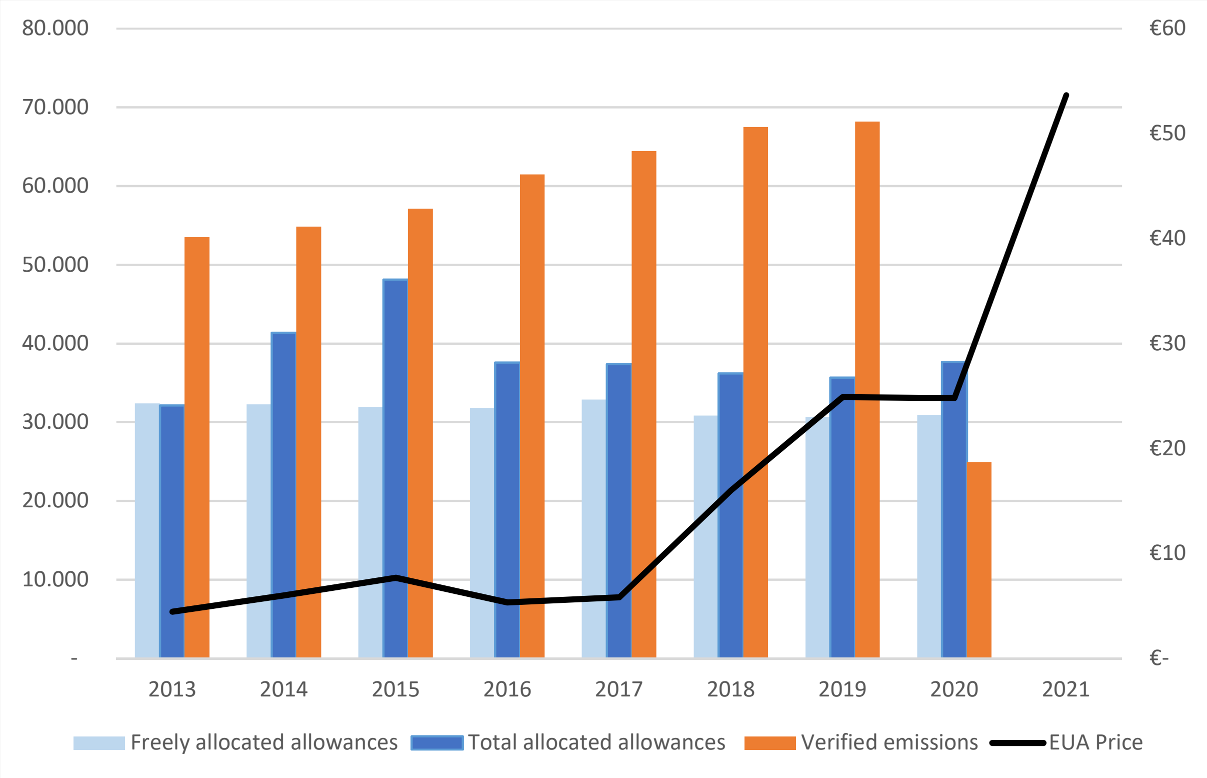
Table 2.4: Emissions Trading Systems (ETS) covering aviation, worldwide

Emissions Trading System	Covered scope	Operating since	Aviation included since
EU ETS	Domestic and Intra-EEA	2005	2012
Swiss ETS	Domestic and from/to EEA	2008	2020
New Zealand ETS	Domestic	2008	2008
Shanghai, Tianjin (China) ETS	Domestic	2013	2013
Korean ETS	Domestic	2015	2015
Fujian, Guangdong (China) ETS	Domestic	2016	2016
British ETS	Domestic and from/to EEA	2021	2021

Source: Based on ICAP 2020.

The European Emissions Trading System (EU ETS) started operations in 2005 and covers the countries of the EEA. In the beginning, the EU ETS incorporated only energy intensive sectors and energy suppliers. In 2012, aviation, including air passenger services and air cargo services, was added to the EU ETS. In the first year, all flights departing and landing in the EEA were covered by the EU ETS. However, the geographical scope was changed in 2013 to the “reduced scope” only, including intra-EEA air traffic. At the time aviation was included into the EU ETS, the cost of the certificates (European Emissions Allowances, EUA) was about 7 EURO. Verified emissions from aviation under the scope of the EU ETS kept rising until the COVID-19 pandemic hit the sector. Until 2020, emissions from aviation surpassed the volume of certificates allocated to the aviation sector (free allowances and purchased allowances) (see Figure 2.1). Airlines therefore needed to purchase additional certificates from other sectors to fulfill their obligations, which are to hold certificates for each ton of emitted CO_2. In contrast to other sectors that are included in the EU ETS, the amount of freely allocated certificates for the aviation sector has up to now not been reduced and in practice, no cap on emissions exists since airlines can purchase additional certificates from other sectors on the EUA market (European Commission 2015, 2021c). Since 2017 the price of the certificates has been rising due to various improvements in the design of the EU ETS but also due to strengthened political pressure on reducing GHG emissions. In past years, some changes of the EU ETS were implemented such as the installation of a market stability reserve (MSR) that led to a reduction in the supply of EU ETS certificates (European Commission 2021c). Moreover, by announcing the European Green Deal in 2020 and communicating the Fit-for-55 strategy in 2021, more pressure has been put on all industry sectors by the European Commission to enhance their decarbonization process (European Commission 2021a). With regards to the aviation sector, the number of free allowances within the EU ETS might be reduced to zero until 2027 according to the EU’s proposals.

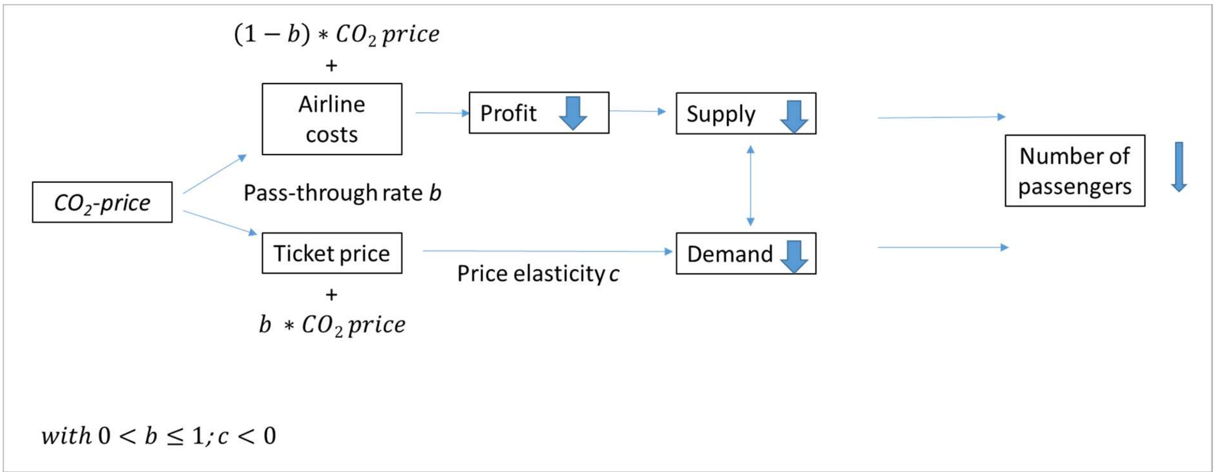
Figure 2.1: The EU ETS and aviation



Sources: EEA 2021; Sandbag Climate Campaign CIC 2021. Notes: No data on emissions from 2021 available as of 28.01.2022; Emissions are given in 1,000 tCO_2; EUA = European Emissions Allowance.

Theoretically, the effect of environmental policies on aviation demand can be displayed quite simply. Environmental charges that are levied directly to the customer directly increase the ticket and end price. Negative price elasticities then enforce a reduction in aviation demand. Hence, with regard to emissions trading systems, the case is different since the airlines – instead of the customers - purchase the emissions certificates on the certificate market. The airlines then have to decide how to handle the extra costs and to what extent these are passed on to the customer. Theoretical and empirical studies on that subject are not in consent on how airlines generally handle cost increases resulting from additional surcharges (European Commission 2019; Koopmans and Lieshout 2016). Koopmans and Lieshout argue that the pass-through rate greatly depends on the market form (monopoly, oligopoly, perfect competition) and on the type of cost increases (firm-specific or sector-wide). They see a pass-through of less than 50% for airline-specific costs, and pass-through rates of more than 50% for industry-wide costs. Most aviation markets can be characterized as an oligopoly and the costs from an ETS like the EU ETS, for example, would represent sector-wide costs. Concerning the strategic actions of airlines, most studies on that subject assume a Cournot- oligopoly, where firms compete for the quantities and then set the prices via yield management (Barbot et al. 2014; Brander and Zhang 1990; Koopmans and Lieshout 2016; Nava et al. 2018). It can therefore be assumed that in the case of environmental charges that are levied on the airlines – such as the EU ETS - the extra costs are passed-through to the customers up to 100%. The pass-through of the additional costs to the customer leads to a reduction in aviation demand. The amount of demand reduction depends on the level of the negative price elasticities (between -1.23 and-0.89, see Chapter 2.1). Figure 2.2 shows the aforementioned theoretical effects of a CO_2 price levied on airlines with the pass-through rate *b* (with $0<b\leq 1$) and the price elasticity *c* (with *c* <0). The effects that are shown are based on the assumption, that no alternative technology that saves CO_2 emissions is available.

Figure 2.2: Theoretical effects of a CO_2 price on aviation demand



Source: Own figure.

The effect of environmental charges on aviation demand has been analyzed in previous theoretical and empirical studies. Mayor and Tol (2007) analyze the impact of a price change of the Air Passenger Duty (APD) in the UK. They could not find significant overall effects on passenger numbers or emissions. They did conclude that shorter destinations would suffer from a higher price of the APD. By this, more distant destinations would gain customers since the ticket tax is levied with a fixed amount and does not depend on the distance. Lu (2009) modeled the impact of environmental charges on passenger numbers for different airline business models. Pagoni and Psaraki-Kalouptsidi (2016) used a game-theoretical approach to simulate reactions of airlines due to additional environmental costs. Both studies assumed that airlines passed costs on to airline passengers, which will lead to a reduction in air passenger numbers. Three recent papers and studies empirically analyzed the effects of environmental policies on aviation demand. Markham et al. (2018) analyzed the effect of a national carbon levy for Australia that also applied to the aviation sector. The authors could not find any effects on passenger numbers, but the levy was only in place for two years. Falk and Hagsten (2019) analyzed the effect of the flight departure tax that had been introduced in Austria and Germany in 2011. Their analysis reveals relatively high demand losses up to 9% in the first year and of 5% in each of the following years. The European Commission analyzed the economic impacts of different possible kinds of aviation taxes in a recent report called "Taxes in the field of aviation" for each of the EU countries (European Commission 2019). For Germany, for example, they calculated a reduction in demand of -16% due to introducing a VAT on international flights and a demand reduction of -12% due to a fuel tax on kerosene. Scheelhaase et al. (2021) analyzed the effect of a CO_2 price of 180 Euro per ton of CO_2. In the scenario that assumed a 100% pass-on to customers, demand reductions ranged between -11% for the shortest distance analyzed and -33% for the furthest destination.

Most studies on the effects of the EU ETS on aviation were written prior to the inclusion into the existing EU ETS in 2012. These studies forecast the effects with different data simulation methods. Apart from demand and environmental effects in terms of CO_2 reductions, various other economic effects on the aviation sector such as effects on costs, revenue, efficiency and the competitive situation were analyzed. Very early commissioned feasibility studies worked to evaluate different policy options and how to integrate aviation into the EU ETS (Boon et al. 2007; European Commission 2006; PWC 2005; Wit et al. 2005). Further papers simulated environmental and economic impacts of the EU ETS on aviation (Anger 2010; Faber and Huigen 2018; Malina et al. 2012; Mendes and Santos 2008; Morrell 2007; Peter et al. 2016; Scheelhaase and Grimme 2007; Scheelhaase et al. 2010; Vespermann and Wald 2011; Vespermann and Wittmer 2011). All studies assumed a 100% pass-through of the additional costs to the customers from purchasing allowances. The simulated demand reductions for the intra-EEA scope range between -0.1% and -1.3% compared to a Business as usual (BAU) scenario of 4% demand growth p.a. (European Commission 2006; Peter et al. 2016;

Scheelhaase et al. 2010; Scheelhaase and Grimme 2007; Wit et al. 2005). Few papers were published after the inclusion of aviation into the EU ETS (Cui et al. 2017; Cui et al. 2016; Li et al. 2016; Meleo et al. 2016; Nava et al. 2018), but none of the published studies tackled the reaction of demand due to the EU ETS. Table 2.5 shows an overview of the mentioned papers that simulated the effects of the EU ETS on aviation demand.

Table 2.5: Simulation studies on the effect of the EU ETS and aviation demand (air passengers)

No.	Authors	Year	Period	Geographical scope	Initial allocation method	Pass-through of costs	**Effects on BAU demand** *(depending on geographical scope and EUA price)*								
							BAU air traffic growth p.a.	**Intra-EEA flights**		**Departing flights from EEA**			**Departing and arriving flights from/to EEA**		
1	Wit et al.	2005	2008-2012	1: Intra-EEA flights 2: Departing flights from EEA 3: EEA airspace	Baseline, Benchmarking, Auctioning	0% or 100% for free allowances, 100% for purchased allowances	5%	**10 €**	**30 €**	**10 €**		**30 €**	**10 €**		**30 €**
								-0.1%; -0.5%	-0.2%; -1.3%	-0.1%; -0.7%		-0.4%; -2.1%	-0.5%		-1.4%
2	PWC	2005	2008-2020	Departing flights from EEA airports	Grandfathering, Auctioning	100%	4.2%			**20 €**		**40 €**			
										-0.08%; *-0.13%*		*-0.17%;* *-0.28%*			
3	European Commission	2006	2005-2020	1: Intra-EEA flights 2: Departing flights from EEA 3: Arriving and departing flights to/from EEA	Auctioning	100%	depending on region and timeframe	***6 €***	***30 €***	***6 €***		***30 €***	***6 €***		***30 €***
								-0.12%; -0.16%	-0.6%; -0.76%	-0.3%; -0.4%		-1.5%; -1.9%	-0.48%; -0.64%		-2.4%; -3.04%
4	Boon et al.	2007	2012	All flights departing from and arriving at EEA airports	Auctioning and benchmarking, auctioning	47,3% - 100%	n/a						**15 €**		**45 €**
													-0.3%; -1.6%		-0.9%; -4.5%
5	Scheelhaase and Grimme	2007	2008 / 2012	1. Intra-EEA flights 2. All flights departing from and arriving at EEA airports	Grandfathering, benchmarking	100% for purchased allowances, 0% for free allowances	2% - 15% (Depending on airline)	**15 €**	**20 €**				**30 €**		
								2008: LCC: -0.19%/-0.07%; NWC: 0% 2012: LCC: -0.78%/-0.29%; NWC -0.02%/-0.01%	2008: LCC: /; NWC: -0.37%/-0.15% 2012: LCC: /; NWC: -0.29%/-0.12%				2008: LCC: -2.43%/-0.52%; NWC: -0.56%/-0.16% 2012: LCC: -5.56%/-1.20%; NWC -1.51%/-0.44%		
6	Mendes and Santos	2008	2013 - 2017	All flights departing from EEA airports	Auctioning, Grandfathering,	100%	4%			**7 €**	**15 €**	**30 €**			
										-2.01% - -0.01%	-4.31% - -0.03%	-8.63% - -0.06%			
7	Anger	2010	2020	All flights departing from and arriving at EEA airports	85% allocated free, 15% auctioning	100%	2.5%						**5 €**	**20 €**	**40 €**
													-0.04%	-0.54%	0.98%

No.	Authors	Year	Period	Geographical scope	Initial allocation method	Pass-through of costs	Effects on BAU demand *(depending on geographical scope and EUA price)*			
							BAU air traffic growth p.a.	Intra-EEA flights	Departing flights from EEA	Departing and arriving flights from/to EEA
8	Scheelhaase et al.	2010	2012	All flights departing from and arriving at EEA airports	85% allocated free, 15% auctioning	100%	4%			**20 €** Calculated for different airline companies, about -2%
9	Faber and Brinke	2011	2013-2020	All flights departing from and arriving at EEA airports	85% allocated free, 15% auctioning	100%	n/a			**10 €**: -0.5% **30 €**: -2.4% **50 €**: -2.6%
10	Vespermann and Wald	2011	2009-2020	All flights departing from and arriving at EEA airports	85% allocated free, 15% auctioning	100%	depending on region and timeframe			**25 €** -0.8%
11	Vespermann and Wittmer	2011	2009-2020	All flights departing from and arriving at EEA airports	85% allocated free, 15% auctioning	100%	depending on region and timeframe			**25 €** -1.25 % for Lufthansa Airlines
12	Malina et al.	2012	2012-2020	All flights departing from and arriving at EEA airports	Grandfathering	0-100% for purchased and for free allowances	3.65%			**20 $ (2012) - 27 $ (2020)** -0.03% to -0.00% for US carriers
13	Peter et al.	2016	2012	1: Intra-EEA flights 2: EEA airspace	Grandfathering	0% or 100% for free allowances, 100% for purchased allowances	3.9%	**25 €** LCC: -2.8%/-0.8% NWC.: -0.4%/-0.1%		**25 €** LCC: -4%/-1.1% NWC: -1.7%/-0.55%

Sources: Based on Anger 2010; Boon et al. 2007; Brinke and Faber 2011; European Commission 2006; Malina et al. 2012; Mendes and Santos 2008; Peter et al. 2016; PWC 2005; Scheelhaase et al. 2010; Scheelhaase and Grimme 2007; Vespermann and Wald 2011; Vespermann and Wittmer 2011; Wit et al. 2005.

3. Methodology

3.1. The gravity model

The gravity model is considered to be the workhorse of empirical data analysis in the area of international trade economics (Baier and Bergstrand 2007; Head and Mayer 2014; Yotov et al. 2016). Initially, the gravity model was more or less an intuitive equation based on Newton's law of universal gravitation. This model stated that the attraction of two entities depends positively on their masses and negatively on the distance between them (Anderson 2011; Tinbergen 1962). Early beginnings of the success of the gravity model in trade economics trace back to the 1960's when Tinbergen (1962) analyzed international trade flows by formulating a basic gravity model. Since the 1990s, this model has become the standard model in empirical trade economics (Head and Mayer 2014). Ravenstein had already formulated an economic gravity model in the field of migration economics in 1889. Equation (3.1.1) shows a basic cross section gravity model equation. X_{ij} represents the flow of goods or people between origin *i* and destination *j*. Y_i and E_j represent the factors of production at origin *i* and destination *j* such as, for example, the GDP. This mass of attraction is divided by the distance d_{ij} between the origin and destination (Anderson 2011). *i* and *j* can, for example, represent different countries, regions or cities.

$$X_{ij} = Y_i E_j \, / \, d_{ij}^2 \tag{3.1.1}$$

The gravity model usually not only includes GDP as a measure of size, and distance as a measure of trade costs, but also includes further control variables that impact bilateral trade or migration intensity, such as common language, common borders and colonial ties. The first gravity models were purely empirical models and are usually considered as "*atheoretical*" empirical models (Yotov et al. 2016). These lacking microfoundations were the basis of the main critiques raised by scientists against the gravity model for a long period. The model became more popular when different theoretical foundations were formulated that led to the rise of the so called *structural* gravity model. Since the seminal work by Anderson and van

Wincoop (AvW) and their structural specification of the gravity model of trade in 2003, so called *multilateral resistance terms (MRTs)* have been included into the model to account for multilateral but unobservable barriers to trade (Anderson and van Wincoop 2003). The merit of the paper was to show the importance of including MRTs into the gravity equation as the "theoretically appropriate average trade barriers" (Anderson and van Wincoop 2003). The coefficients of the determinants of trade flows would otherwise be biased (Anderson 2011; Anderson and van Wincoop 2003). By this, the traditional gravity model got its requested microfoundations. Baldwin and Taglioni (2007) even called not including MRTs into the gravity model the "Gold medal mistake". Equation (3.1.2) shows the theory-founded structural gravity model in a cross-section setting following Beverelli et al. (2018b). X_{ij} represents the bilateral trade or aviation flows between country *i* and country *j*, T_{ij} is a vector of determinants like distance, regional trade agreements, Y_i is the value of production of country *i* (exports from country i to country j) and E_j is the value of production of country *j* (imports to country i from country j). Π_i and P_j are the respective MRTs. Equation (3.1.3) shows the definition of the MRTs.

$$X_{ij} = T_{ij} \frac{Y_i \, E_j}{\Pi_i \, P_j} \tag{3.1.2}$$

$$\text{with } \Pi_i = \sum_j \frac{T_{ij} E_j}{P_j} \text{ and } P_j = \sum_i \frac{T_{ij} Y_i}{\Pi_i} \tag{3.1.3}$$

The common way of controlling for these multilateral resistance terms is to add fixed effects (FE) to the empirical model (Baldwin and Taglioni 2007; Fally 2015; Feenstra 2004; Larch et al. 2019b; Santos Silva and Tenreyro 2006, 2010). In a cross-section structural gravity model, country fixed effects should control for the country-specific (exporter/importer) and unobservable barriers to trade. Baier and Bergstrand (2007) enhanced the AvW-structural gravity model due to their concerns of possible endogeneity in the analysis of the effects of trade policies on trade flows. They showed that the inclusion of time-varying country fixed effects and additional time-invariant country-pair fixed effects into the model in a panel-data framework controls for possible matters of endogeneity. Country-pair fixed effects control for potential endogeneity by absorbing most of the linkages between the endogenous policy variables and the remainder error term (Yotov et al. 2016). In addition, the country-pair fixed effects control for any unobservable bilateral resistances to trade. Further developments concerning theoretical and empirical gravity model specifications were advanced in the just recent years. New structural gravity models include intranational (domestic) trade flows and so called “international border dummies” (Bergstrand et al. 2015; Larch et al. 2019a; Yotov et al. 2016). The rationale for the inclusion of domestic flows is to capture trade diversions from intranational to international trade flows that may arise due to RTAs. Moreover, in consistence with theory, consumers choose between domestic goods and international goods. The international border dummies should control for globalization effects such as technology and innovations and represent the average declining international trade costs relative to intranational trade costs (Bergstrand et al. 2015). Finally, the use of panel data should generally be preferred over cross-section data, since it is considered to lead to an improved estimation efficiency (Olivero and Yotov 2012; Yotov et al. 2016).

However, the practice of adding fixed effects to the gravity model to account for multilateral resistance terms has also been criticized by several authors, especially in the case of estimating the effects of policy dummy variables. Hornok (2013) argues that by adding exporter-/importer-time (country-time) fixed effects to the model, the identification of the effects of several policy dummies (like EU, EURO, WTO) cannot be estimated precisely, since the dummy variables may run perfectly collinear with the fixed effects. Cipollina et al. (2016) even argue that adding fixed effects to the gravity model leads to an overestimation of the effects of the policy dummy variables. And Stack (2009) points out that by including time-varying fixed effects and time-invariant country-pair (exporter-importer) fixed effects, other important explanatory variables are dropped from the regressions. Relevant information may be excluded from the estimation due to this. Other options exist to control for the MRTs, but these are less convenient than adding fixed effects to an empirical model. Based on Head and Ries (2001) and Novy (2011), Hornok (2013) proposes adding a time-varying trade cost index instead of fixed effects. Moreover, before the use of fixed effects became popular, authors also constructed so-called *remoteness indices* to approximate the MRTs (Yotov et al. 2016).

Gravity equations in aviation economics had already been formulated for air travel demand analysis and forecasting in the US in the 1950s (Harvey 1951; Matsumoto 2007; Richmond 1955). Harvey (1951) had adopted Newton's law of universal gravitation and related the demand for air travel to the product of the population of two cities divided by their distance. Richmond (1955) had added a wide list of variables to the simple gravity equation (airfreight numbers, mail and telephone contacts, rail passengers). Other variables included into the gravity model in aviation economics are, for example, income levels, education level, different employment measures, air fare levels, travel time and service frequencies (Grosche et al., 2007; Matsumoto, 2007). Cristea et al. (2015) applied variables such as geographic area, WTO membership and differences in annual temperatures. Policy variables that are included in a gravity model as a main variable of interest primarily concern air travel liberalization issues, such as OSAs and ASAs (Piermartini and Rousová 2013; Zhang et al. 2018). Up to now, most studies in the area of aviation economics apply the atheoretical version of the gravity model. Due to this, accounting for multilateral resistance terms has so far not been frequently considered in aviation economics, and only a few papers have included fixed effects into the gravity model specification; see Cristea et al. 2015; Geloso Grosso and Shepherd 2011; Piermartini and Rousová 2013; Zhang et al. 2018. Of these studies, Geloso Grosso and Shepherd (2011), for example, estimate the effects of the Air Liberalization Index with a structural gravity model in a cross-section model with the inclusion of time-invariant country fixed effects.

3.2. Estimation techniques

Originally, gravity models were – and often still are - estimated using the ordinary least squares (OLS) linear estimator (Head and Mayer 2014; Yotov et al. 2016). The estimation of a linear regression model therefore comes with basic assumptions that need to be fulfilled by the dataset. Well simplified and without reproducing the respective formulas, these assumptions are the following: Expected value of the error term = 0, no heteroscedasticity, no autocorrelation, no measurement error, no multicollinearity, linear relationship of X and Y, no omitted variables bias, and no endogeneity (McDaniel 2019; Verbeek 2008; Wooldridge 2010, 2016).

Assumptions 1-3 are the Gauss-Markov assumptions and apply to the error term. If the assumptions are met, OLS is considered being the best linear unbiased estimator. The challenge with trade and aviation datasets is that they usually would not fulfill the assumption of homoscedasticity (Santos Silva and Tenreyro 2006; Yotov et al. 2016). To check for heteroscedasticity, the Breusch-Pagan / Cook-Weisberg test and the White's test can be performed. In both cases, if the null hypothesis is rejected (p-value=0), the data used is heteroscedastic. The issue of heteroscedasticity was raised by a seminal paper by Santos Silva and Tenreyro (2006). The authors show that the OLS estimator brings inconsistent results in the presence of heteroscedasticity. In order to avoid inconsistent estimates in the presence of heteroscedasticity, the authors advocate against a log-linearized estimation and for the poisson quasi-maximum likelihood – also called - poisson pseudo-maximum likelihood estimation (PPML).[15] PPML – instead of the maximum likelihood estimator - does not necessitate the data to follow a normal distribution (Fally 2015; Santos Silva and Tenreyro 2006). Subsequent studies also proved the superiority of PPML over OLS in gravity model estimations. See for example Bergstrand et al. 2015; Correia et al. 2020; Fally 2015; Larch et al. 2019b; Santos Silva and Tenreyro 2010, 2011; Yotov et al. 2016.

Moreover, poisson pseudo-maximum likelihood estimations are robust to many zero flows since the dependent variables is not log-linearized. Most trade datasets consist of many zero flows with regards to the dependent variable. This could either be due to missing data, but also due to the fact that there simply is no trade between two countries. Hence, with the common practice of using the logarithmic form of the dependent variable, the observations with zero flows will be dropped from the regression. A common practice to keep zero flows is to add +1 to the dependent variable; this is therefore not recommended for gravity model

[15] Sometimes, the poisson pseudo-maximum likelihood estimation is referred to as the poisson quasi-maximum likelihood estimator like in Wooldridge 2016.

estimations since this may bias the interpretation of the elasticities of the regressions coefficients (Head and Mayer 2014; Yotov et al. 2016). Another problem with gravity models is the possible endogeneity of policy variables as for example RTAs. Concerning the issue of possible matters of endogeneity, this can be solved - as shown in the previous chapter - by including country-pair fixed effects to the model.

Within trade economics, most scholars now estimate gravity models with the poisson pseudo-maximum likelihood (PPML) estimator, which can be seen as the current standard method for gravity model estimations. Estimating a structural gravity model that includes time-varying country fixed effects and time-invariant country-pair effects with PPML therefore now constitutes the "gold standard" in econometric trade analysis. Computational advances in just recent years make it possible to estimate such dynamic gravity models with a full set of fixed effects and with PPML (Correia et al. 2020; Larch et al. 2019b).[16] With regards to test statistics, the coefficient of determination (R^2) or the pseudo R^2 can also be applied with PPML. Although the value of the R^2 is usually quite high (> 0.9) and therefore does not reveal as much information as for OLS. Therefore, in the case of PPML, the Regression Equation Specification Error Test (RESET) can be applied. The model is considered to suffer from misspecification if the test shows a $p < 0.05$ (5% significance level). A misspecification would mean that relevant variables have been omitted from the model (Santos Silva and Tenreyro 2006; Verbeek 2008; Wooldridge 2016).

Equations (3.2.1), (3.2.2) and (3.2.3) represent various regression estimation equations for a panel data set based on the afore described different gravity model specifications and based on Yotov et al. (2016). Equation (3.2.1) shows a traditional gravity OLS estimation without controlling for the MRTs. Apart from the GDP of the destination and origin ($Y_{it}\ and\ Y_{jt}$) and the distance between country i and j and the standard gravity model variables, the equation includes colonial ties, same language and common border ($GRAVITY_{ij}$). Moreover, the equation includes a dummy policy variable that applies to trade/aviation flows of the

[16] Correia et al. 2020 programmed a special STATA command to estimate gravity model with high-dimensional fixed effects either with OLS (reghdfe) or PPML (ppmlhdfe).

respective countries *i* and *j*. This could either be a trade or air service agreement or an environmental policy variable $(policy_{ijt})$. Finally, the equation includes the error term ε_{ijt}. The dependent variable and the continuous control variables are log-linearized.

$$ln\, X_{ijt} = \beta_0 + \beta_1\, ln\, Y_{it} + \beta_2\, ln\, Y_{jt} + \beta_3\, ln\, dist_{ij} + \sum_{k=4}^{6} \beta_k\, GRAVITY_{ij} + \beta_7\, policy_{ijt} + \varepsilon_{ijt}$$

(3.2.1)

Equation (3.2.2) shows a structural gravity OLS estimation that controls for the MRTs and for endogeneity by including country-time and country-pair fixed effects. By this, the time-varying country-specific variables (GDP) and the time-invariant country-pair-specific variables (distance, colonial ties common language, and common border) will be dropped from the regressions. λ_{it} are the country-time fixed effects of country i, μ_{jt} are the country-time fixed effects of country j and ν_{ij} are the country-pair fixed effects.

$$ln\, X_{ijt} = \beta_0 + \beta_1\, policy_{ijt} + \lambda_{it} + \mu_{jt} + \nu_{ij} + \varepsilon_{ijt}$$

(3.2.2)

Finally, Equation (3.2.3) shows the PPML regression equation controlling for MRTs in form of fixed effects. The PPML equation is given in exponential and multiplicative form and the dependent variable is kept in values.

$$X_{ijt} = exp\left[\beta_1\, policy_{ijt} + \lambda_{it} + \mu_{jt} + \nu_{ij}\right] + \varepsilon_{ijt}$$

(3.2.3)

New advances in the use of statistical software now make it possible, to estimate dynamic structural gravity models that include a full set of fixed effects. Correia et al. (2020) recently programmed a PPML Stata command called *ppmlhdfe*:

Example of ppmlhdfe Stata command:

ppmlhdfe trade policy1 policy2, absorb (iso_o_year iso_d_year country_pair) vce(cluster country_pair)

(with country-time and country-pair fixed effects, standard errors clustered by country-pair)

With regard to estimations methods of gravity models in the area of aviation economics, ordinary least squares (OLS) regression is commonly used for cross-section estimations (Boonekamp et al. 2018; Grosche et al. 2007; Hazledine 2009). Panel data gravity models are encountered less frequently. Zhang and Zhang (2016), for example, estimate a panel dataset with a panel fixed effects and panel random effects model and Hazledine (2017) with (pooled) OLS. More recently, the poisson pseudo-maximum likelihood (PPML) estimation has also been applied to aviation economics (Cristea et al. 2015; Geloso Grosso and Shepherd 2011; Piermartini and Rousová 2013; Zhang et al. 2018).

3.3. Data sources

Comprehensive data on international and intranational air cargo flows and air passenger flows on a country-pair basis is offered by Eurostat. International air cargo and air passenger numbers include intra-EU traffic numbers as well as extra-EU traffic. The time range in Eurostat covers the years since 1993, but comprehensive data is only available from the beginning of the 2000s. Other aviation specific data sources like for example Sabre are commercial databases and data is not offered free of charge. In Eurostat, the unit of measure of air cargo flows is 1,000 tons of freight and mail, the unit of measure with regards to passenger flows is the number of passengers. Eurostat distinguishes between passengers on board and passengers carried and between freight and mail on board and freight and mail loaded and unloaded. To only count passengers or freight that originate and end in/at the respective countries, passengers carried and mail and freight loaded or unloaded should be taken. According to Eurostat, passengers carried refer to “All passengers on a particular flight (with one flight number) counted once only and not repeatedly on each individual stage of that flight." and freight and mail loaded and unloaded refers to "All freight and mail loaded onto or unloaded from an aircraft." (Eurostat 2022). The measure *passengers carried* therefore includes all passengers on a particular flight counted only once on each individual stage of that flight. To account properly for an estimation with country fixed effects, unilateral flows should be used instead of bilateral flows.

Data on the geo-economic gravity model variables like GDP, GDP per capita or population size is offered by various official data sources. These mainly include the Word Development Indicators database by the World Bank and the International Financial Statistics database by the International Monetary Fund (IMF). This also applies to other country-specific and time-variant economic indicators like the consumer price index as a possible additional gravity model variable. Temperature differences between countries are also considered as geo-economic gravity model variables. Average temperature per country data is offered by the World Bank's Climate Change Knowledge Portal. Monthly average kerosene prices per gallon in US dollars given by the U.S. Energy Information Administration (EIA).

The standard gravity model variables distance, colonial ties, common borders and common language can be taken from the CEPII gravity dataset (CEPII 2011). Data on policy variables that are relevant for air transport or trade flows may stem from various sources. The information on EU, Schengen and Euro membership can be taken from the respective official sources like the European Commission for example. Information on RTAs that apply between countries is offered by the CEPII gravity dataset as well as by Mario Larch's Regional Trade Agreements Database. RTAs capture all multilateral and bilateral regional trade agreements as notified to the WTO (Larch, 2020). The information on the Air Liberalization Index (ALI) is offered by the WTO's Air Services Agreements Projector (WTO, 2011a). If possible, in addition to policy dummy variables, the actual cost of a policy measurement should be taken. This is possible for cost related policy measures in the field of environmental charges for example. This applies to the EU ETS which can be displayed with a policy dummy variable taking the value of 1 if the EU ETS applies between the respective countries. Or - as in the case of the EU ETS – the precise cost information can be taken instead of the dummy variable. Daily EU ETS allowance prices are available for example from the Sandbag Climate Campaign CIC (Sandbag

Climate Campaign CIC 2020) or from the Ember climate organization. Table 3.1 summarizes the just mentioned data sources for aviation specific gravity modeling.

Table 3.1: Data sources for aviation specific gravity modelling

Data	Database	Scope	Link
Air transport numbers (Air passengers and air freight and mail volumes)	Eurostat (Tables: avia_gonc, avia_goincc, avia_goexcc, avia_panc, avia_paincc, avia_paexcc)	From/to and within Europe	https://ec.europa.eu/eurostat/data/database
Geo-economic data (GDP, GDP per capita, population size, consumer price index)	Word Development Indicators database by the World Bank International Financial Statistics by the International Monetary Fund (IMF) Gravity database by CEPII	Worldwide	https://databank.worldbank.org/source/world-development-indicators https://data.imf.org/?sk=4c514d48-b6ba-49ed-8ab9-52b0c1a0179b http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp
Average annual temperatures	World Bank's Climate Change Knowledge Portal	Worldwide	https://climateknowledgeportal.worldbank.org/
Time-invariant gravity model variables (distance, common language, common border, colonial ties)	GeoDist database by CEPII Language database by CEPII	Worldwide	http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp
Kerosene prices	U.S. Energy Information Administration	In US dollars	https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm
Air Liberalization Index (ALI)	WTO's Air Services Agreements Projector	Worldwide	https://www.wto.org/asap/index.html
Regional trade agreements (RTA)	Gravity database by CEPII Mario Larch's Regional Trade Agreements Database	Worldwide	http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp https://www.ewf.uni-bayreuth.de/en/research/RTA-data/index.html
Environmental instruments (EU ETS)	Ember - Daily Carbon Prices Sandbag - CO2 emission allowance	In Euro	https://ember-climate.org/data/carbon-price-viewer/ https://sandbag.be/index.php/carbon-price-viewer/

Notes: All information as of February 2022. For a table including trade gravity model data sources see Yotov et al. (2016).

4. Empirical studies

4.1. The determinants of air cargo flows and the role of multinational agreements: An empirical comparison with trade and air passenger flows

Published as:[17]

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[17] The text of the paper in this thesis includes some of the robustness checks in the text rather than in the Appendix for ease of reading.

[18] Sources: https://abdc.edu.au/research/abdc-journal-quality-list/ and https://jcr-clarivate-com.eaccess.ub.tum.de/jcr/home as of 06.02.2022.

Abstract

Air cargo accounts for less than 1% of the total trade volume worldwide, but when measured in value, airfreight makes up about 35% of all trade. In the past decade, total air cargo volumes of the EU countries have been rising constantly at an average rate of 2.2% p.a. However, during that same period, total trade and air passenger numbers both rose by an average of 4.6% each year. Up to now, scholars have analyzed the determinants of air cargo flows to a much lesser degree than they have analyzed the determinants of total trade flows. Therefore, this paper analyzes the effect of the standard gravity model variables and of various multinational agreements - namely the Euro, the European Union (EU), the Schengen Agreement, and other regional trade agreements (RTAs) - on the volume of air cargo flows. The dataset generated for this paper covers the years 1994 until 2016 and contains about 1,000 country-pairs in total. To compare the impacts, the dataset created for this analysis contains intra- and extra-European air cargo flows as well as data on air passenger and total trade flows. Methodology-wise, different dynamic structural gravity models are formulated and estimated with poisson pseudo-maximum likelihood (PPML). The results suggest that the impact of the analyzed multinational agreements on air cargo flows diverge completely from their impact on total trade flows - however the effects on air cargo flows are more similar to the effects on air passenger flows. The Euro affects air cargo flows and air passenger flows positively. The EU membership impacts trade and air passenger flows positively but has no significant effect on air cargo flows. A Schengen membership promotes air passenger numbers and the amount of air cargo flows between two countries. Other RTAs impact total trade, but not trade by air. As 50% of air cargo volumes are transported in passenger aircrafts, air cargo may depend too much on air passenger services in order to fully exploit the effects of RTAs as trade is able to do. By this, air cargo transportation services likely may not operate on the optimal set of routes. It may be necessary to foster air cargo network management that is more independent from air passenger transportation services. Methodology-wise, this paper used a structural gravity model including intranational flows, time-varying international border dummies, and origin-year, destination-year, and country-pair fixed effects to control for multilateral resistances, endogeneity, and globalization effects.

4.1.1. Introduction

Air cargo accounts for less than 1% of the total trade volume worldwide, but when measured in value, airfreight makes up about 35% of all trade (IATA 2015). Airplanes transport high value goods in particular, such as consumer electronics, pharmaceuticals, vaccines, and medical instruments. Transport of these products necessitates high quality and security standards, both in the air and during loading and unloading at the airports. Moreover, since transportation by air is much faster than ground transportation, aircrafts are the favored mode of transport in the case of valuable and perishable freight. In the past decade, total air cargo volumes of the EU countries have been rising constantly at an average rate of 2.2% p.a. However, during that same period, total trade rose by an average of 4.6% p.a. In addition, the number of passengers transported by air has also increased at an average rate of over 4% each year.[19] Air cargo and air passenger transportation are linked, since these air services often operate on the same routes and use the same infrastructure, or even the same airplanes. Passenger planes transport half of all transported airfreight in their bellies.

Up to now, scholars have analyzed the determinants of air cargo flows to a much lesser degree than they have analyzed the determinants of total trade flows. In the area of trade economics, empirical studies typically investigate the determinants of bilateral trade flows by applying a gravity model approach. The gravity model is an economic model that successfully explores the amount of spatial interaction between countries, regions, or cities. This model relates to Newton's law of universal gravitation and indicates that the attraction between two entities depends positively upon the size of them and negatively upon the distance between them. In recent decades, the gravity model became the "workhorse" of international trade analysis (Anderson 2011; Head and Mayer 2014), but it also serves well in the analysis of air transportation flows, tourism flows, migration flows or foreign direct investment (FDI) flows between countries. The traditional gravity model predominately includes the variables GDP or

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[19] The growth rate figures are calculated with data derived from Eurostat on passenger numbers, air cargo volumes (in tons), and trade volumes (in Euros, deflated) between 2010 and 2019. That includes data within and to and from the EU-27 countries plus the United Kingdom. See Eurostat 2021a, 2021b.

GDP per capita, population, distance, and additional variables that represent bilateral trade costs (colonial ties, common borders, and same languages). Empirical evidence strongly supports that distance impacts bilateral trade negatively, whereas the other mentioned gravity model variables impact trade flows between two regions positively (Head and Mayer 2014). As to be shown in the following literature review section, up to now, no clear conclusion is possible with respect to the impact of the classical gravity model variables such as distance, common borders, colonial ties, or common languages on bilateral cargo flows. The impact of currency unions such as the Euro and economic integration unions such as the EU, the Schengen Agreement is even still unexplored. Previous studies have focused on single source countries or certain regional markets but have not analyzed air cargo flows within and to/from the European market.

Therefore, this paper intends to give four contributions, three empirical ones and one methodological one: Firstly, apart from the analysis of the impact of the classical gravity model variables on air cargo flows, this paper analyzes the impact of various multinational agreements on the volume of air cargo flows. These are the Euro, the EU, the Schengen Agreement, and other RTAs. Secondly, the dataset generated for this paper covers the years 1994 until 2016 for a sample of 16 EU countries including the UK, as both origin and destination, combined with 55 other European and worldwide destinations. Thirdly, this paper compares the effects of these variables on air cargo flows with their effect on trade flows and on passenger flows. Air cargo is – as explained in the beginning of this introductory section – closely related to air passenger services since it uses the same mode of transportation. Finally, concerning the methodological contribution, this paper applies the newest econometric advances from the area of trade econometrics to an analysis of air cargo flows. This contains the estimation of different structural gravity models with fixed effects in a panel-dataset setting. Moreover, the regressions are performed with the poisson pseudo-maximum likelihood (PPML) estimator.

The remainder of the paper is structured as follows: Section 4.1.2 covers the literature review on the effects of the gravity model variables and of multinational agreements on air cargo but also on trade and on air passenger flows. Section 4.1.3 gives background information on the methodology used in this paper and presents the latest structural gravity model specifications and estimation methods from the area of trade economics. Building on this, the empirical strategy of this paper is introduced. This includes the econometric gravity models to be estimated and the formulation of various robustness checks. Section 4.1.4 gives a data description, and section 4.1.5 presents the results of the gravity model estimations and the robustness checks. The paper closes with section 4.1.6, which provides the conclusions of this research.

4.1.2. Literature review

The roots of the gravity model in aviation economics trace back to the 1950s, when the model helped the investigation and forecasting of the volume of passenger flows within the U.S. (Harvey 1951). Since the 2000s, further studies have applied the gravity model to the analysis of passenger flows. Early contributions include Matsumoto (2004, 2007), Grosche et al. (2007) and Hazledine (2009). More recent contributions were made by Piermartini and Rousová (2013), Cristea et al. (2015), and Boonekamp et al. (2018). Moreover, tourism flows between countries have been analyzed within a gravity model framework by Keum (2010), Morley et al. (2014), and Galli et al. (2016). Gravity model applications for air cargo were developed much later than for passenger flows and research in that area is still scarce. Turner (2002) applied the gravity model to the analysis of domestic and international air cargo flows to and from Vancouver. Matsumoto (2004, 2007) combined a gravity model-based analysis of passenger flows with the analysis of air cargo flows, but only for a very restricted number of city-pairs. Further research also focused on air cargo flows within a certain geographic area (Alexander and Merkert 2017; Button et al. 2015; Geloso Grosso and Shepherd 2011) or to and from a specific origin country (Alexander and Merkert 2020; Gong et al. 2018; Hwang and Shiao 2011; Yamaguchi 2008).

According to previous empirical studies, GDP mainly affects air cargo and air passenger flows positively (Boonekamp et al. 2018; Cristea et al. 2015; Gong et al. 2018; Hwang and Shiao 2011; Turner 2002). The impact of the other gravity model variables is hence not clear.

Distance impacts cargo flows negatively, such as in trade economics (Button et al. 2015; Geloso Grosso and Shepherd 2011; Gong et al. 2018; Hwang and Shiao 2011), but some studies also indicate a positive impact of distance on air cargo flows (Matsumoto 2004, 2007; Turner 2002). Studies on air travel flows found a non-linear relationship between distance and the volume of passenger flows (Cristea et al. 2015). Moreover, previous studies give conflicting results concerning the impact of sharing a common border or a common language on airfreight (Alexander and Merkert 2020; Geloso Grosso and Shepherd 2011; Gong et al. 2018). Apart from the classical gravity model variables, additional air service-related variables such as price and frequency are often included in aviation economics gravity models (Boonekamp et al. 2018; Button et al. 2015; Geloso Grosso and Shepherd 2011). Whereas rising prices impact demand negatively, increased frequency impacts aviation demand positively.

The effect of regional trade agreements (RTAs) on trade flows is of great interest in trade economics. Decreasing or removing tariffs on international trade reduces trade costs and should influence bilateral trade flows positively. Several studies empirically confirmed the trade-enhancing effects of the EU, the Schengen Agreement, or of other RTAs. The effects are mostly positive and significant, although with different magnitudes of the estimated effects (Baier and Bergstrand 2007; Bergstrand et al. 2015; Cipollina and Salvatici 2010; Felbermayr et al. 2018; Felbermayr and Steininger 2019; Head and Mayer 2014). The famous debate on the effect of currency unions on trade has, however, been very controversial. The debate was initiated by Rose (2000), who concluded from his empirical research that trade is more than three times greater if countries share the same currency. According to further studies conducted by the same author, a common currency doubled bilateral trade and the Euro increased trade by up to 50% (Glick and Rose 2002, 2016). The results were put into perspective by newer studies, which could only find small and non-significant effects of the Euro on trade flows (Baldwin and Taglioni 2007; Larch et al. 2019b; Santos Silva and Tenreyro 2010). The differing results are mainly due to different gravity model specifications and estimation techniques.

Papers that have studied the effect of bi- or multinational agreements on air cargo flows have mainly examined the impact of air liberalization agreements such as Open Skies Agreements (OSA) and Air Service Agreements (ASA).[20] Hwang and Shiao (2011) analyzed international air cargo flows to and from Taiwan and included a dummy variable for a bilateral Open Skies Agreements (OSA) between Taiwan and the US. Their results show that the OSA increased the amount of transported goods by air between the two countries by about 10%. Geloso Grosso and Shepherd (2011) utilize the Aviation Liberalization Index (ALI) on a dataset that includes air cargo flows between the countries of the Asia-Pacific Economic Cooperation (APEC). The ALI is a constructed and expert-based index provided by the WTO that translates the openness of bi- or multilateral aviation markets into a continuous variable (WTO 2011a, 2011b). Overall, Geloso Grosso and Shepherd (2011) found positive but small effects of the ALI on air cargo flows. Hence, for manufactured goods transported by air, the effect of the ALI is positive and significant with a coefficient that translates into an effect of 1.4%. Gong et al. (2018) analyzed international air cargo flows to and from China and included a dummy that indicates the complete liberalization of air services from China to the US. The effect on exports from China to the US is positive, relatively high (above 80%), and significant. Cristea et al. (2015) and Piermartini and Rousová (2013) analyzed the effect of the Air Liberalization Index (ALI) on air passenger flows. Both studies found significant positive effects, although in a relatively small degree (between 1% and 3%). Alexander and Merkert (2020) analyzed the US international air freight market. They included a foreign trade agreement (FTA) dummy into their air cargo gravity model and found a strong positive and significant effect of FTAs on air cargo flows. Lastly, with regards to the effect of currency unions on air transport flows, two recent papers analyze the effect of the Euro on tourism flows (Saayman et al. 2016; Santana-Gallego et al. 2016). Both studies find relative strong and significant effects of the Euro on the amount of tourism flows between two countries. Saayman et al. (2016) additionally analyze the effect of

[20] Open Skies Agreements (OSA) and Air Service Agreements (ASA) are bi- or multinational agreements with the intention to reduce or completely remove barriers that apply to air travel or air transport services between the respective countries. The process of air liberalization started in the 1990's, and in 1992 the first international OSA signed was between the U.S. and the Netherlands. See Alexander and Merkert 2020; Piermartini and Rousová 2013.

economic integration agreements and conclude from their results, that the effect of the EU is weaker than the effect of a common currency.

4.1.3. Methodology and empirical model

This paper follows the structural gravity model approach, which can be traced back to Anderson and van Wincoop (2003). After much criticism that the traditional gravity model lacked theoretical foundations, Anderson and van Wincoopp (AvW) presented an approach of a micro-founded gravity model. The merit of the paper was to show the importance of including (unobservable) multilateral resistance terms (MRTs) in the gravity equation - the "theoretically appropriate average trade barrier" (Anderson 2011; Anderson and van Wincoop 2003). The common method to control for MRTs is to include inward and outward (exporter/importer or origin/destination) fixed effects in the gravity model (Baldwin and Taglioni 2007; Feenstra 2004). Baier and Bergstrand (2007) enhanced the AvW-structural gravity model due to their concerns of possible endogeneity in the analysis of the effects of trade policies on trade flows. They showed that in a panel-data model, the inclusion of time-varying origin and destination fixed effects and additional time-invariant country-pair fixed effects controls for possible matters of endogeneity.[21] In addition, the country-pair fixed effects control for any unobservable bilateral resistances to trade. In recent years there have been further developments concerning theoretical and empirical gravity model specifications. New structural gravity models also include intranational trade flows (Beverelli et al. 2018a; Heid et al. 2021) and time-varying international border dummies (Bergstrand et al. 2015; Larch et al. 2019a; Yotov et al. 2016). The rationale for including domestic flows is to capture trade diversions from intranational to international trade flows that may arise due to RTAs. Moreover, consistent with the theory, consumers choose between domestic goods and international goods. The international border dummies should control for globalization effects such as technology and innovations, and represent the average declining international trade costs relative to intranational trade costs (Bergstrand et al. 2015). Finally, it is now standard

[21] Country-pair fixed effects control for potential endogeneity by absorbing most of the linkages between the endogenous policy variables and the remainder error term. See Yotov et al. 2016.

practice within trade economics to run gravity models with the poisson pseudo-maximum likelihood (PPML) estimator. Santos Silva and Tenreyro (2006) and subsequent studies showed the superiority of the PPML estimator over OLS if the data used is heteroscedastic and contains many zero flows (Bergstrand et al. 2015; Correia et al. 2020; Fally 2015; Larch et al. 2019b; Santos Silva and Tenreyro 2010, 2011; Yotov et al. 2016).

Only a limited number of papers in the gravity model literature on the analysis of air cargo flows adopted these new theoretical and empirical advances from trade economics. Most recent papers still use linear estimators such as OLS (Alexander and Merkert 2020; Button et al. 2015; Gong et al. 2018; Hwang and Shiao 2011). In addition, fixed effects are only included in form of a linear Fixed Effects Estimator (FE-Model) and the traditional, a-theoretical gravity model predominates. Geloso Grosso and Shepherd (2011) stand in contrast, since they estimate the effects of the Air Liberalization Index (ALI) with a structural gravity model and PPML, although in a cross-section model and therefore with time invariant origin and destination fixed effects. Cristea et al. (2015) apply the Poisson estimator to a structural air passenger gravity model.

In this study, the different forms of the structural gravity model presented in the beginning of this section will be applied: Firstly, a basic structural gravity model is formulated that contains time-varying origin and destination fixed effects to control for the multinational resistance terms (MRTs). Equation 4.1.1 gives the respective gravity regression equation in PPML-form.

$$X_{ijt} = exp\left[\beta' GRAVITY_{ij} + \beta' AGRMNT_{ijt} + \lambda_{it} + \mu_{jt}\right] + \varepsilon_{ijt}$$

$with\ i \neq j$

(4.1.1)

The dependent variable X_{ijt} represents the volume of international air cargo flows (aircargo), trade flows (trade) and air passengers flows (airpax) between two countries i and j at time t. $GRAVITY_{ij}$ denotes a vector that includes the time-invariant gravity model variables distance (dist), colonial ties (COL), common language (COML) and common border (CONT). Since it is common practice with air passenger gravity models (Cristea et al. 2015; Piermartini and

Rousová 2013), the temperature differences between two countries (temp_diff) will also be included into the model. The temperature differences capture touristic relationships and higher temperature differences are expected to affect passenger flows positively. The policy variables are summarized by the vector $AGRMNT_{ijt}$. The vector includes the variables Euro (EURO), European Union (EU), Schengen Agreement (SCHENG) and other RTAs (OTHER_RTA). λ_{it} and μ_{jt} are the time-varying origin and destination fixed effects and ε_{ijt} denotes the error term.

Secondly, to account for domestic trade and aviation flows, the dependent variable X_{ijt} in equation (4.1.2) represents the volume of international *and* intranational air cargo, trade and air passenger flows. The international border dummy INTER differentiates intranational from international flows. This dummy variable takes the value of 1 if country i is not equal to country j and therefore an international border separates the two countries.

$$X_{ijt} = exp\left[\beta' GRAVITY_{ij} + \beta' AGRMNT_{ijt} + \beta' INTER_{ij} + \lambda_{it} + \mu_{jt}\right] + \varepsilon_{ijt} \tag{4.1.2}$$

Thirdly, to control for matters of endogeneity and following the structural gravity model approach by Baier and Bergstrand (2007), the first model (Equation (4.1.1)) is enhanced by additional country-pair fixed effects. Equation (4.1.3) gives the respective regression equation with time-varying origin and destination fixed effects and with the time-invariant country-pair fixed effects ν_{ij}.

$$X_{ijt} = exp\left[\beta' AGRMNT_{ijt} + \lambda_{it} + \mu_{jt} + \nu_{ij}\right] + \varepsilon_{ijt}$$

$$with\ i \neq j \tag{4.1.3}$$

Finally, to account for globalization effects, the fourth model will follow the new structural gravity model approach by Bergstrand et al. (2015). The model includes intranational flows and time-varying international border dummies. The international border dummies in equation (4) are defined as: $INTER_{ijt} = D_t * INTER_{ij}$, where D_t is a year dummy.

$$X_{ijt} = exp\left[\beta' AGRMNT_{ijt} + \beta' \sum_{t} INTER_{ijt} + \lambda_{it} + \mu_{jt} + \nu_{ij}\right] + \varepsilon_{ijt}$$

(4.1.4)

Some basic robustness checks will be performed on the impact of the policy variables on air cargo, trade, and passenger flows. The number of variables in the vector $AGRMNT_{ijt}$ will be reduced since the policy variables EU, EURO and SCHENG might interact with each other and influence the estimates. In addition, the geographical scope and time-range of the analysis will be changed. The regressions are therefore run on a sub dataset that only contains the intra-European country-pairs. To differentiate the time-range of the dataset, only observations from the years 1994 until 2011 will be analyzed. The Air Liberalization Index (ALI) - for which data is only available until 2011 - can thus be inserted into the model.

4.1.4. Data

Data on international and intranational air cargo flows and air passenger flows on a country-pair basis is retrieved from Eurostat (Eurostat 2020a). The unit of measure of air cargo flows is tons;[22] the unit of measure of passenger flows is the number of passengers carried. Data on international and intranational trade flows come from the WTO's Structural Gravity Manufacturing Sector Dataset and include trade flows of manufactured goods in nominal US dollars (Monteiro 2020). For usage in this dataset, the trade flows are deflated to real values with the GDP deflator from the World Bank's WDI Database (World Bank 2021). The dataset generated for this study covers the years 1994 until 2016[23] and contains about 1,000 country-pairs in total. The country-pairs include the 16 major EU countries as origin and destination countries, combined with each other and with another 14 European and 41 worldwide destinations. The countries taken into account as the major EU countries are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, the

[22] The numbers on air cargo flows from Eurostat include freight and mail transported by air.
[23] The WTO's Structural Gravity Manufacturing Sector Dataset currently contains data only until 2016.

Netherlands, Poland, Portugal, Spain, Sweden and the United Kingdom. Each country-pair is defined on a one-way basis and therefore represents the amount of unilateral air cargo, trade or passenger flows. There is always an observation for a counter country-pair. The control variables distance, colonial ties, common border and common language stem from the CEPII Gravity Database (CEPII 2011). Differences in yearly average temperatures are calculated from the World Bank's Climate Change Knowledge Portal (World Bank 2011).

Data on the policy variables stem from various sources. The information on EU, Schengen and Euro membership comes from the respective official sources.[24] The variable *OTHER_RTA* includes RTAs that apply to extra-EU aviation or trade flows. The information on RTAs captures all multilateral and bilateral regional trade agreements as notified to the WTO (Larch 2020). The information on the Air Liberalization Index (ALI) is taken from the WTO's Air Services Agreements Projector (WTO 2011a). The ALI is a continuous indicator, taking the values from zero to 50 if an air liberalization agreement applies between two country-pairs. The higher the value of the index, the deeper is the respective agreement and the less friction applies to international aviation. To differentiate from country-pairs in the dataset that do not have an air agreement in place, the variable *ali* is increased by one compared to the original ALI. The index now runs from one to 51 in this analysis. Consequently, a value of zero indicates that there is no ALI in effect between two countries. Data on the ALI is available up to 2011. To preserve zero values of the continuous variables *temp_diff* (in the case of domestic flows) and *ali*, the square root of the original value is taken instead of the natural log. Table 4.1 displays the summary statistics of the mentioned variables, grouped in the categories dependent variables, gravity variables, and policy variables.[25]

[24] Table 4.10 in the Appendix lists the European countries included in the dataset and indicates the beginning of a EU, Schengen and Euro membership.
[25] Table 4.11 in the Appendix gives the summary statistics when only international flows are included (i≠j).

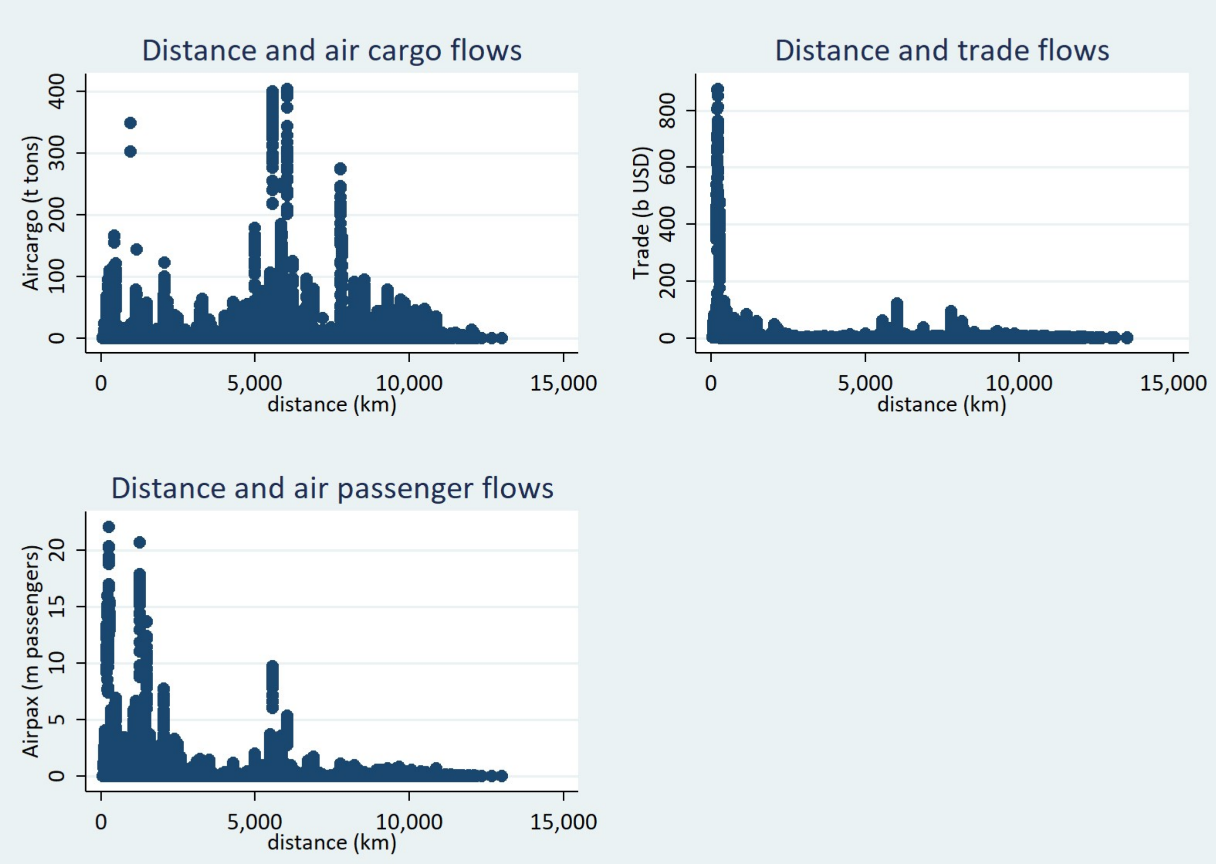
Table 4.1: Summary statistics

Variable	Count	Mean	Min	Max	Unit/*Type*	Group
aircargo	28,984	6,498.83	0	404,143	tons	Dependent variables (X_{ijt})
trade	41,207	4.96e+09	0	8.75e+11	USD, deflated	
airpax	32,713	411,807.89	0	2.21e+07	passengers	
dist	46,736	4,501.87	59.62	13,501.46	km	Gravity variables ($GRAVITY_{ij}$)
COML	46,736	0.04	0	1	*dummy*	
COL	46,736	0.05	0	1	*dummy*	
CONT	46,736	0.04	0	1	*dummy*	
temp_diff	46,736	9.11	0	26.15	Celsius	
EURO	46,736	0.06	0	1	*dummy*	Policy variables ($AGRMNT_{ijt}$)
EU	46,736	0.21	0	1	*dummy*	
SCHENG	46,736	0.71	0	1	*dummy*	
OTHER_RTA	46,736	0.15	0	1	*dummy*	
ali	36,576	13.08	0	51	*continuous*	
INTER	46,736	0.98	0	1	*dummy*	Border dummies ($INTER_{ij}$ / $INTER_{ijt}$)
INTER_t	46,736	0.04	0	1	*dummies*	

Notes: Continuous variables are written in lower case letters, dummy variables are written in capital letters. i = Country i, j = Country j, t = Year.

For a first and descriptive analysis, Figure 4.1 displays the relationship between the dependent variables and the variable distances in three different graphs. The dimension distance affects the amount of air cargo, trade and passenger flows differently. While the amount of flows peak at medium and greater distances in the case of air cargo, in the case of trade flows, the amount of flows peak at very short distances. In the case of air passenger flows, the relationship with distance has two peaks, one at shorter distances and one smaller peak at medium distances. According to the dataset, intranational trade flows account for 61% of the total trade volume, whereas 22% of all air passengers are from domestic flows and only 6% of all air cargo tons are transported on intranational routes. In the case of air cargo flows, the country-pair with the single highest volume (in tons) is USA-Germany in 2011. For trade flows, the respective country-pair is Germany-Germany in 2007, and the country-pair with the highest number of air passengers is Spain-Spain in 2007.

Figure 4.1: The impact of distance on air cargo, trade, and air passenger flows



Notes: Including intranational and international air cargo, trade, and air passenger flows. b=billion, m=million, t=thousand, USD=US Dollars (deflated).

4.1.5. Results and discussion

Tables 4.2 to 4.4 show the results of the regressions on air cargo flows, trade, and air passenger flows. All regressions are processed with the PPML estimator since the data used in this paper is heteroscedastic. Moreover, the dependent variables are not log linearized and zero flows can be taken into account.[26] The first two columns of Table 4.2 contain the results for the gravity model variables with regard to air cargo flows. Both regressions (1) and (2) include time-varying origins and destination fixed effects. The second regression also incorporates intranational flows. The variables distance, common language, and colonial ties have a positive and highly significant impact on air cargo flows. The effect of a common border is non-significant. Temperature differences between two countries significantly affect trade

[26] The regressions are computed with the Stata command *ppmlhdfe* by Correia et al. 2020.

by air negatively. Shifting from regression (1) to regression (2) does not change the direction of the impact of the significant standard gravity variables, though the magnitude of the coefficients is reduced. In the case of the variable temperature differences, the negative impact is strengthened in magnitude when entering intranational flows. The coefficient of the variable international border (INTER) is negative (-1.067) and significant at the 5% level. This negative border effect indicates that the amount of cargo flows per observation is reduced if an international border exists between countries i and j. With regard to the effect of the policy variables, the four different structural gravity models give contradictory results. The impact of the Euro and of a Schengen membership, for example, changes from negative and highly significant in column (1) to positive and highly or well significant in column (4). The effects of the variables EU and OTHER_RTA also invert, though all estimates are non-significant. The estimates imply that when controlling for endogeneity in regression (3) and (4), the impact of the Euro, the EU, and other RTAs inverts. The impact of the Schengen Agreement changes from negative to positive when including intranational flows. The structural gravity model that includes intranational flows and controls for endogeneity and globalization effects is the most comprehensive and up-to-date. Column (4) therefore shows the preferred model in this study and the results with regard to the policy variables are the following: Adoptation of the Euro impacts air cargo flows positively (0.446) and the results are highly significant. Also, Schengen membership affects air cargo flows positively and significantly (0.339). Somewhat surprisingly, membership in the EU and other RTAs do not influence air cargo flows. Both results are non-significant, but whereas the coefficient of the EU variable is small but positive (0.034), the coefficient of other RTAs is negative (-0.250). For brevity, only the results of every fifth international border dummy are reported, as well as the result of 2015’s dummy. The last international border dummy (INTER_2016) is dropped from the regression, since it is collinear with the fixed effects. The results of the other border dummies are to be interpreted relative to that omitted dummy (Bergstrand et al. 2015; Larch et al. 2019a; Yotov et al. 2016). All coefficients of the border dummies are negative, and from 2004 on, the value of the border dummy’s coefficients is constantly decreasing and significant. The results show that the negative border effect - which was also proofed by the negative impact of the dummy variable INTER - has been shrinking since 2004. The results indicate that the costs of international air cargo goods relative to the costs of domestic air cargo goods have been declining since 2004. Though the coefficient of the last border dummy of the year 2015 is still -0.285 and a border effect still applies in 2015.

Table 4.2: Regression results - Air cargo flows

	(1)	(2)	(3)	(4)
	aircargo	aircargo	aircargo	aircargo
ln(dist)	0.652***	0.602***		
	(0.130)	(0.161)		
COML	0.455***	0.412***		
	(0.096)	(0.104)		
COL	0.801***	0.586***		
	(0.075)	(0.104)		
CONT	-0.009	0.101		
	(0.177)	(0.192)		
sq(temp_diff)	-0.170***	-0.258***		
	(0.061)	(0.075)		
EURO	-0.498***	-0.310*	0.382***	0.446***
	(0.151)	(0.169)	(0.088)	(0.090)
EU	-0.262	-0.405	0.127	0.034
	(0.282)	(0.283)	(0.195)	(0.182)
SCHENG	-0.483***	0.813***	-0.129*	0.339**
	(0.158)	(0.217)	(0.077)	(0.132)
OTHER_RTA	0.492	0.474	-0.166	-0.250
	(0.360)	(0.355)	(0.363)	(0.358)
INTER		-1.067**		
		(0.487)		
INTER_1994				-0.399
				(0.381)
INTER_1999				-0.266
				(0.186)
INTER_2004				-0.780***
				(0.178)
INTER_2009				-0.639***
				(0.164)
INTER_2014				-0.350**
				(0.147)
INTER_2015				-0.285**
				(0.144)
Origin-year and destination-year FE	x	x	x	x
Country-pair FE			x	x
Intranational flows		x		x
N	28,377	28,939	27,535	28,097
Pseudo-R^2	0.878	0.849	0.969	0.969

Notes: All models are estimated with PPML. The estimates of the constant and the fixed effects are not reported. Only the estimates of the international border dummies of every fifth year and of the year 2015 are reported. Standard errors, clustered by country-pair, are given in parentheses. * p<0.1, ** p<0.05, *** p<0.01. FE = fixed effects.

The results of the regressions on the dependent variable trade flows are shown in Table 4.3. Distance has a negative and significant impact on trade flows. Sharing a common language or a common border affects trade positively. The impact of colonial ties changes from positive and highly significant to almost zero and non-significant when including intranational flows. The negative impact of higher temperature differences on trade flows is significant and is strengthened in the second regression, as is the case for air cargo flows. As mentioned in the data section, intranational trade accounts for 61% of the total trade volume. The strong impact of the variable INTER (-2.448) endorses the higher value of domestic trade flows compared to international trade flows. With regard to the policy variables, the impact of the Euro becomes positive and significant when including intranational flows, but turns to zero when controlling for endogeneity. The effect of a Schengen membership changes from positive to almost zero when including country-pair fixed effects. The impact of the EU changes from negative to positive when including intranational trade flows. Looking at the last column and at the preferred model, the following conclusion can be drawn: The Euro does not affect trade flows - the coefficient is small in magnitude (0.010) and non-significant. This result is in line with the latest research on this subject, in which the effect of the Euro was also small (0.030) and non-significant (Larch et al. 2019b). The effects of the EU and of other RTAs on trade flows also correspond with the results of previous studies (Head and Mayer 2014). Both agreements impact trade flows positively (0.330 and 0.578) and significantly. Moreover, the stronger impact of economic agreements on trade flows when regressing a model that includes intranational flows and international border dummies was also found in previous research (Bergstrand et al. 2015). A Schengen membership does not impact trade flows. The negative amount of the international border dummies' coefficients consequently shrinks over time. The effect is in line with previous research (Bergstrand et al. 2015; Larch et al. 2019a; Yotov et al. 2016) and represents the decreasing border effect. The costs of international trade flows relative to the costs of domestic trade flows consequently have decreased over time to a border effect of only -0.057 in 2015.

Table 4.3: Regression results - Trade flows

	(1)	(2)	(3)	(4)
	trade	trade	trade	trade
ln(dist)	-0.238***	-0.510***		
	(0.078)	(0.066)		
COML	0.597***	0.586***		
	(0.092)	(0.124)		
COL	0.238***	0.047		
	(0.082)	(0.129)		
CONT	0.490***	0.385***		
	(0.085)	(0.086)		
sq(temp_diff)	-0.144***	-0.270***		
	(0.039)	(0.043)		
EURO	-0.114	0.234***	0.010	0.010
	(0.088)	(0.077)	(0.037)	(0.032)
EU	-0.301***	0.248***	0.073	0.330***
	(0.115)	(0.086)	(0.060)	(0.041)
SCHENG	0.447***	0.488***	-0.004	0.008
	(0.091)	(0.049)	(0.032)	(0.023)
OTHER_RTA	0.801***	1.325***	0.300**	0.578***
	(0.153)	(0.142)	(0.122)	(0.130)
INTER		-2.448***		
		(0.161)		
INTER_1994				-0.833***
				(0.069)
INTER_1999				-0.738***
				(0.044)
INTER_2004				-0.568***
				(0.044)
INTER_2009				-0.364***
				(0.027)
INTER_2014				-0.126***
				(0.018)
INTER_2015				-0.057***
				(0.015)
Origin-year and destination-year FE	x	x	x	x
Country-pair FE			x	x
Intranational flows		x		x
N	40,521	41,207	40,521	41,207
Pseudo-R^2	0.947	0.977	0.995	0.998

Notes: All models are estimated with PPML. The estimates of the constant and the fixed effects are not reported. Only the estimates of the international border dummies of every fifth year and of the year 2015 are reported. Standard errors, clustered by country-pair, are given in parentheses. * p<0.1, ** p<0.05, *** p<0.01. FE = fixed effects.

Table 4.4 gives the results of the regressions on air passenger flows. Distance impacts passenger flows positively, though the impacts reduce to almost zero when including intranational flows. The variables common language and colonial ties impact passenger flows positively and are as highly significant as they are for trade and air cargo flows. The effect of a common language is higher on air passenger numbers than on air cargo or trade flows. A common border affects air passenger flows negatively, and the negative effect is also significant when including intranational flows. In contrast to the results on air cargo and trade flows, but as expected, temperature differences impact passenger flows positively and to a significant degree when only regressing on international air passenger flows. The dummy variable INTER is negative (-1.602) and highly significant, such as in the regressions on air cargo and trade flows. A negative border effect also applies in the case of air passenger flows, and an international border between county i and j reduces the volume of air passenger flows per observation. The effect of the Euro is positive (0.106) and significant at the 5% level when looking at the results in column (4). Although when not controlling for endogeneity the impact is negative (regression (1) and (2)). EU or Schengen membership influences bilateral air passenger numbers positively (0.317 and 0.144)) and both impacts are highly significant. The impact of both variables is consequently positive throughout all regressions. Other RTAs – as expected – do not affect passenger air travel. The coefficients of the international border dummies are negative and significant. They basically stayed stable until 2009 and were reduced to -0.044 in 2015. However, although the globalization effect is weaker, the coefficients of the international border dummies are lower in the regressions on air passenger flows with a maximum of -0.365 than they are in the regressions on air cargo (maximum of -0.780) or trade flows (maximum -0.833). The price discrepancy between domestic and international air travel destinations can be assumed to be lower since the medium distance of international air passenger flows is shorter than the medium distance of international air cargo or trade flows.

Table 4.4: Regression results - Air passenger flows

	(1)	(2)	(3)	(4)
	airpax	airpax	airpax	airpax
ln(dist)	0.142*	0.024		
	(0.085)	(0.087)		
COML	0.682***	0.770***		
	(0.114)	(0.120)		
COL	0.626***	0.630***		
	(0.141)	(0.150)		
CONT	-0.164	-0.322***		
	(0.113)	(0.099)		
sq(temp_diff)	0.160*	-0.024		
	(0.089)	(0.094)		
EURO	-0.197*	-0.265*	0.063	0.106**
	(0.116)	(0.155)	(0.041)	(0.045)
EU	0.781***	0.307*	0.397***	0.317***
	(0.171)	(0.163)	(0.077)	(0.066)
SCHENG	0.347***	0.572***	0.182***	0.144***
	(0.091)	(0.115)	(0.035)	(0.042)
OTHER_RTA	0.065	-0.521**	0.135	0.063
	(0.221)	(0.220)	(0.154)	(0.146)
INTER		-1.602***		
		(0.263)		
INTER_1994				-0.309**
				(0.128)
INTER_1999				-0.307***
				(0.060)
INTER_2004				-0.365***
				(0.044)
INTER_2009				-0.301***
				(0.033)
INTER_2014				-0.063***
				(0.010)
INTER_2015				-0.044***
				(0.010)
Origin-year and destination-year FE	x	x	x	x
Country-pair FE			x	x
Intranational flows		x		x
N	32,127	32,713	32,025	32,611
Pseudo-R^2	0.892	0.899	0.990	0.992

Notes: All models are estimated with PPML. The estimates of the constant and the fixed effects are not reported. Only the estimates of the international border dummies of every fifth year and of the year 2015 are reported. Standard errors, clustered by country-pair, are given in parentheses. * p<0.1, ** p<0.05, *** p<0.01. FE = fixed effects.

Table 4.5 displays the robustness checks on air cargo flows. For a better comparison, regressions (0) gives again the estimates of the preferred regression (4) from Table 4.2 The results of the robustness checks confirm the positive impact of the Euro and of the Schengen Agreement on air cargo flows. The EU still does not impact air cargo flows, even when leaving the Euro and Schengen membership out of the regressions (regression (2)). The robustness checks also approve the negative but non-significant impact of other RTAs on air cargo flows. The results for the ALI (0.021) are in line with previous studies. Geloso Grosso and Shepherd (2011) – although with a different geographic scope – estimated small effects of the ALI (0.014) for air trade with manufactured goods.

Table 4.5: Robustness checks - Air cargo flows

	(0)	(1)	(2)	(3)	(4)	(5)
	aircargo	aircargo	aircargo	aircargo	aircargo	aircargo
	Total dataset	Total dataset	Total dataset	Total dataset	Intra-Europe	1994-2011
EURO	0.446***	0.417***			0.365***	0.425***
	(0.090)	(0.091)			(0.085)	(0.087)
EU	0.034		0.090		-0.076	-0.033
	(0.182)		(0.181)		(0.214)	(0.170)
SCHENG	0.339**			0.270*	0.665***	0.221*
	(0.132)			(0.140)	(0.182)	(0.118)
OTHER_RTA	-0.250	-0.250	-0.197	-0.261		-0.054
	(0.358)	(0.345)	(0.357)	(0.346)		(0.362)
sq(ali)						0.021*
						(0.011)
N	28,097	28,097	28,097	28,097	10,920	19,662
Pseudo-R^2	0.969	0.969	0.968	0.968	0.968	0.974

Notes: All models are estimated with PPML and include intranational flows as well as origin-year, destination-year, and country-pair fixed effects. The estimates of the constant, the international border dummies and the fixed effects are not reported. Standard errors, clustered by country-pair, are given in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

With regard to trade flows, the Euro does not affect bilateral trade flows, even if the variables EU and SCHENG are dropped from the regressions (Table 4.6, regression (1)). Hence, the impact of a Schengen membership becomes positive and significant when leaving the EU and the Euro out of the regressions (regression (3)). The positive and highly significant results for EU membership and other RTAs on trade flows are confirmed by the robustness checks.

Table 4.6: Robustness checks - Trade flows

	(0)	(1)	(2)	(3)	(4)	(5)
	trade	trade	trade	trade	trade	trade
	Total dataset	Total dataset	Total dataset	Total dataset	Intra-Europe	1994-2011
EURO	0.010	-0.064			0.020	-0.019
	(0.032)	(0.040)			(0.030)	(0.027)
EU	0.330***		0.329***		0.347***	0.274***
	(0.041)		(0.047)		(0.039)	(0.037)
SCHENG	0.008			0.061**	0.002	-0.006
	(0.023)			(0.029)	(0.026)	(0.018)
OTHER_RTA	0.578***	0.539***	0.582***	0.506***		0.426***
	(0.130)	(0.137)	(0.130)	(0.136)		(0.129)
N	41,207	41,207	41,207	41,207	13,644	32,225
Pseudo-R^2	0.998	0.998	0.998	0.998	0.999	0.999

Notes: All models are estimated with PPML and include intranational flows as well as origin-year, destination-year, and country-pair fixed effects. The estimates of the constant, the international border dummies and the fixed effects are not reported. Standard errors, clustered by country-pair, are given in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Finally, the results of the additional regressions for air passenger flows (Table 4.7) are in line with those of the main regression in Table 4.4. The impact of the Euro, the EU, and of a Schengen membership is positive and significant throughout all different robustness checks. The effect of other RTAs is still non-significant, which is well justified in the case of air passenger flows. The effect of the ALI on air passenger flows is also non-significant (regression (5)). Previous studies on that subject showed a small positive impact of the ALI on air passenger numbers however (about 1% to 3% impact) (Cristea et al. 2015; Piermartini and Rousová 2013).[27]

[27] When running the robustness check on a dataset that only covers the observations until 2008 (to not include the impact of the financial crisis), the impact of the ALI on air passenger numbers turns slightly positive but is still non-significant.

Table 4.7: Robustness checks - Air passenger flows

	(0)	(1)	(2)	(3)	(4)	(5)
	airpax	airpax	airpax	airpax	airpax	airpax
	Total dataset	Total dataset	Total dataset	Total dataset	Intra-Europe	1994-2011
EURO	0.106**	0.107**			0.138***	0.071*
	(0.045)	(0.045)			(0.043)	(0.043)
EU	0.317***		0.342***		0.331***	0.291***
	(0.066)		(0.067)		(0.083)	(0.090)
SCHENG	0.144***			0.148***	0.177***	0.127***
	(0.042)			(0.041)	(0.053)	(0.041)
OTHER_RTA	0.063	-0.138	0.093	-0.150		0.112
	(0.146)	(0.142)	(0.146)	(0.142)		(0.121)
sq(ali)						-0.003
						(0.010)
N	32,611	32,611	32,611	32,611	13,989	24,042
Pseudo-R^2	0.992	0.992	0.992	0.992	0.994	0.993

Notes: All models are estimated with PPML and include intranational flows as well as origin-year, destination-year, and country-pair fixed effects. The estimates of the constant, the international border dummies and the fixed effects are not reported. Standard errors, clustered by country-pair, are given in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

To summarize the results of the regressions, Table 4.8 gives only the results on the impact of multinational agreements according to regressions (4) of the Tables 4.2, 4.3 and 4.4. These regressions include intranational flows, origin-year and destination-year fixed effects and country-pair fixed effects.

Table 4.8: Summary - The effect of multinational agreements

	aircargo	trade	airpax
EURO	0.446***		0.106**
EU		0.330***	0.317***
SCHENG	0.339**		0.144***
OTHER_RTA		0.578***	

Notes: The results are based on the regressions (4) of Tables 4.2, 4.3 and 4.4. Only significant coefficients are considered. * p<0.1, ** p<0.05, *** p<0.01.

Since the results on air cargo flows with regard to the impact of the policy variables are surprising, to what extend air cargo flows, trade flows, and air passenger flows affect each other has been analyzed by conducting three additional regressions. These regressions include only the amount of air cargo, trade, and air passenger flows as variables as well as origin-year and destination-year fixed effects, country-pair fixed effects and international border dummies. The results are given in Table 4.9. Bilateral air cargo flows are positively influenced by air passenger numbers (0.346, significant at the 1% level) but are not impacted by bilateral trade numbers (-0.021, non-significant). Trade is mildly impacted by air passenger flows (0.054, significant at the 1% level) but not by air cargo flows (-0.000). And finally, air passenger numbers are mildly impacted by both air cargo flows (0.043, significant at the 1% level) and trade flows (0.075, significant at the 1% level). The strongest impact is the effect of passenger numbers on the volume of air cargo flows. This comes as no surprise, since 50% of the amount of air cargo is transported in the bellies of passenger planes.

Table 4.9: Impact analysis

	(1)	(2)	(3)
	aircargo	trade	airpax
ln(aircargo)		-0.000	0.043***
		(0.005)	(0.007)
ln(trade)	-0.021		0.075***
	(0.020)		(0.017)
ln(airpax)	0.346***	0.054***	
	(0.038)	(0.018)	
N	23,877	20,551	20,848
Pseudo-R^2	0.978	0.998	0.995

Notes: All models are estimated with PPML and include intranational flows as well as origin-year, destination-year, and country-pair fixed effects. The estimates of the constant effects, the fixed effects, and of the international border dummies are not reported. Standard errors, clustered by country-pair, are given in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01.

4.1.6. Conclusion

Based on the analysis in this paper, the following conclusions with regard to the impact of multinational agreements are drawn: First, the Euro affects air cargo flows and air passenger flows positively. The EU membership impacts trade and air passenger flows positively but has no significant effect on air cargo flows. A Schengen membership promotes air passenger numbers and the amount of air cargo flows between two countries. Other RTAs impact total trade, but not trade by air. Trade flows are not impacted by the Euro or by a Schengen membership (see Table 4.8). Overall, the results on the impact of the policy variables on air cargo flows are somewhat surprising. Firstly, air cargo does not seem to have statistically gained from multinational, regional trade agreements such as the EU and other RTAs so far. According to economic theory, trade agreements foster trade between two countries by reducing or removing tariffs and other non-monetary barriers to trade. As air cargo flows are per meaning trade flows, the EU and other RTA should have fostered air cargo flows as well. Secondly, in this research, the effect of a common currency is positive on passenger flows but also on air cargo flows. The enhancing effect of the Euro on passenger flows likely is triggered by the positive effect of the Euro on tourism flows. As shown by previous research, the common currency raises bilateral tourism flows between two countries. The effect of the Euro on trade flows has been negated by this paper as well by previous research. Therefore, the positive effect of the Euro on air cargo flows appears unexpected. Thirdly, a Schengen membership facilitates the free movement of people as no visa is required to enter another member country. This policy measure therefore should foster air passenger flows but should have no effect on air cargo flows. Lastly, the international border dummies revealed a declining negative border effect for air cargo, trade, and air passenger numbers. However, in the case of air cargo flows, the cost discrepancies between intranational and international air cargo flows have not been reduced to the extent they have been in the case of trade or air passenger flows; globalization effects therefore have promoted air cargo flows to a much lesser degree than total trade flows.

In summary, as shown by this study, air cargo flows are positively impacted by the two variables that mainly enhance passenger flows – the Euro and Schengen membership. Since half of total air cargo volumes are transported in the bellies of passenger planes, air passenger services determine on which routes 50% of total air cargo is transported. Air cargo may depend too much on air passenger services in order to fully exploit the effects of RTAs as trade is able to do in general. By this, air cargo transportation services likely do not operate on the optimal set of routes. This might be one of the possible explanations for the lower growth rates compared to total trade flows that are shown in the Introduction. Moreover, when air cargo depends this much on air passenger planes, air cargo is extremely affected by shock events that affect air passenger services. Not only in the light of the current pandemic, but also in order to gain from RTAs that should reduce trade costs, it seems necessary to foster air cargo network management that is more independent from air passenger transportation services.

With regard to the methodology used in this study, four different structural gravity models were applied. This paper showed the importance of correctly specifying a structural gravity model in the area of aviation economics. Currently, the most comprehensive and up-to-date structural gravity model includes intranational flows, time-varying international border dummies, and origin-year, destination-year, and country-pair fixed effects. The model thus controls for multilateral resistances, endogeneity, and globalization effects. In this paper's regressions, the inclusion of intranational flows and controlling for endogeneity changed the impact of the policy variables, especially in the case of air cargo and trade flows. Controlling for endogeneity inverted the impact of the Euro on air cargo flows to be positive, and the inclusion of intranational flows turned the effect of a Schengen membership positive. Previous gravity model estimations in the area of aviation economics were predominantly based on linear estimators such as OLS. Since air cargo and air passenger data may share the characteristic of heteroscedasticity with datasets on trade flows, a Poisson-based estimator should be applied instead of a linear estimator.

Appendix

Table 4.10: European countries included in the dataset and beginning of EU, Schengen and Euro membership

	EU	Schengen[2]	Euro
Austria	1995	1998	2002
Belgium	1958	1995	2002
Bulgaria	2007		
Croatia	2013		
Cyprus	2004		2008
Czech Republic	2004	2008	
Denmark	1973	2001	
Estonia	2004	2008	2011
Finland	1995	2001	2002
France	1958	1995	2002
Germany	1958	1995	2002
Greece	1981	2000	2002
Hungary	2004	2008	
Ireland	1973		2002
Italy	1958	1997	2002
Latvia	2004	2008	2014
Lithuania	2004	2008	2015
Luxembourg	1958	1995	2002
Malta	2004	2008	2008
Netherlands	1958	1995	2002
Norway		2001	
Poland	2004	2008	
Portugal	1986	1995	2002
Romania	2007		
Slovakia	2004	2008	2009
Slovenia	2004	2008	2007
Spain	1986	1995	2002
Sweden	1995	2001	
Switzerland		2009	
United Kingdom	1973-2020		

Notes: The total number of countries included in the dataset are the following: (i) 16 major EU countries as origin countries: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, the Netherlands, Poland, Portugal, Spain, Sweden and the United Kingdom; (ii) 14 additional European countries as destination countries: Bulgaria, Croatia, Cyprus, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Malta, Norway, Romania, Slovakia, Slovenia, Switzerland; (iii) Another 41 countries worldwide as destination countries: Algeria, Angola, Argentina, Bahrain, Brazil, Canada, Chile, China, Colombia, Ecuador, Egypt, Ethiopia, India, Indonesia, Iran, Israel, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Lebanon, Malaysia, Mexico, Morocco, Nigeria, Oman, Qatar, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Taiwan, Thailand, Tunisia, Turkey, Ukraine, United Arab Emirates, United States, Vietnam. (2) In the case of the information on Schengen membership, the year is shown when Schengen became effective and not when the Schengen agreement was ratified. When the respective date was for example 01.12.2001, the year 2002 is taken as the effective year.

Table 4.11: Summary statistics - International country-pairs

Variable	Count	Mean	Min	Max	Unit/*Type*	Group
aircargo	28,422	6,228.11	0	404,143	tons	Dependent variables (X_{ijt}, with *i≠j*)
trade	40,521	1.94e+09	0	1.30e+11	USD, deflated	
airpax	32,127	328,145.00	0	2.07e+07	passengers	
dist	46,000	4,571.25	59.62	13,501.46	km	Gravity variables ($GRAVITY_{ij}$, with *i≠j*)
COML	46,000	0.04	0	1	*dummy*	
COL	46,000	0.05	0	1	*dummy*	
CONT	46,000	0.04	0	1	*dummy*	
temp_diff	46,000	9.26	0.05	26.15	Celsius	
EURO	46,000	0.06	0	1	*dummy*	Policy variables ($AGRMNT_{ijt}$, with *i≠j*)
EU	46,000	0.21	0	1	*dummy*	
SCHENG	46,000	0.72	0	1	*dummy*	
OTHER_RTA	46,000	0.16	0	1	*dummy*	
ali	36,000	13.29	0	51	*continuous*	

Notes: Continuous variables are written in lower case letters, dummy variables are written in capital letters. i = Country i, j = Country j, t = Year.

4.2. The effect of the European Emissions Trading System (EU ETS) on aviation demand: An empirical comparison with the impact of ticket taxes

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[28] The text of the paper in this thesis additionally includes the equations of the robustness checks and tables that show regressions estimated with OLS for a broader understanding and for ease of reading.
[29] Sources: https://abdc.edu.au/research/abdc-journal-quality-list/ and https://jcr-clarivate-com.eaccess.ub.tum.de/jcr/home as of 06.02.2022.

Abstract

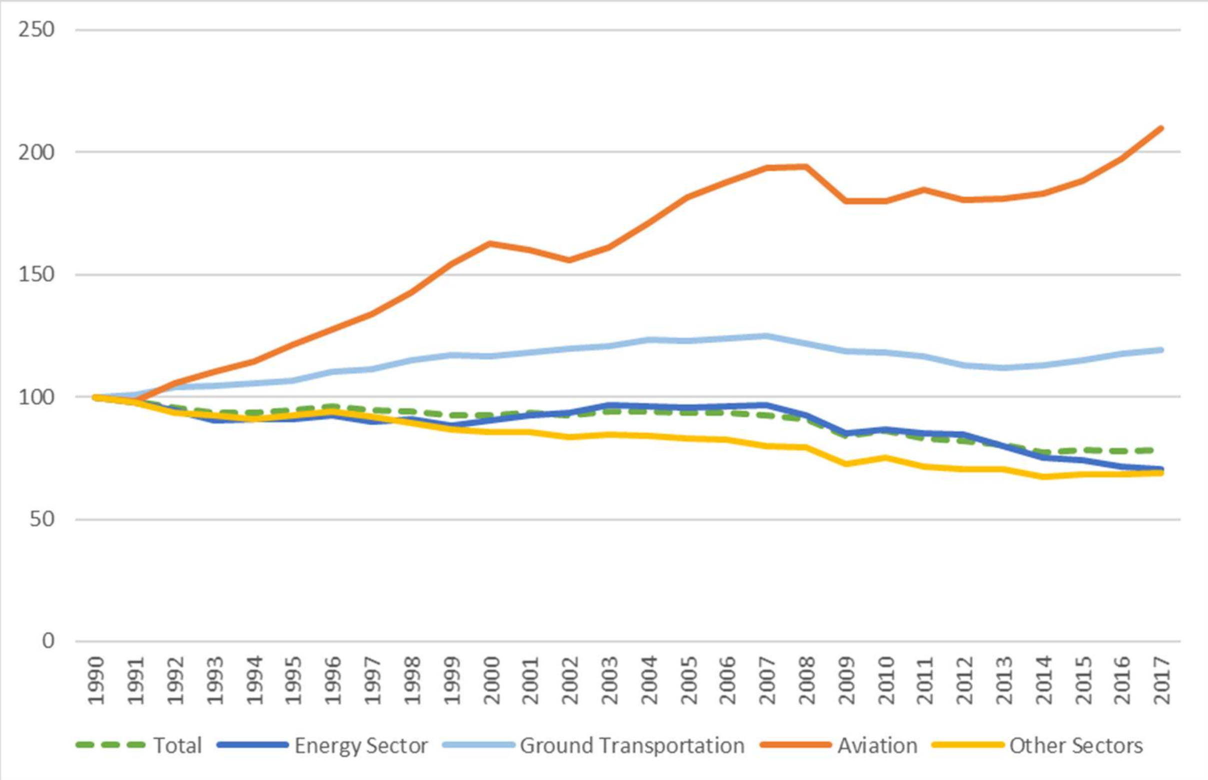
Overall greenhouse gas emissions in the European Union (EU) have fallen by now to an index of 78 compared to 1990 – but a different picture applies to the transportation sector. The index of emissions from ground transportation rose to 119 in 2017, while the index for the aviation sector increased even further to 210. Greenhouse gas emissions from the transportation sector now account for one quarter of the EU's greenhouse gas emissions, with 3.9% of total emissions coming from the aviation sector. To regulate the rising environmental impact of flying, the EU integrated aviation into the European Emissions Trading System (EU ETS) in 2012. Several studies simulated the expected effects on air travel demand, the demand reductions were considered as the only way to decrease emissions from flying as the airline industry faces high abatement costs. Up to now, no empirical paper analyzed the ex-post effects of the EU ETS on aviation demand. Therefore and firstly, this paper aims to verify whether the expected effects on the aviation sector due to the EU ETS can be approved. This paper gives an empirical ex-post evaluation on the effect of the EU ETS on aviation demand using a gravity model approach. The dataset used includes bilateral passenger numbers for 407 country-pairs for the years 2000-2018. Secondly, the effect of the EU ETS on aviation demand is analyzed in comparison to the effects of a ticket tax. And thirdly, this paper intends to give a contribution to the up to now scarce amount of literature that tackles the adequate specification of fixed effects for a structural gravity model in aviation economics within the framework of a poisson pseudo-maximum likelihood (PPML) estimation. The results of the estimates suggest that the EU ETS has had until 2018 no statistically significant effects on intra-EEA (European Economic Area) air passenger flows. The ticket tax (Luftverkehrabgabe) brings about statistically significant and robust demand reductions on the affected country-pairs. Because prices per passenger of the aviation tax are much higher than the EU ETS price per passenger, theoretical demand elasticities support the stronger effect of the tax on passenger flows. But although the tax reduces demand, this policy may still not be the adequate measure as the aviation taxes that are in place do not relate to the amount of CO_2 emitted by air travel. Generally, policy instruments are preferred that incentivize emission reductions, as is the case with kerosene taxes or emissions trading systems (ETS).

4.2.1. Introduction

Since the 1970s, global greenhouse gas emissions have doubled while global average temperatures are currently between 0.8°C and 1.2°C above pre-industrial levels (IPCC 2018; OECD 2015). The Paris Agreement (2015) proposes limiting the temperature surplus to 1.5°C in order to prevent severe climate change effects. The treaty is one of the most prominent extensions of the United Nations Convention on Climate Change besides the Kyoto Protocol that began 10 years earlier. The Kyoto Protocol sets targets to reduce greenhouse gas emissions in participating countries. Since then, greenhouse gas emissions in most OECD countries and especially in the EU have been declining, due to changing energy consumption patterns (BP 2019; OECD 2015). Figure 4.2 shows the progression of greenhouse gas emissions for different (sub-) sectors in the twenty-seven EU countries and the United Kingdom. By 2017, overall greenhouse gas emissions in the EU had fallen to an index of 78 compared to 1990. This development constitutes a 20% reduction in emissions by 2020, thus meeting the EU's target set by the Kyoto Protocol. The energy sector in particular is driving this progress towards an index of 70 through reduced emissions. A different picture applies to the transportation sector. The index of emissions from ground transportation rose to 119 in 2017, while the index for the aviation sector increased even further to 210. Greenhouse gas emissions from the transportation sector in general now account for one quarter of the EU's greenhouse gas emissions, with 3.9% of total emissions coming from the aviation sector (Eurostat 2019). The environmental impact of aviation is expected to be much greater, as greenhouse gases emitted at high altitudes have a 2-3 times greater impact, and figures relating to greenhouse gas emissions exclude other pollutants associated with aviation, such as sulfur oxides (EASA 2019).

The rise in greenhouse gas emissions from aviation is a direct result of the immense increase in passenger volumes since the 1990s, when deregulation led to an enhanced supply of flights and an accompanying decrease in ticket prices (EEA 2018). Since then, air passenger numbers have tripled, while, since 2005, passenger numbers in the EU have risen by as much as 50% from 592 million to 890 million (EASA 2019; EEA 2018). Before the onset of the COVID-19 pandemic, ongoing growth rates of around 2.5% per year were predicted in the aviation sector for the EU (EEA 2018).

Figure 4.2: Greenhouse gas emissions in the EU-27 and the UK, various sectors/sub-sectors, 1990–2017



Source: Own graph using data from Eurostat (2019). Note: 1990 = 100.

In order to control for the environmental impact of flying and not to endanger the goals set by the Kyoto Protocol, the EU decided to integrate aviation within the European Emissions Trading System (EU ETS) in 2012. The inclusion of aviation in the EU ETS was accompanied by great expectations of its impact: "The scheme has the potential to induce behavioral changes in the short and medium run and technological changes in the longer term by sending price signals to the aviation industry" (Anger 2010). In the past, fuel efficiency gains were realized through new fuel-saving airplanes and improved capacity utilization, i.e., more seats per plane and higher seat load factors. Hence, airplanes have a relatively long lifespan of 25 years and more and innovations that can fully reduce greenhouse gas emissions like biofuels or electric engines are still far out of rich for the aviation sector (EASA 2019). Therefore, current efficiency gains are about 1% p.a. (EEA 2018) and are not be able to compensate for passenger growth rates if they return to pre-pandemic levels. From 2012 until 2019, verified emissions from the aviation sector within the context of the EU ETS haven been rising stately up to plus 27% and are surpassing the number of allocated emission certificates (EEA 2020). Therefore, airlines have been buying additional allowances from other sectors to compensate for their emissions. Giving the relatively high abatements costs in the airline industry, demand reductions are therefore currently seen as the only way to reduce emissions from the aviation sector.

This paper aims to verify whether the expected effects on the aviation sector due to the EU ETS can be approved. For this purpose, the effect of the EU ETS on aviation demand is analyzed in comparison to the effects of a ticket tax using a gravity model approach.[30] Additionally, this paper intends to give a contribution to the up to now scarce amount of literature that tackles the adequate specification of fixed effects for a gravity model in aviation economics within the framework of a poisson pseudo-maximum likelihood (PPML) estimation. The remainder of the paper is organized as follows: in the following chapter, some brief background information on environmental policies and the EU ETS are presented as they relate to the aviation sector, along with a literature review on previous studies that simulated the (demand) effects of the EU ETS and of taxes on aviation. Basic considerations concerning the EU ETS allowance market, the aviation sector and the consumer market are given in a short subchapter on theoretical assumptions. Chapter 4.2.4 contains the empirical analysis, including the gravity model specification, the empirical model, and robustness checks. Data and data sources are presented in chapter 4.2.5.Chapter 4.2.6 sets out the findings, along with a discussion of this paper's analysis. The paper closes with a conclusion and some policy recommendations.

4.2.2. Background

Environmental policies covering aviation

From an environmental economics perspective, greenhouse gas emissions are negative external effects resulting from the consumption of air-travel services. Economic theory proposes different market-based instruments to mitigate external effects by allocating a price

[30] In this study, aviation demand represents the demand for air passengers travel services.

to emissions. The effect should be either a reduction in demand for a product that produces the emissions or a more carbon-efficient production process. The most prominent market-based instruments are emission charges or taxes, and cap-and-trade emissions trading systems (ETS). However, in practice, an agreement by the International Civil Aviation Organization (ICAO) from 1944 limits taxes on international aviation, and international flights are exempted from value added taxes or kerosene taxes (ICAO 1944). To compensate for this limited taxation, some countries apply different national charges that are permitted under the ICAO convention (Larsson et al. 2019). So far, Australia, Austria, France, Germany, Italy, Norway and the United Kingdom for example levy an air transportation or passenger tax on aviation.[31]

The EU ETS is currently the largest – and only multinational – emissions-trading system in action. A few other countries have introduced national emissions-trading systems, some of which cover the aviation sector, such as the ETS in New Zealand, South Korea and some parts of China (World Bank 2019). The EU ETS began operating in 2005 and covers the EU countries plus Norway, Iceland and Liechtenstein, representing the European Economic Area (EEA). Installations that were initially incorporated in the EU ETS are power stations and industrial plants. In 2012, air traffic on intra-EEA flights was integrated into the EU ETS. The EU ETS for aviation started in 2012, based on the so-called 'full scope', which covers all flights departing and landing within the EEA. In 2013, the geographical scope was changed to the 'reduced scope', which only includes intra-EEA traffic (European Commission 2008). Switzerland is not included in the EU ETS but established its own national ETS, which does not include aviation. Since then, airlines have to own emission allowances (EUAs) that correspond to the quantity of CO_2 emissions generated. The cap on aviation emissions is set at a constant level, equivalent to 95% of the historical aviation emissions. Most of the allowances are allocated freely to aircraft operators, with 15% of allowances being auctioned. Aviation allowances are fully tradable within the airline sector but cannot be used by other sectors to fulfill their

[31] For an overview on taxes covering the aviation sector, see European Commission 2019 and Faber and Huigen2018.

obligations. In contrast, the aviation sector is allowed to buy allowances from other sectors (European Commission 2003, 2015).

Literature review

The vast majority of studies analyzing the environmental and economic effects of integrating the aviation sector in the EU ETS were written prior to its incorporation. Forecasted effects are primarily related to demand and CO_2 reductions and the impact on an airline's costs, revenue, efficiency and competitiveness. Moreover, initial studies served as commissioned feasibility studies for the EU on how to integrate aviation into the existing EU ETS (Boon et al. 2007; European Commission 2006; Wit et al. 2005). Further papers simulated the effects resulting from different policy options of the EU ETS regarding assumptions made on the geographical scope, initial method of allocating allowances, and market price of the allowances (Anger 2010; Brinke and Faber 2011; Mendes and Santos 2008; Morrell 2007; Scheelhaase and Grimme 2007; Vespermann and Wald 2011).

All studies saw little potential for technically induced emission reductions within the airline industry, due to the high marginal abatement costs. It was therefore anticipated that the aviation industry would be a major buyer of EUAs, also buying allowances from other sectors. Most studies assumed that the additional costs of purchasing allowances would be passed on in full to customers. It was therefore expected that emission reductions in the aviation sector would only be realized to the extent of reductions in demand. However, the amount of the additional costs was calculated to be relatively small, due to the fact that allowance prices were expected to be low and the majority of the allowances would be granted freely to airline companies. The forecast demand reductions compared to a business-as-usual scenario (+4% demand p.a.) in an intra-EEA scope ranged from –0.1% to –1.3%, and for low-cost carriers (LCC) up to –3% (European Commission 2006; Scheelhaase and Grimme 2007; Wit et al. 2005).

Few papers have been written since aviation was incorporated in the EU ETS. Meleo et al. (2016) investigated the impact on the Italian aviation sector using data on allocated allowances and emissions from 2012–2014. The estimated price and revenue effects are both below 1%, and demand effects are not explicitly mentioned. Li et al. (2016) analyzed airline efficiency from 2008–2012 for twenty-two international airlines. Airline efficiency increased for most airlines. European airlines in particular further increased their efficiency as a possible effect of the upcoming EU ETS. Cui et al. (2016) studied the effect on airline performance (measured in total revenue) for 2008–2014 and estimated an improved performance of airlines through the adoption of EU ETS requirements. Cui et al. (2017) examined the effect on airline pollution abatement costs for 2012–2014 but concluded that the EU ETS had little influence on them. Finally, Nava et al. (2018) devised a theoretical Cournot-Nash equilibrium model for the airline sector under the EU ETS, which included additional costs and efficiency incentives in the cost function. Theoretically, they specified that the optimum quantity under the EU ETS would be reduced, due to the additional costs.

Studies on the effects of other environmental policies on the aviation sector are closely linked to literature on the effects of the EU ETS. Lu (2009) modeled the impact of aviation charges on air passenger demand for different airline business models, while Pagoni and Psaraki-Kalouptsidi (2016) applied a game-theoretical approach to simulate the reactions of airlines to additional environmental costs. Both studies assumed that airlines passed on costs to airline passengers, leading to a reduction in air passenger demand. Two recent papers empirically analyzed the effects of environmental policies on aviation. In the case of Australia, Markham et al. (2018) studied the effect of a national carbon levy that also applied to the aviation sector. The authors could not detect any effect on the level of domestic passenger kilometers flown, hence the levy was only in place for two years. Falk and Hagsten (2019) investigated the effect of the flight departure tax on air passenger numbers introduced in Austria and Germany in 2011. Their analysis indicated demand losses of up to 9% in the first year and of 5% in subsequent years.

4.2.3. Theoretical considerations

The EU ETS allowance market

Within the framework of the EU ETS, airlines are obliged to hold allowances that account for the quantity of emissions produced. If emissions exceed the amount of the allowances allocated free of charge, airlines have to acquire additional certificates in an auctioning process or else purchase them from other airlines or sectors on the allowance market.

Similarly, if emissions fell below the amount of freely allocated allowances, airlines could also sell these certificates to other airlines. Given the explanations in the Introduction and Background sections (chapters 4.2.1 and 4.2.2), it can be assumed that the airline sector is a net buyer of allowances from other sectors, due to its high marginal abatement costs and that it does not possess any allowances that are left over to sell (Anger 2010; Meleo et al. 2016; Vespermann and Wald 2011).

The aviation market

Airlines need to resolve the extent to which they pass on the costs of purchasing additional allowances to the customer. In contrast to taxes or air travel charges, EU ETS allowance costs do not form an explicit part of the price a customer pays when buying a ticket. The review of the literature on the subject of the effects of the EU ETS on aviation showed that most studies assumed a 100% pass-through of the extra cost. Hence, theoretical and empirical studies on that subject are not consistent with the way airlines generally handle cost increases from additional surcharges (European Commission 2019; Koopmans and Lieshout 2016). Koopmans and Lieshout (2016) argue that the pass-through greatly depends on the market form (monopoly, oligopoly, perfect competition) and type of cost increase (firm-specific or sector-wide). For airline-specific costs, they see a pass-through of less than 50%, and for industry-wide cost increases, more than 50%. Concerning the strategic actions of airlines, most studies on the airline sector assume a Cournot oligopoly, where firms compete for the quantities and then set the prices via yield management (Barbot et al. 2014; Brander and Zhang 1990; Koopmans and Lieshout 2016; Nava et al. 2018). As the costs from the EU ETS represent sector-wide expenditures, the theoretical considerations undermine the assumption that all airlines react in the same way by passing on up to 100% of the extra costs to the customers.[32]

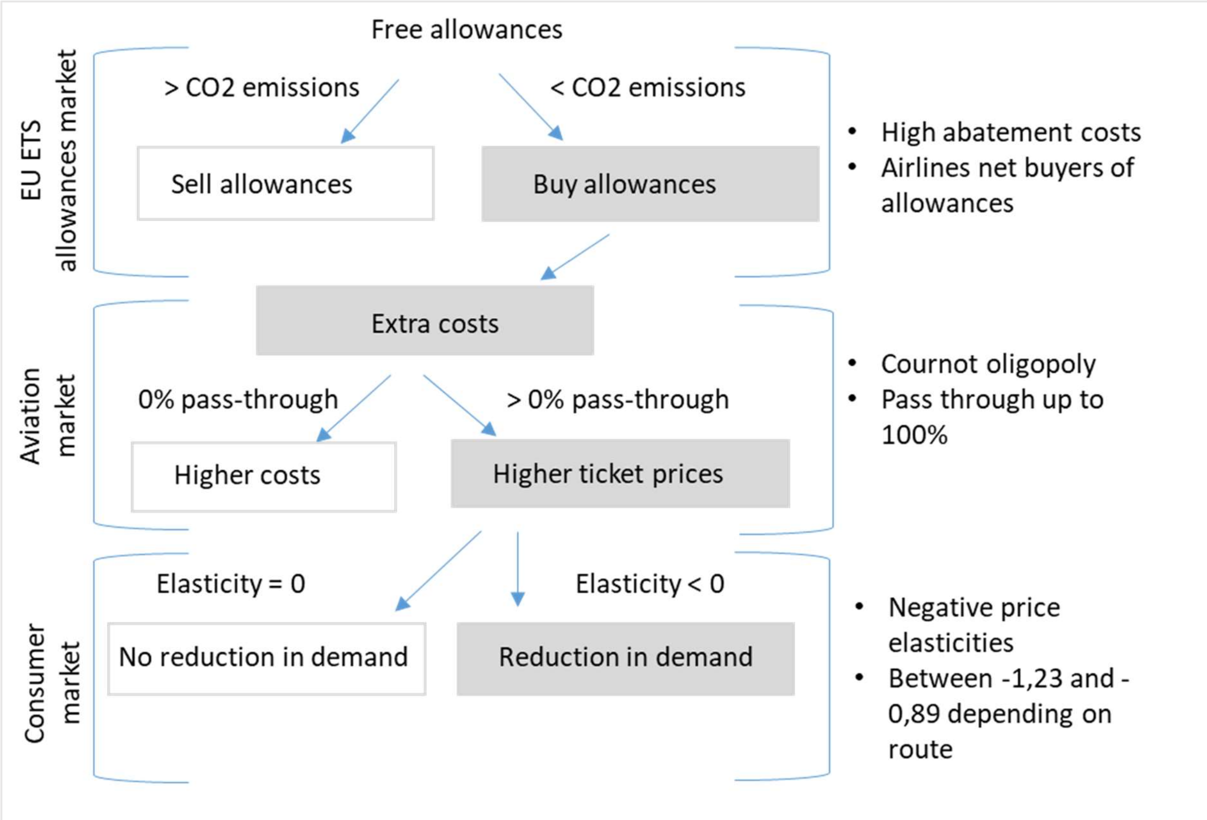
[32] Depending on the geographical scope of the airline's operations, the airline can more or less choose whether to pass on the amount of costs from the allowances to all customers or only to customers on intra-EEA routes. However, as European airlines compete on intercontinental flights against other airlines that do not operate within the EEA, it can be assumed that the additional costs will not be transferred to routes not covered by the EU ETS.

The consumer market

The reaction of demand to price changes is analyzed within the concept of price elasticities. Since the 1980s, various studies have calculated the price elasticities of air travel demand. The studies confirm a negative price elasticity, but one which differs greatly among the different types of customers, the region, and the length of the route. Leisure and low cost customers (LCC) are considered to be more price sensitive than business travelers (Brons et al. 2002; IATA 2008). Mean estimates of overall price elasticity in the EU range between –0.8 (European Commission 2005) to –1.4 (InterVistas 2007). Hence some authors suggest that the reaction of air travel demand to price changes is almost inelastic, with elasticities of only –0.29 to –0.44 (Molloy et al. 2012). A recent publication by the European Commission differentiates by route length and assumes the highest price elasticity for domestic traffic (–1.23). Intra-EU traffic (–1.12) and intercontinental traffic (–0.89) have lower elasticities due to the declining number or complete lack of possibilities for using other modes of transportation (European Commission 2019).[33] Figure 4.3 shows a chain of effects including the assumptions discussed in this chapter.

[33] Price reactions for first and business class travelers are seen to be 0.552 points lower than for leisure travelers.

Figure 4.3: The impact of the EU ETS on aviation demand



Source: Based on Barbot et al. 2014; Brander and Zhang 1990; European Commission 2019; Koopmans and Lieshout 2016; Nava et al. 2018; Vespermann and Wittmer 2011.

4.2.4. Methodology

The Gravity Model

An empirical analysis of the effects of the EU ETS on aviation demand needs to be conducted on a country-pair level, as the EU ETS only applies to intra-EEA air traffic. The empirical model commonly used for analyzing interactions between countries is the gravity model. The model is based on Newton's law of universal gravitation, which states that the attraction between two entities depends positively upon their masses and negatively upon the distance between them (Anderson 2011; Tinbergen 1962). The following Equation (4.2.1) provides a basic one-period gravity model equation, with the amount of the predicted interaction between country i and j (Y_{ij}), the size of the masses of the two countries (GDP_i; GDP_j), the distance between the two countries and a constant α.

$$Y_{ij} = \alpha \frac{GDP_i \, GDP_j}{distance_{ij}}$$

(4.2.1)

Since the 1960s, the gravity model has been the most frequently applied toolkit for data analysis in the area of trade economics like analyzing the effects of trade policies on trade flows (Baier and Bergstrand 2007; Head and Mayer 2014). The model usually not only includes GDP as a measure of size and distance as a measure of trade costs, but also further control variables that impact bilateral trade intensity, such as common language, common borders and colonial ties. Since the seminal work by Anderson and van Wincoop and their structural specification of the gravity model of trade in 2003, multilateral resistance terms are included in the model to account for multilateral but unobservable barriers to trade (Anderson and van Wincoop 2003). The common way of controlling for these multilateral resistance terms is to add different fixed effects to the empirical model (Baldwin and Taglioni 2007; Fally 2015; Larch et al. 2019b; Santos Silva and Tenreyro 2006, 2010).[34]

The application of gravity models to the area of international trade represents the most prominent and mostly explored usage in economics. Nevertheless, gravity equations in aviation economics were formulated for air travel demand analysis and forecasting in the U.S. as early as in the 1950s (Harvey 1951; Matsumoto 2007; Richmond 1955). Harvey (1951) for example, simply related the demand for air travel to the product of the population of two cities divided by their distance. Richmond (1955) added a wide list of variables to the simple gravity equation, seeking to describe the intensity of interactions between two cities (airfreight numbers, mail and telephone contacts, rail passengers, etc.). Other variables applied to the gravity model are income and income distribution measures, education level, different employment measures, air fare levels, travel time and service frequencies (Grosche et al. 2007; Matsumoto 2007). Cristea et al. (2015) used a wide range of additional variables, such as geographic area, WTO membership and differences in annual temperature. The

[34] Hence, the practice of adding fixed effects to the model to account for multilateral resistance terms has also been criticized. See for example Cipollina et al. 2016; Hornok 2013; Stack 2009. For a discussion on alternative ways to incorporate multilateral resistance terms see Hornok 2013 and Yotov et al. 2016.

variables used in gravity models in aviation economics can largely be grouped into two categories: geo-economic and service-related (Grosche et al. 2007). Policy variables that are included in a gravity model as a main variable of interest primarily concern air travel liberalization issues and how these transportation policies affect air passenger flows (Piermartini and Rousová 2013; Zhang et al. 2018). Accounting for multilateral resistance terms in the form of different fixed effects has so far not been frequently considered in aviation economics, only a few papers have included fixed effects to the gravity model specification (Cristea et al. 2015; Geloso Grosso and Shepherd 2011; Piermartini and Rousová 2013; Zhang et al. 2018).

With regard to estimations methods of gravity models in the area of aviation economics, ordinary least squares (OLS) regression is commonly used for cross-section estimations (Boonekamp et al. 2018; Grosche et al. 2007; Hazledine 2009). Panel data gravity models are encountered less frequently. Zhang and Zhang (2016), for example, estimate a panel dataset with panel fixed effects and panel random effects, Hazledine (2017) with (pooled) OLS. Since more recently, the poisson pseudo-maximum likelihood (PPML) estimation is also applied to aviation (Cristea et al. 2015; Geloso Grosso and Shepherd 2011; Piermartini and Rousová 2013; Zhang et al. 2018). The PPML estimation can be seen as the current standard method for gravity model estimations in the area of trade economics, since the influential article by Silva and Tenreyro in 2006. In order to avoid inconsistent estimates in the presence of heteroscedasticity, the authors advocate against a log-linearized estimation and for a Poisson-based method. Moreover, PPML estimations are robust to many zero flows with regard to the dependent variables. (Fally 2015; Santos Silva and Tenreyro 2006).

Empirical Model

This study analyzes the effects of selected explanatory variables on the dependent variable: the amount of passenger flows between country i and j at time t (pax_{ijt}). The main variable of interest is EU ETS coverage in order to verify whether the demand reductions assumed by previous studies and in the theoretical considerations due to the EU ETS apply. In this paper's model, EU ETS coverage is initially represented by the dummy variable $euets$. The variable takes the value of one for all intra-EEA flights from 2012 onwards. Apart from GDP *(gdp)* representing the size of the countries, the following control variables are included: distance *(dist)*, colonial ties *(col)*, common border *(contig)* and common language *(lang).* These variables are standard gravity model variables to properly specify the bilateral costs of interactions (passenger flows) between two countries (Baier and Bergstrand 2007; Head and Mayer 2014). To account for price developments that are relevant to air passengers, the consumer price index *(conpr)* and the yearly average kerosene price *(fuel)* are included into the model. To capture the touristic relationships between two countries, the temperature difference between country i and country j are given by the variable *temp* (Cristea et al. 2015). An additional variable is the time-varying dummy for EU and EEA membership *(eea)*, which turns from zero to one if both countries of a specific country-pair belong to the EU or the EEA. Any multinational or regional integration is expected to foster air traffic activities between countries. To account for cost developments in the area of aviation apart from the kerosene price, a variable *cost* is entered. The variable incorporates fuel efficiency gains and other developments such as an increase in the numbers of flights and competitors that reduce the cost of flying for passengers. The paper's model does not contain a variable for the amount of bilateral trade between the countries, as this kind of variable is most likely to be endogenous. Rather than taking country-specific GDP values and consumer price indices, the product of countries i and j to capture the market potential and the joint effects is taken (Boonekamp et al. 2018). In aviation economics, bilateral passenger flows can be regarded as the sum of equally distributed unilateral flows, as air passengers (usually) travel there and back. The data used contains no information on where passengers come from (nationality). Therefore, there is no need to take the country-specific values for GDP and consumer price index into account.

When analyzing passenger flows within the EEA, few time-varying country-specific barriers to aviation should apply. The EEA enables the free movement of goods and people and the EU ensures a deregulated airline sector. National airlines operate throughout Europe, and time-varying costs in the aviation sector are not exclusively country-specific. The resistance terms that may stem from the fact that countries are not yet part of the EEA within the time-frame analyzed, are captured with the variable on EEA membership (*eea*). Therefore the model runs with non-time-varying country fixed effects and secondly with additional country-pair fixed effects to capture unobservable, time-invariant country-specific and route-specific resistance terms. Instead of entering time-variant country fixed effects or additional time fixed effects, the variable cost is included in the model to account for time-specific cost developments in more detail than it would be possible with time dummies. The model is estimated using the poisson pseudo-maximum likelihood (PPML) estimation, since the data used in this paper – like trade data generally as well - is heteroscedastic (Larch et al. 2019b).[35] It has been proved in several studies with regards to trade economics that using a log-linearized specification (like OLS) would lead to inconsistent results in the presence of heteroscedasticity (Fally 2015; Larch et al. 2019b; Santos Silva and Tenreyro 2006, 2010, 2011). The inconsistency of the results has been proved especially with regards to the effects of policy dummy variables. Moreover when using a Poisson-based estimation, the dependent variable is not log-linearized and zero flows therefore are kept in the sample. Equation (4.2.2) represents the basic gravity model regression equation in PPML-form (Larch et al. 2019b), with the coefficients β_1 *to* β_{11}, the fixed effects $\nu_{i,j/ij}$ and the error term ε_{ijt}. All continuous variables, with the exception of the dependent variable, are converted to the natural log-form.

$$
\begin{aligned}
pax_{ijt} = \ exp\,\big[\,&\beta_1\,ln\big(gdp_{ijt}\big) + \beta_2\,ln\big(conpr_{ijt}\big) + \beta_3\,ln\big(temp_{ij}\big) + \beta_4\,ln\big(dist_{ij}\big) + \beta_5\,col_{ij} \\
&+ \beta_6\,contig_{ij} + \beta_7\,lang_{ij} + \beta_8\,eea_{ijt} + \beta_9\,ln(cost_t) + \beta_{10}\,ln(fuel_t) \\
&+ \beta_{11}euets_{ijt} + \nu_{i,j/ij}\big] + \varepsilon_{ijt}
\end{aligned}
\tag{4.2.2}
$$

Robustness checks

Different additional estimations as robustness checks are performed: First, the influence of the EU ETS is compared with that of another environmental policy measure. As mentioned in the Background chapter, 4.2.2, some countries levy passenger taxes on aviation. Therefore a dummy variable *tax* instead of the EU ETS dummy will be inserted in the gravity equation. The

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[35] See Fally 2015; Santos Silva and Tenreyro 2006. The White test is performed to check for heteroscedasticity, and the null hypothesis (the data is homoscedastic) was clearly rejected.

dummy takes the value of one, if a national aviation tax with specific country-pairs applies (Equation (4.2.3)).

$$pax_{ijt} = exp\left[\beta_1 \, ln(gdp_{ijt}) + \beta_2 \, ln(conpr_{ijt}) + \beta_3 \, ln(temp_{ij}) + \beta_4 \, ln(dist_{ij}) + \beta_5 \, col_{ij} + \beta_6 \, contig_{ij} + \beta_7 \, lang_{ij} + \beta_8 \, eea_{ijt} + \beta_9 \, ln(cost_t) + \beta_{10} \, ln(fuel_t) + \boldsymbol{\beta_{11} tax_{ijt}} + v_{i,j/ij}\right] + \varepsilon_{ijt}$$

(4.2.3)

Second, the dummy policy variables *euets* and *tax* will be substituted with the actual prices of that policy measure, to attain a finer analysis. Although it is common practice with gravity models to estimate the effects of policy measures by inserting dummies into the model, this procedure is not free from disapproval and might give inconsistent results (Benedictis and Taglioni 2011). In a first step therefore the *euets* dummy will be substituted with the yearly average EU ETS allowance price (*euets_price*). Additionally, the annual prices per passenger and route length are calculated for the EU ETS, the tax and the fuel price variable (*euets_pax*, *tax_pax* and *fuel_pax*). For both robustness checks two and three, instead of logs, the squared root of the newly constructed variables is taken to keep zero values on city-pairs and or time-ranges that are not covered by the policy measure (Equations (4.2.4), (4.2.5) and (4.2.6). To calculate fuel prices per passenger and distance the average kerosene consumption per passenger is combined with the distances between each country-pair and the respective annual fuel price. To calculate the passenger- and route-specific EU ETS prices, the average amount of CO_2 emitted per liter of kerosene per passenger is combined with the annual EUA allowance prices and the route length.[36]

$$pax_{ijt} = exp\left[\beta_1 \, ln(gdp_{ijt}) + \beta_2 \, ln(conpr_{ijt}) + \beta_3 \, ln(temp_{ij}) + \beta_4 \, ln(dist_{ij}) + \beta_5 \, col_{ij} + \beta_6 \, contig_{ij} + \beta_7 \, lang_{ij} + \beta_8 \, eea_{ijt} + \beta_9 \, ln(cost_t) + \beta_{10} \, ln(fuel_t) + \boldsymbol{\beta_{11} sq(euets\_price_{ijt})} + v_{i,j/ij}\right] + \varepsilon_{ijt}$$

(4.2.4)

[36] Further details on how the variables are calculated will follow in the next table.

$$pax_{ijt} = exp\left[\beta_1 \, ln(gdp_{ijt}) + \beta_2 \, ln(conpr_{ijt}) + \beta_3 \, ln(temp_{ij}) + \beta_4 \, ln(dist_{ij}) + \beta_5 \, col_{ij} + \beta_6 \, contig_{ij} + \beta_7 \, lang_{ij} + \beta_8 \, eea_{ijt} + \beta_9 \, ln(cost_t) + \boldsymbol{\beta_{10}} \, \boldsymbol{sq}(\boldsymbol{fuel\_pax_{ijt}}) + \boldsymbol{\beta_{11}} \boldsymbol{sq}(\boldsymbol{euets\_pax_{ijt}}) + \nu_{i,j/ij}\right] + \varepsilon_{ijt}$$

(4.2.5)

$$pax_{ijt} = exp\left[\beta_1 \, ln(gdp_{ijt}) + \beta_2 \, ln(conpr_{ijt}) + \beta_3 \, ln(temp_{ij}) + \beta_4 \, ln(dist_{ij}) + \beta_5 \, col_{ij} + \beta_6 \, contig_{ij} + \beta_7 \, lang_{ij} + \beta_8 \, eea_{ijt} + \beta_9 \, ln(cost_t) + \boldsymbol{\beta_{10}} \, \boldsymbol{sq}(\boldsymbol{fuel\_pax_{ijt}}) + \boldsymbol{\beta_{11}} \boldsymbol{sq}(\boldsymbol{tax\_pax_{ijt}}) + \nu_{i,j/ij}\right] + \varepsilon_{ijt}$$

(4.2.6)

Third, in this paper a novel variable is constructed to perform a placebo test.[37] The placebo variable simulates the EU ETS in force between 2004 and 2007 rather than since 2012. This test is performed using a dummy (*placebo*), a yearly average allowance price (*placebo_price*) and a calculated price per passenger and route length (*placebo_pax*). In the fourth and final robustness test, the main estimations are run with different sets of fixed effects and particularly with time-varying country fixed effects together with time-invariant country-pair fixed effects, to account for the current standard of fixed effect specifications in trade economics. The use of country fixed effects together with country-pair fixed effects has been widely accepted within trade economics; with panel data, time-varying country fixed effects are accompanied by time-invariant country-pair fixed effects (Baldwin and Taglioni 2007; Fally 2015; Larch et al. 2019b; Santos Silva and Tenreyro 2006, 2010). The aim of this paper is to verify whether the assumption made in the empirical model to use time-invariant country fixed effects in conjunction with the chosen control variables and especially with the cost index variable is plausible for the analysis of passenger flows within the EEA.

[37] Aichele and Felbermayr 2013 performed a placebo test to verify the effect of the Kyoto Protocol on CO_2 emissions by changing the year of the Kyoto ratification to a 'placebo' year.

4.2.5. Data

Data on passenger flows was retrieved from the Eurostat database (Eurostat 2020b). The data excludes intra-country passenger flows by purpose, as domestic air transportation competes strongly with other modes of transport like transportation by train and car. The time range in Eurostat covers the years since 1993, but comprehensive data is only available from the beginning of the 2000s. Therefore data from 2002–2018 is used, and the final dataset includes 407 country-pair combinations on intra-EEA traffic. Eurostat distinguishes between passengers on board and passengers carried, with passengers carried including all passengers on a particular flight counted only once on each individual stage of that flight. In this analysis, passengers carried is taken in order not to double count passengers (Eurostat 2020a, 2020b, 2020c). To account properly for an estimation with country fixed effects, unilateral flows are used instead of bilateral flows. To retrieve unilateral flows, the reported bilateral flows were divided by two (as air passengers usually travel vice-versa) and assigned the unilateral flows to the each travel direction of a country-pair. The amount of zero flows in the dataset is approximately 5%. Data on GDP and the consumer price index as geo-economic variables originates from the World Bank Database (World Bank 2019). The standard gravity model variables of distance, colonial ties, common borders and common language stem from the CEPII gravity dataset (CEPII 2011). Average temperature per country data comes from the World Bank's Climate Change Knowledge Portal (Cristea et al. 2015; World Bank 2011). The monthly average kerosene prices per gallon in US dollars are taken from the U.S. Energy Information Administration (EIA) and converted into yearly average prices (U.S. Energy Information Administration 2020). Daily EU ETS allowance prices are taken from the Sandbag Climate Campaign CIC and similarly converted into yearly average prices (Sandbag Climate Campaign CIC 2020). The annual reduction in the average cost of flying is calculated at 2.5% p.a. with the year 2002 indexed to one. The variable incorporates fuel efficiency gains and further developments that reduce the cost of flying for passengers (such as increased flights and competitors). Information as to which countries in the dataset levy a flight departure tax originates from the European Commission (European Commission 2019). In the used time range, only Austria and Germany levied a new air transportation tax, both of which were implemented in 2011. The taxes apply for all country-pairs from and to Austria and Germany, respectively. In France, Italy and the United Kingdom, existing aviation taxes had been in place since before 2002. The placebo variable is equivalent to the EU ETS variable, but covers the time period 2004–2007.

To calculate prices per passenger and distance for fuel-consumption, the average kerosene consumption in 2017 is regressed back as far as 2002. Moreover, the average kerosene consumption per passenger is combined with the distances between each country-pair to generate the passenger- and route-specific value of the fuel usage. To calculate the passenger- and route-specific EU ETS and placebo EU ETS prices, the average amount of CO_2 emitted per liter of kerosene per passenger was combined with the distance and the annual EUA allowance prices.[38] For the passenger- and route-specific value of the tax it is possible to take the official values of the charges, as they are defined per passenger and country-pair. Table 4.12 and Table 4.13 give an overview of the variables included in the model and Table 4.13 gives the calculated prices of fuel usage, the EU ETS, the tax and placebo EU ETS per passenger, and route length.

[38] The average fuel consumption per passenger per 100 km in 2017 was 3.58 liters of kerosene. One liter of kerosene accounts for 25g CO_2. The data originates from the German Aviation Association 2018 as data from the International Air Transport Association (IATA) includes worldwide figures. For regressing the fuel consumption back until 2002, different fuel efficiency gain figures are taken (2010–2018: 1%; 2002–2009: 2%) based on EASA 2019 When calculating the costs for the allowances, the opportunity costs were also considered with a 100% pass-through rate as in Malina et al. 2012; Peter et al. 2016; Wit et al. 2002.

Table 4.12: Information on variables

Variable	Explanation	Description	Data sources
Dependent variable:			
pax_{ijt}	unilateral passenger flows between country i and j at time t	continuous, time-variant	Eurostat
Control variables for basic model:			
gdp_{ijt}	GDP at constant 2010 US$ of country i and j at time t; (gdp_{it} * gdp_{jt})	continuous, time-variant	World Bank Database
$conpr_{ijt}$	consumer price index of country i and j at time t, 2010 = 100; (con_pr_{it} * con_pr_{jt})	continuous, time-variant	World Bank Database
$temp_{ij}$	difference in average yearly temperature between country i and j (|temp i - temp j|)	continuous, time-invariant	World Bank Database
$dist_{ij}$	distance between country i and j	continuous, time-invariant	CEPII Gravity Dataset
col_{ij}	colonial ties between country i and j (yes=1; no=0)	dummy, time-invariant	CEPII Gravity Dataset
$contig_{ij}$	common border between country i and j (yes=1; no=0)	dummy, time-invariant	CEPII Gravity Dataset
$lang_{ij}$	common language of country i and j (yes=1; no=0)	dummy, time-invariant	CEPII Gravity Dataset
eea_{ijt}	indicating, if country-pair ij belongs to EU or EEA at time t (yes=1; no=0)	dummy, time-variant	European Commission
$cost_t$	yearly change in average cost of flying, 2002=1 with efficiency gains of 2.5% p.a.	continuous, time-variant	Own calculations
$fuel_t$	yearly average kerosene price per gallon in US$, calculated from monthly averages	continuous, time-variant	U.S. Energy Information Administration
$euets_{ijt}$	indicating, if country-pair ij is covered by the EU ETS at time t (yes=1; no=0), since 2012	dummy, time-variant	European Commission

Table 4.13: Additional control variables for robustness checks

Variable	Explanation	Description	Data sources
tax_{ijt}	indicating, if country-pair ij is covered by the Austrian or German air transportation tax at time t (yes=1; no=0), since 2011	dummy, time-variant	European Commission
$placebo_{ijt}$	indicating, if country-pair ij is covered by a placebo EU ETS at time t (yes=1; no=0), years 2004-2007	dummy, time-variant	Own calculations
$euets\_price_{ijt}$	yearly average EU ETS allowance (EUA) price per ton CO_2 in euro, calculated from monthly averages	continuous, time-variant	Sandbag Climate Campaign CIC
$fuel\_pax_{ijt}$	kerosene price per passenger and country-pair (kerosene price per passenger in t * $distance_{ij}$)	continuous, time-variant	Own calculations, U.S. Energy Information Administration, German Aviation Association
$euets\_pax_{ijt}$	EU ETS allowance price per passenger and country-pair (euets price per passenger in t * $distance_{ij}$)	continuous, time-variant	Own calculations, Sandbag Climate Campaign CIC, German Aviation Association
tax_pax_{ijt}	tax amount per passenger and $country\text{-}pair_{ij}$ at time t	continuous, time-variant	Own calculations, German and Austrian Government
$placebo\_pax_{ijt}$	placebo allowance price per passenger and country-pair (placebo price per passenger in t*$distance_{ij}$)	continuous, time-variant	Own calculations, Sandbag Climate Campaign CIC, German Aviation Association

Table 4.14: Variable values per passenger and route length (country-pair)

Variable	fuel_pax	euets_pax	tax_pax	placebo_pax
Observations > 0	13838	5644	880	3256
Mean	30,06	0,95	7,17	1,06
Std. Dev.	19,55	0,71	1,02	0,84
Min	0,53	0,02	3,50	0,02
Max	124,90	5,32	8,00	5,32
Currency	USD	euro	euro	euro

Source: Own calculations using data from the German Aviation Association 2018; Sandbag Climate Campaign CIC 2020; U.S. Energy Information Administration 2020. Calculations for euets_pax and placebo_pax include opportunity costs.

4.2.6. Results and discussion

Columns (1) and (2) in Table 4.15 display the regression results of the basic gravity model equation that incorporate the EU ETS dummy variable.[39] The coefficients of the variables GDP, temperature differences, colonial ties, common language, EEA and cost developments show the expected signs and are all significant at the 1% or 5% level. Concerns of multicollinearity especially concerning the variables euets and eea, have been checked. The mean VIF (Variable Inflation Factor) of the basic regression is 3.21, for euets the VIF is 3.98 and for eea the VIF is 1.52. Only the variable cost shows a higher VIF (10.46) which is still acceptable for control variables in a large dataset. The variables consumer price and common border also give the expected negative direction of influence, though not to a significant degree. Distance is, as commonly experienced for gravity models, negatively linked, but does not show a strong influence. Hence, the variable did not give clear results in previous studies on the effects on passenger flows (Hazledine 2017), indicating a possible non-linear relationship between distance and passenger numbers. The effect can be seen in conjunction with the variable common border, which also exhibits a negative influence. The impact of the kerosene price was expected to be stronger and significant. Though the circumstance that airlines hedge against price and currency changes with regard to kerosene price could be an explanation for

[39] All regressions are computed with the Stata command *ppmlhdfe* by Correia et al. 2020.

the weak influence of fuel price changes on the amount of passengers. The main variable of interest, EU ETS coverage, indicates a small negative effect on passenger flows in regressions (1) and (2) (coefficients –0.026 and –0.025), though not to a significant degree. The demand effects due to the EU ETS coverage would apply to a reduction of up to –2.57% and –2.47%.[40]

Regressions (3) to (6) reveal the results of the first robustness check. Entering a different policy measure, namely the air transportation tax, shows that the influence of this policy measure is apparently higher (coefficients –0.131 and –0.062) than the influence of the EU ETS on passenger flows and distinctly significant at the 1% and 5% level. The impact of the tax leads to a reduction in passenger flows of –12.28% and –6.01%. Adding the additional variable tax together with the EU ETS dummy (regressions (5) and (6)) into the model, leads to an impact of the EU ETS of zero and –1.49% (coefficients 0.000 and –0.015). The influence of all other independent variables basically remains unchanged when entering the additional variable *tax*. With regard to test statistics, only the regressions with country fixed effects (regressions (1), (3) and (5)) pass the Reset test,[41] therefore the second and third robustness check only run with simple country fixed effects.

[40] To calculate the elasticities: 100 * (exp(β) – 1); with the estimated coefficient β.

[41] To check the adequacy of the model the Ramsey (RESET) test is performed like in Santos Silva and Tenreyro 2006. The model is considered to suffer from misspecification if $p < .05$ (5% significance level).

Table 4.15: Basic estimation and robustness check with tax dummy

Estimation	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML
Variable(s) of interest	EUETS: Dummy	EUETS: Dummy	Tax: Dummy	Tax: Dummy	EUETS & Tax: Dummy	EUETS & Tax: Dummy
Fixed effects	Country	Country and Pair	Country	Country and Pair	Country	Country and Pair
ln(gdp)	0.490***	0.491***	0.502***	0.500***	0.501***	0.490***
	(0.101)	(0.102)	(0.099)	(0.095)	(0.108)	(0.104)
ln(conpr)	-0.195	-0.186	-0.291	-0.241	-0.290	-0.231
	(0.234)	(0.235)	(0.235)	(0.229)	(0.241)	(0.235)
ln(dist)	-0.165*	0.000	-0.167*	0.000	-0.167*	0.000
	(0.090)	(.)	(0.090)	(.)	(0.090)	(.)
ln(temp)	0.177***	0.000	0.177***	0.000	0.177***	0.000
	(0.055)	(.)	(0.055)	(.)	(0.055)	(.)
colony	0.901***	0.000	0.914***	0.000	0.914***	0.000
	(0.182)	(.)	(0.178)	(.)	(0.178)	(.)
contig	-0.074	0.000	-0.076	0.000	-0.076	0.000
	(0.125)	(.)	(0.125)	(.)	(0.125)	(.)
comlang	0.499**	0.000	0.480**	0.000	0.480**	0.000
	(0.207)	(.)	(0.199)	(.)	(0.199)	(.)
eea	0.532***	0.516***	0.528***	0.520***	0.528***	0.519***
	(0.070)	(0.069)	(0.073)	(0.069)	(0.073)	(0.069)
ln(cost)	-1.492***	-1.484***	-1.647***	-1.515***	-1.648***	-1.564***
	(0.267)	(0.268)	(0.279)	(0.274)	(0.266)	(0.263)
ln(fuel)	-0.010	-0.009	0.004	-0.000	0.004	-0.003
	(0.017)	(0.017)	(0.018)	(0.017)	(0.019)	(0.018)
euets	-0.025	-0.026			-0.000	-0.015
	(0.016)	(0.016)			(0.018)	(0.017)
tax			-0.131***	-0.062**	-0.131***	-0.059**
			(0.039)	(0.028)	(0.040)	(0.029)
N	13,838	13838	13,838	13,838	13,838	13,838
R^2	0.9153	0.9834	0.9149	0.9832	0.9149	0.9832
RESET test p-values	0.1064	0.0004	0.1861	0.0043	0.1859	0.0032

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

The regression results of the second robustness check, which uses more precise policy variables than the previous regressions with dummy variables, are shown in Table 4.16. First the annual EU ETS allowance price *euets_price* is included in the model (regression (7)) in place of the dummy *euets*. The results indicate that the influence of the EU ETS is -0.10%, while when the passenger- and route-specific variable *euets_pax* is entered, the influence of the EU ETS is -1.5% (regression (8)). However the results concerning the EUETS remain not significant. With regard to tax, the negative and significant influence is confirmed by the finer analysis, though leading to smaller demand reductions of –3.60% (regressions (9) and (10)). The influence of the fuel variable turns distinctly negative (–0.090 and –0.087) and is significant at the 1% level, when entering passenger- and route-specific variables. With regards to the other independent variables, three of them change in their direction of impact and in their significance. That are the variables distance, cost and the consumer price. In the newly entered passenger– and route specific variables, the information on the distance and also the fuel efficacy gains are already included, so the variables distance and cost loose their impact and significance. The impact of the consumer price index changes from negative to positive and to highly significant. Theoretically, both directions of the influence of the consumer price on passenger flows could be justified. Higher prices lead to a reduced demand and on the other hand rising prices indicate economic prosperity leading to rising demand in air services.

Table 4.16: Robustness check with passenger- and route-specific variable

Estimation	(1) PPML	(7) PPML	(8) PPML	(3) PPML	(9) PPML	(10) PPML
Variable(s) of interest	EUETS: Dummy	EUETS: Market price	EUETS: Pax- and route-specific	Tax: Dummy	Tax: Pax- and route-specific	EUETS & Tax: Pax- and route-specific
ln(gdp)	0.490***	0.507***	0.537***	0.502***	0.542***	0.532***
	(0.101)	(0.096)	(0.097)	(0.099)	(0.101)	(0.100)
ln(conpr)	-0.195	-0.210	0.748***	-0.291	0.685***	0.679***
	(0.234)	(0.229)	(0.230)	(0.235)	(0.230)	(0.230)
ln(dist)	-0.165*	-0.165*	0.024	-0.167*	0.013	0.017
	(0.090)	(0.090)	(0.092)	(0.090)	(0.092)	(0.092)
ln(temp)	0.177***	0.177***	0.179***	0.177***	0.179***	0.179***
	(0.055)	(0.055)	(0.054)	(0.055)	(0.055)	(0.055)
colony	0.901***	0.901***	0.887***	0.914***	0.897***	0.897***
	(0.182)	(0.182)	(0.180)	(0.178)	(0.177)	(0.177)
contig	-0.074	-0.074	-0.067	-0.076	-0.069	-0.069
	(0.125)	(0.125)	(0.121)	(0.125)	(0.122)	(0.122)
comlang	0.499**	0.499**	0.509**	0.480**	0.496**	0.496**
	(0.207)	(0.207)	(0.200)	(0.199)	(0.195)	(0.195)
eea	0.532***	0.533***	0.475***	0.528***	0.470***	0.472***
	(0.070)	(0.070)	(0.066)	(0.073)	(0.068)	(0.068)
ln(cost)	-1.492***	-1.412***	-0.182	-1.647***	-0.314	-0.382
	(0.267)	(0.277)	(0.294)	(0.279)	(0.277)	(0.295)
ln(fuel)	-0.010	-0.005		0.004		
	(0.017)	(0.016)		(0.018)		
fuel_pax			-0.090***		-0.087***	-0.087***
			(0.011)		(0.011)	(0.011)
euets	-0.025					
	(0.016)					
euets_price		-0.001				
		(0.004)				
euets_pax			-0.015			-0.016
			(0.019)			(0.020)
tax				-0.131***		
				(0.039)		
tax_pax					-0.036**	-0.036**
					(0.014)	(0.014)
N	13,838	13,838	13,838	13,838	13,838	13,838
R^2	0.9153	0.9153	0.9153	0.9149	0.9149	0.9148
RESET test p-	0.1064	0.1313	0.0854	0.1859	0.1319	0.1087

All regressions with country fixed effects, robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4.17 shows the results of the third robustness test, the placebo test. The variable for EU ETS coverage is substituted by a placebo variable indicating the EU ETS in force between 2004 and 2007. Comparing the effects of a placebo treatment with the effect of the EU ETS shows that in the time range 2004–2007, the placebo variable brings about positive effects on passenger flows (coefficients 0.044, 0.014 and 0.077). Moreover, the influence of the placebo variables is distinctly significant at the 1% and 5% level.[42] As shown in the Literature chapter (4.2.2), business-as-usual growth rates at that time were about 4% p.a., which would accomplish with the influence of the placebo dummy variable *placebo* in regression (11).

Table 4.17: Robustness check with placebo variable

Estimation	(11) PPML	(12) PPML	(13) PPML
Variable of interest	Placebo: Dummy	Placebo: Market price	Placebo: Pax- and route-specific price
Fixed effects	Country	Country	Country
ln(fuel)	-0.015	-0.015	
	(0.018)	(0.018)	
fuel_pax			-0.097***
			(0.011)
placebo	0.044**		
	(0.017)		
placebo_price		0.014**	
		(0.005)	
placebo_pax			0.077***
			(0.011)
N	13,838	13,838	13,838
R^2	0.9158	0.9158	0.9159
RESET test p-values	0.1013	0.0965	0.0245

All regressions with country fixed effects, robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Note: The results of the control variables do not change significantly and are therefore not displayed in this table.

[42] The results of the control variables do not change significantly and are therefore not displayed in Table 4.17. See Table 4.19 for the complete regression results.

In the final robustness check, the regressions with different fixed effects (FE) specifications (Table 4.20, Table 4.21 and Table 4.22 in the Appendix) are estimated. Regressions A1 give the estimates of the basic and preferred model, regressions A2 to A6 are with changing fixed effects. Of most interest are the regressions A6 with time-varying country FE and country-pair FE, representing the current standard specification in trade economics. In Table 4.20 (EU ETS dummy) and Table 4.21 (EU ETS price) the regressions A6 indicate a small negative, though not significant influence (–0.026 and –0.010) on passenger flows. The results are in line with the estimates of this paper's basic estimation with country fixed effects. However, in both Table 4.20 and Table 4.21, the regressions A6 fail the Reset test. Moreover, only significant results are that of estimates A3 and A4 with elasticities about –24% and –10%. But given the forecasted effects of the EU ETS (see chapter 4.2.2), it can be doubted that the EU ETS has had such a strong demand-reducing influence on passenger flows. With regard to the tax dummy (Table 4.22), all additional regressions confirm the negative influence of the tax, though with quite different values of the coefficients for the significant results (between –1.148 and –0.062). Estimation A5 with country-time FE is obviously overestimated (–1.148), while estimation A6 with the additional country-pair FE (–0.171) ranges more closely to this paper's estimates but would not pass the Reset Test.[43]

Table 4.18 summarizes the findings on the effects of the EU ETS and the air transportation tax on passenger flows. The regression results are compared with calculated demand reduction due to the theoretical price elasticities and with previous studies. To calculate the demand reductions due to theoretical price elasticities, the mean values of the EU ETS and the tax per passenger and route (0.95 Euro and 7.17 Euro, see Table 4.14) are combined with the given price elasticities for intra-EU traffic (–1.12).44 Looking at the impact of the EU ETS on demand, elasticities from the regressions range between –2.47% and 0.00%, but are statistically not significant. The calculated demand elasticity from the theoretical assumptions is –1.07%. The

[43] Additionally, I ran the basic estimation, the robustness check with the tax and the robustness checks with different fixed effects also with OLS. The effect of the dummy variable *euets* seems to be overestimated, hence the results of the variables *euets_price* and *euets_pax* seem to be more in line with the PPML results. The results of the estimation with country-time and country-pair effects does not give rational results (-0.717) for the EU ETS dummy. See Table 4.23 and Table 4.24 in the Appendix.
[44] Additionally, an average one-way ticket price within the EEA of 100 Euro is assumed.

literature review basically gives the same results, with forecast demand reductions between –0.1% and –1.3%. For the tax, the significant elasticities resulting from this study's estimations are –12.28% and –3.60%; the theoretical demand elasticity is –8.03%. A previous study on the effect of the Austrian and German transportation tax revealed reductions of –9% (first year) and –5% (subsequent years). This paper's results are in line with theoretical demand elasticities and previous studies, though the estimations using the dummy variables seem to overestimate the policy effect. Though none of the results estimated in this study are significant. It can be therefore concluded that the EU ETS has until now had no significant demand effect.

Table 4.18: Summary of results

	Regressions			Theory	Previous simulations
EU ETS	Estimation	Coefficients	Elasticities[1]	Elasticities[2]	Elasticities[3]
	(1) EUETS: Dummy	-0.025	-2.47%	-1,07%	between -0.1% and -1.3%
	(10) EUETS & Tax: Price per pax and route	-0.016	-1.60%		
	(8) EUETS: Price per pax and route	-0.015	-1.50%		
	(7) EUETS: Market price	-0.001	-0.10%		
	(5) EUETS & Tax: Dummy	-0.000	0.00%		
	Regressions			Theory	Previous studies
Tax	Estimation	Coefficients	Elasticities[1]	Elasticities[2]	Elasticities[4]
	(3) Tax: Dummy	-0.131***	-12,28%	-8,03%	-9% / -5%
	(5) EUETS & Tax: Dummy				
	(9) Tax: Price per pax and route	-0.036**	-3,60%		
	(10) EUETS & Tax: Price per pax and route				

Notes: (1) Elasticities of the dummy variables are calculated with the formula: 100 * (exp(β) – 1); with the estimated coefficient β; (2) To calculate the theoretical elasticities, the mean price of the EU ETS and the tax per passenger and route are multiplied by the average price elasticities for intra-EEA traffic (–1.12) and an assumed average one-way ticket price of 100 Euro; (3) see European Commission 2006; Scheelhaase and Grimme 2007; Wit et al. 2005; (4) see Falk and Hagsten 2019. Pax = Passenger. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

4.2.7. Conclusion and policy implications

This paper analyzed the influence of the European Emissions Trading System (EU ETS) on the amount of passenger flows using a gravity model approach with a fixed effects. The regressions with the poisson pseudo-maximum likelihood (PPML) estimator show the following results: the EU ETS has up to now had no significant demand-reducing effect on passenger flows. The aviation tax, which was controlled for, shows a significant and robust negative effect on passenger flows (see Table 4.18). Because prices per passenger of the Austrian and German aviation tax are much higher than the EU ETS price per passenger, theoretical demand elasticities support the stronger effect of the tax on passenger flows.

But although the tax reduces demand, this policy may still not be the adequate measure. The tax value does not relate to the amount of CO_2 emitted by air travel; rather, it is levied per passenger. Generally, policy instruments are preferred that incentivize emission reductions, as is the case with kerosene taxes or an emissions trading system (ETS). Since 2018, the price of EU ETS allowances rose significantly to over 20 euros. It has yet to be seen whether the higher price of the allowances will lead to the EU ETS having a greater effect. The EU ETS has been in the third phase since 2013, and the European Commission has committed to continuing the EU ETS for aviation until 2023. As of 2024, the scope of the EU ETS for aviation has not yet been determined. Also, a global solution, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), is being discussed, but which only would cover emissions from additional air traffic growth in international aviation. Therefore, in order to be able to use air travel services and not harm the climate, it is both essential and urgent that an emission-friendly technology is found. Only a few airlines have so far conducted flight tests with biofuels (EASA 2019), for example. It should be in the interest of governments and international institutions alike to focus more on this issue and to invest in research on alternative and sustainable fuels and electric aviation engines.

With regards to the adaptation of the gravity model of international trade to the area of aviation economics, more research and contributions would appear necessary in light of the adequate model specifications. Most importantly, this implies controlling correctly for multilateral resistance terms in the form of fixed effects. A fixed effects setting other than those used in trade economics appears necessary to enable the correct specification of a gravity model in aviation economics. The assumptions in aviation economics seem to be quite different, especially when analyzing a joint economic region like the European Economic Area (EEA), where there are few frictions to aviation and time-varying costs are not country-specific. Therefore time invariant country fixed effects were used in this paper instead of time-varying country fixed effects. To capture time-varying cost effects, a cost index variable was used in the estimations. All in all, few papers have until now addressed the issue of fixed effects in the context of aviation economics, and in particular for panel data estimations using the PPML estimator.

Appendix

Table 4.19: Robustness check with placebo variable – complete table

Estimation	(11) PPML	(12) PPML	(13) PPML
Variable of interest	Placebo: Dummy	Placebo: Market price	Placebo: Pax- and route-specific price
Fixed effects	Country	Country	Country
ln(gdp)	0.472***	0.469***	0.460***
	(0.101)	(0.102)	(0.102)
ln(conpr)	-0.113	-0.128	0.928***
	(0.241)	(0.239)	(0.239)
ln(dist)	-0.167*	-0.166*	0.030
	(0.090)	(0.090)	(0.092)
ln(temp)	0.177***	0.177***	0.179***
	(0.055)	(0.055)	(0.054)
colony	0.900***	0.900***	0.887***
	(0.182)	(0.182)	(0.180)
contig	-0.075	-0.075	-0.067
	(0.125)	(0.125)	(0.121)
comlang	0.497**	0.497**	0.509**
	(0.207)	(0.207)	(0.200)
eea	0.515***	0.518***	0.449***
	(0.071)	(0.071)	(0.068)
ln(cost)	-1.387***	-1.400***	-0.086
	(0.278)	(0.277)	(0.283)
ln(fuel)	-0.015	-0.015	
	(0.018)	(0.018)	
fuel_pax			-0.097***
			(0.011)
placebo	0.044**		
	(0.017)		
placebo_price		0.014**	
		(0.005)	
placebo_pax			0.077***
			(0.011)
N	13,838	13,838	13,838
R2	0.9158	0.9158	0.9159
RESET test p-values	0.1013	0.0965	0.0245

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4.20: Robustness check (euets dummy) with different fixed effects

Estimation	(A1) PPML	(A2) PPML	(A3) PPML	(A4) PPML	(A5) PPML	(A6) PPML
Variable(s) of interest	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy
Fixed effects	Country	Country and Pair	Country and time	Country, Pair and time	Country-time	Country-time and pair
ln(gdp)	0.490***	0.491***	0.234*	0.226*	0.000	0.000
	(0.101)	(0.102)	(0.121)	(0.122)	(.)	(.)
ln(conpr)	-0.195	-0.186	0.266	0.294	0.000	0.000
	(0.234)	(0.235)	(0.262)	(0.265)	(.)	(.)
ln(dist)	-0.165*	0.000	-0.165*	0.000	-0.160*	0.000
	(0.090)	(.)	(0.090)	(.)	(0.090)	(.)
ln(temp)	0.177***	0.000	0.177***	0.000	0.176***	0.000
	(0.055)	(.)	(0.055)	(.)	(0.056)	(.)
colony	0.901***	0.000	0.901***	0.000	0.898***	0.000
	(0.182)	(.)	(0.182)	(.)	(0.182)	(.)
contig	-0.074	0.000	-0.074	0.000	-0.071	0.000
	(0.125)	(.)	(0.125)	(.)	(0.125)	(.)
comlang	0.499**	0.000	0.498**	0.000	0.498**	0.000
	(0.207)	(.)	(0.207)	(.)	(0.207)	(.)
eea	0.532***	0.516***	0.505***	0.490***	0.405**	0.289*
	(0.070)	(0.069)	(0.073)	(0.072)	(0.197)	(0.175)
ln(cost)	-1.492***	-1.484***	0.000	0.000	0.000	0.000
	(0.267)	(0.268)	(.)	(.)	(.)	(.)
ln(fuel)	-0.010	-0.009	0.000	0.000	0.000	0.000
	(0.017)	(0.017)	(.)	(.)	(.)	(.)
euets	-0.025	-0.026	-0.277***	-0.280***	0.248	-0.026
	(0.016)	(0.016)	(0.054)	(0.051)	(0.222)	(0.098)
N	13,838	13,838	13,838	13,838	13,838	13,838
R^2	0.9153	0.9834	0.9175	0.9852	0.9275	0.9969
RESET test p-values	0.1064	0.0004	0.4427	0.0623	0.6277	/

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4.21: Robustness check (euets_price) with different fixed effects

Estimation	(A1) PPML	(A2) PPML	(A3) PPML	(A4) PPML	(A5) PPML	(A6) PPML
Variable(s) of interest	EUETS: Market price	EUETS: Market price	EUETS: Market price	EUETS: Market price	EUETS: Market price	EUETS: Market price
Fixed effects	Country	Country and Pair	Country and time	Country, Pair and time	Country-time	Country-time and pair
ln(gdp)	0.507***	0.508***	0.234*	0.226*	0.000	0.000
	(0.096)	(0.097)	(0.121)	(0.122)	(.)	(.)
ln(conpr)	-0.210	-0.201	0.266	0.294	0.000	0.000
	(0.229)	(0.230)	(0.262)	(0.265)	(.)	(.)
ln(dist)	-0.165*	0.000	-0.165*	0.000	-0.160*	0.000
	(0.090)	(.)	(0.090)	(.)	(0.090)	(.)
ln(temp)	0.177***	0.000	0.177***	0.000	0.176***	0.000
	(0.055)	(.)	(0.055)	(.)	(0.056)	(.)
colony	0.901***	0.000	0.901***	0.000	0.898***	0.000
	(0.182)	(.)	(0.182)	(.)	(0.182)	(.)
contig	-0.074	0.000	-0.074	0.000	-0.071	0.000
	(0.125)	(.)	(0.125)	(.)	(0.125)	(.)
comlang	0.499**	0.000	0.498**	0.000	0.498**	0.000
	(0.207)	(.)	(0.207)	(.)	(0.207)	(.)
eea	0.533***	0.517***	0.505***	0.490***	0.405**	0.289*
	(0.070)	(0.069)	(0.073)	(0.072)	(0.197)	(0.175)
ln(cost)	-1.412***	-1.405***	0.000	0.000	0.000	0.000
	(0.277)	(0.278)	(.)	(.)	(.)	(.)
ln(fuel)	-0.005	-0.005	0.000	0.000	0.000	0.000
	(0.016)	(0.017)	(.)	(.)	(.)	(.)
euets_price	-0.001	-0.001	-0.103***	-0.104***	0.092	-0.010
	(0.004)	(0.004)	(0.020)	(0.019)	(0.082)	(0.036)
N	13,838	13,838	13,838	13,838	13,838	13,838
R^2	0.9153	0.9835	0.9175	0.9852	0.9275	0.9969
RESET test p-values	0.1313	0.0006	0.5579	0.0010	0.6542	/

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4.22: Robustness check (tax dummy) with different fixed effects

Estimation	(A1) PPML	(A2) PPML	(A3) PPML	(A4) PPML	(A5) PPML	(A6) PPML
Variable(s) of interest	Tax: Dummy	Tax: Dummy	Tax: Dummy	Tax: Dummy	Tax: Dummy	Tax: Dummy
Fixed effects	Country	Country and Pair	Country and time	Country, Pair and time	Country-time	Country-time and pair
ln(gdp)	0.502***	0.500***	0.280**	0.237*	0.000	0.000
	(0.099)	(0.095)	(0.139)	(0.128)	(.)	(.)
ln(conpr)	-0.291	-0.241	0.133	0.258	0.000	0.000
	(0.235)	(0.229)	(0.277)	(0.265)	(.)	(.)
ln(dist)	-0.167*	0.000	-0.167*	0.000	-0.186**	0.000
	(0.090)	(.)	(0.090)	(.)	(0.091)	(.)
ln(temp)	0.177***	0.000	0.177***	0.000	0.176***	0.000
	(0.055)	(.)	(0.055)	(.)	(0.056)	(.)
colony	0.914***	0.000	0.912***	0.000	1.021***	0.000
	(0.178)	(.)	(0.178)	(.)	(0.174)	(.)
contig	-0.076	0.000	-0.076	0.000	-0.095	0.000
	(0.125)	(.)	(0.125)	(.)	(0.128)	(.)
comlang	0.480**	0.000	0.483**	0.000	0.317*	0.000
	(0.199)	(.)	(0.199)	(.)	(0.186)	(.)
eea	0.528***	0.520***	0.499***	0.485***	0.423**	0.291*
	(0.073)	(0.069)	(0.074)	(0.071)	(0.192)	(0.172)
ln(cost)	-1.647***	-1.515***	0.000	0.000	0.000	0.000
	(0.279)	(0.274)	(.)	(.)	(.)	(.)
ln(fuel)	0.004	-0.000	0.000	0.000	0.000	0.000
	(0.018)	(0.017)	(.)	(.)	(.)	(.)
tax	-0.131***	-0.062**	-0.113**	-0.037	-1.148***	-0.171***
	(0.039)	(0.028)	(0.046)	(0.032)	(0.208)	(0.036)
N	13,838	13,838	13,838	13,838	13,838	13,838
R^2	0.9149	0.9832	0.9168	0.9849	0.9287	0.9969
RESET test p-values	0.1861	0.0043	0.1182	0.0173	0.0016	0.0004

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4.23: Robustness check with OLS – EU ETS and tax

Estimation	OLS	OLS	OLS	OLS	OLS
Variable(s) of interest	EUETS: Dummy	EUETS: Market price	EUETS: Pax- and route-specific price	Tax: Dummy	Tax: Pax- and route-specific price
Fixed effects	Country	Country	Country	Country	Country
lngdp	0.966***	1.037***	1.075***	1.039***	1.041***
	(0.149)	(0.144)	(0.146)	(0.142)	(0.142)
lnconpr	0.469	0.439	0.477	0.424	0.426
	(0.319)	(0.321)	(0.321)	(0.319)	(0.319)
lndist	-0.897***	-0.897***	-0.904***	-0.899***	-0.898***
	(0.096)	(0.096)	(0.096)	(0.095)	(0.095)
lntemp	0.022	0.022	0.022	0.022	0.022
	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)
colony	0.642**	0.642**	0.641**	0.645**	0.644**
	(0.326)	(0.326)	(0.326)	(0.326)	(0.326)
contig	-0.643***	-0.643***	-0.644***	-0.645***	-0.644***
	(0.214)	(0.214)	(0.214)	(0.214)	(0.214)
comlang	-0.101	-0.101	-0.101	-0.109	-0.108
	(0.324)	(0.324)	(0.324)	(0.324)	(0.324)
eueea	0.280***	0.280***	0.287***	0.275***	0.277***
	(0.089)	(0.089)	(0.089)	(0.089)	(0.089)
lncost	-0.981*	-0.621	-0.041	-0.439	-0.426
	(0.507)	(0.515)	(0.537)	(0.481)	(0.481)
lnkerosene	0.040	0.055	0.073	0.078	0.075
	(0.049)	(0.048)	(0.049)	(0.049)	(0.049)
euets	-0.170***				
	(0.042)				
euets_price		-0.030**			
		(0.014)			
euets_pax			0.044		
			(0.054)		
tax				-0.220***	
				(0.058)	
tax_p					-0.078***
					(0.022)
N	13192	13192	13192	13192	13192
R^2	0.696	0.695	0.695	0.696	0.696
F	49.981	44.732	43.808	46.170	45.810

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4.24: Robustness check with OLS and different fixed effects

Estimation	OLS	OLS	OLS	OLS	OLS	OLS
Variable(s) of interest	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy	EUETS: Dummy
Fixed effects	Country	Country and pair	Country and time	Country,time and pair	Country-time	Country-time and pair
lngdp	0.966***	0.989***	0.498***	0.535***	0.000	0.000
	(0.149)	(0.144)	(0.192)	(0.187)	(.)	(.)
lnconpr	0.469	0.505*	1.260***	1.278***	0.000	0.000
	(0.319)	(0.288)	(0.373)	(0.337)	(.)	(.)
lndist	-0.897***	0.000	-0.898***	0.000	-0.887***	0.000
	(0.096)	(.)	(0.096)	(.)	(0.100)	(.)
lntemp	0.022	0.000	0.022	0.000	0.023	0.000
	(0.057)	(.)	(0.057)	(.)	(0.059)	(.)
colony	0.642**	0.000	0.639*	0.000	0.644*	0.000
	(0.326)	(.)	(0.326)	(.)	(0.337)	(.)
contig	-0.643***	0.000	-0.640***	0.000	-0.652***	0.000
	(0.214)	(.)	(0.214)	(.)	(0.221)	(.)
comlang	-0.101	0.000	-0.099	0.000	-0.118	0.000
	(0.324)	(.)	(0.325)	(.)	(0.333)	(.)
eueea	0.280***	0.358***	0.146	0.233***	0.540*	0.945***
	(0.089)	(0.079)	(0.099)	(0.087)	(0.301)	(0.206)
lncost	-0.981*	-0.924**	0.000	0.000	0.000	0.000
	(0.507)	(0.455)	(.)	(.)	(.)	(.)
lnkerosene	0.040	0.034	0.000	0.000	0.000	0.000
	(0.049)	(0.047)	(.)	(.)	(.)	(.)
euets	-0.170***	-0.180***	-0.061	-0.231*	1.562***	-0.717***
	(0.042)	(0.042)	(0.128)	(0.121)	(0.471)	(0.231)
N	13192	13192	13192	13192	13158	13158
R^2	0.696	0.883	0.697	0.884	0.718	0.903
F	49.981	86.632	14.919	13.765	17.201	10.823

Robust and clustered (by country-pair) standard errors in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

5. Conclusion and policy implications

This thesis intends to fill the research gaps explained in Chapter 1.3 concerning the effects of multinational economic agreements and of environmental policy instruments on air transport demand and concerning a correct structural gravity model specification in the field of aviation economics. The following conclusions can be drawn from the thesis:

Effect of economic agreements

Firstly, this thesis analyses the impact of different economic agreements on aviation demand. The impact of the Euro, the European Union (EU), other regional trade agreements (RTAs) and air service agreements (ASAs) on air cargo flows is analyzed and compared with their effect on trade flows and on air passenger flows. As shown by the regressions in Chapter 4.1, the effect of the EU and of other RTAs on air cargo flows is surprisingly very small and not significant or even not positive (0.047 and –0.045). The results stand in contrast to the effect of these variables on total trade flows which are positive and highly significant (0.878 and 0.535). Moreover, even the aviation specific Air Liberalization Index (ALI) only increased air cargo flows by a small degree with a coefficient of only 0.020. The Euro affects air cargo flows and air passenger flows positively and significantly (0.417 and 0.106), hence not total trade (0.008). This effect on trade flows is a result that is shared by previous research. The diverging results of air cargo flows and trade flows are therefore surprising as air cargo flows are part of total trade flows. Therefore, this thesis also analyzed to what extent air cargo flows, trade flows and air passenger flows affect each other. Bilateral air cargo flows are positively influenced by air passenger numbers but not impacted by bilateral trade numbers. Overall, air cargo could not benefit so far from multinational, regional trade agreements such as the EU and other RTAs. Hence total trade flows significantly benefitted from the EU and from other RTAs. Moreover, the amount of air cargo flows between two countries is predominantly determined by the amount air passenger demand. The introduction of this thesis mentions smaller growth rates of air cargo numbers compared to the growth rates of total trade. Air cargo may depend too much on air passenger services in order to fully exploit the effects of RTAs as trade is able to in general. Moreover, when air cargo depends this much on air passenger planes, air cargo is extremely affected by shock events that affect air passenger services, like the COVID-19 pandemic. Air cargo capacity reduced starting in March 2020 due to cancelled passenger aircraft connections and could only be partially offset by additional dedicated freighter capacity. Not only in the light of the COVID-19 pandemic, but also to be able to gain from RTAs that aim to foster trade between countries, it seems necessary to install air cargo network management that is independent from air passenger transportation services and routes. Moreover, more research is necessary in the area of the determinants of air cargo demand, as airplanes transport predominantly only special kinds of products that differ from the products that are transported by ship.

Effect of environmental policies

Secondly, the thesis aims to verify whether the expected effects on the aviation sector due to different environmental policies can be approved. Therefore this thesis compares the impact of the EU ETS with the impact of air transportation taxes on aviation demand. Environmental policies are supposed to internalize the external effects of flying by giving a price to emissions. Looking at the impact of the EU ETS on demand, elasticities from this thesis's regressions range between –2.47% and 0.00%, but are statistically not significant. The regression results are compared with calculated demand reductions due to the theoretical price elasticities (–1.07%) and with previous simulation studies (between –0.1% and –1.3%). For the tax, the significant elasticities resulting from this thesis's estimations are –12.28% and –3.60%; the theoretical demand elasticity is –8.03%. A previous study on the effect of the Austrian and German transportation tax revealed reductions of –9% and –5%. The results from this thesis are, therefore, in line with theoretical demand elasticities and previous studies, though the estimations using the dummy variables seem to overestimate the policy effect. Because prices per passenger of the Austrian and German aviation tax are much higher than the EU ETS price per passenger, theoretical demand elasticities support the stronger effect of the tax on passenger flows. Within the analyzed timeframe, the price of the EU ETS allowances was, on average, only about 7 Euros. As none of the results estimated for the EU ETS in this thesis are significant, it can be concluded that the EU ETS has, until 2018, had no significant demand reducing effect. The aviation tax shows a significant and robust negative effect on passenger flows until then. Hence, although the tax reduces demand, this policy may not be the adequate measure to reduce the environmental impact of flying. The tax value does not relate to the amount of emitted CO_2; it is a fixed amount levied per passenger. Generally, policy instruments should be preferred that incentivize emission reductions, as is the case with kerosene taxes or an emissions trading system (ETS). Since 2018, the price of the EU ETS allowances rose significantly to over 20 Euros and currently evolves at about 80 Euros. It has yet to be seen in further research whether the higher price of the allowances will lead to the EU ETS having a greater effect. Moreover, by announcing the European Green Deal in 2020 and communicating the Fit-for-55 strategy in 2021, more pressure has been put on all industry sectors by the European Commission to enhance their decarbonization process (European Commission 2021d). With regards to the aviation sector, the number of free allowances surrendered within the EU ETS might be reduced to zero until 2027 according to the EU's proposals. Apart from the EU ETS, a global solution is being implemented currently that internalizes the external effects of flying more broadly. Though, this Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) will cover only emissions from additional air traffic growth in international aviation and should therefore be implemented additionally to the current EU ETS. Moreover, additional instruments apart from the EU ETS are also being discussed within the EU'S Fit-for-55 framework. That includes a kerosene tax on intra-European aviation traffic and a binding fuel quota on sustainable aviation fuels (SAFs).

Structural gravity modelling and estimation

And lastly, this thesis applies the newest econometric advances from the area of trade econometrics to a gravity model analysis of air passenger and air cargo flows. That includes the formulation of different structural gravity models with fixed effects and their estimation with the pseudo Poisson Maximum Likelihood (PPML) estimator. Moreover, this thesis showed that instead of using policy dummies, more precise policy measures should be used if possible. As shown with this research and by previous studies, policy dummies may overestimate policy effects. This is especially important if the policy variables represent some kind of cost factor. This thesis also shows the importance of correctly controlling for the multilateral resistance terms in the form of fixed effects. The same fixed effects setting as with trade economics may apply for a worldwide air cargo analysis. Though, a different fixed effects setting appears necessary to enable the correct specification of a gravity model for air passenger flows and when analyzing a joint economic region like the European Economic Area (EEA). In the EEA few frictions apply to aviation and time-varying costs are not country-specific as airlines operate EEA-wide. Therefore, time invariant country fixed effects were used in Chapter 4.2 instead of time-varying country fixed effects. To capture time-varying cost effects, a cost index variable was used in the estimations. With regards to the adaptation of the gravity model of international trade to the area of aviation economics, more research and contributions would appear necessary in light of the adequate model specifications.

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