Carbon Cost Pass-Through in European Aviation *

Adrián Santonja[†] Jordi J. Teixidó[‡] Aleksandar Zaklan[§]

February 24, 2023

This paper studies pass-through of carbon emission costs in the aviation sector covered by the European Union's Emission Trading System (EU ETS), a setting with limited competition on many routes. We estimate pass-through using monthly data on scheduled flights, CO_2 emissions and airfares for all airport routes covered under the EU ETS, combined with information on allowance and fuel prices during 2017-2019. Preliminary results suggest an average pass-through rate of about 100%, with pass-through rates substantially above 100% for short-haul routes and on routes with higher competition intensity. While these findings are in line with theoretical predictions and results for other sectors with limited competition, they deviate from the existing evidence on the EU ETS, which finds at most full pass-through for the power sector. Our findings suggest that free allocation to airlines covered under the EU ETS may have led to windfall profits.

JEL codes: Q54, Q58, L11, L93

Keywords: Carbon cost pass-through, emission trading, EU ETS, aviation

---

[*] Adrián Santonja is thankful for financial support by the German Federal Environmental Foundation (DBU).

[†] German Institute for Economic Research (DIW Berlin) & University of Potsdam

[‡] Universitat de Barcelona

[§] Federal Ministry for Economic Affairs and Climate Action & German Institute for Economic Research (DIW Berlin)

1. Introduction

Governments increasingly recognize that man-made climate change threatens societies' long-term economic, social and political basis, spurring efforts to stabilize the atmospheric stock of greenhouse gases (GHG). Decarbonizing the transportation sector is receiving increasing attention by policymakers due to its significant share of total GHG emissions and lagging performance with respect to abatement. Within transportation, the aviation sector presents particular challenges for climate policy, as rising demand for air travel coupled with factors such as high abatement costs and limited product substitution options has led to a continued increase in emissions. For instance, European aviation emissions may increase by some 150% between 2020 and 2040 (European Commission, 2021). Unabated increases of such magnitude would threaten ambitious climate targets, such as the European objective of carbon neutrality by mid-century.

In this paper, we study the pass-through of carbon emission costs in passenger aviation to consumer ticket prices for flights covered by the European Union's Emission Trading System (EU ETS), the landmark European cap-and-trade scheme. In addition to average pass-through rates, we also consider heterogeneity in pass-through rates. The EU ETS offers a unique setting, as it is currently the only main cap-and-trade program covering aviation. Carbon cost pass-through is an important issue, as it determines whether agents in the aviation sector receive a robust carbon price signal. Only then do consumers of aviation services have an incentive to adjust their demand for air travel, while producers are incentivized to invest in abatement options. Moreover, the rate of pass-through also determines the incidence of the carbon price, i.e. whether airlines or customers ultimately bear the carbon cost. While carbon cost pass-through has been studied in a variety of setting, e.g. in power generation (Fabra and Reguant, 2014; Hintermann, 2016) and retail electricity markets (e.g. Duso and Szücs, 2017), there is limited evidence on pass-through in imperfectly competitive markets (e.g. Miller et al., 2017). To our knowledge, this paper is the first to consider carbon cost pass-through in the aviation sector, a setting with highly fragmented markets and typically very limited competition.

This paper makes two main research contributions. Our baseline analysis of pass-through contributes a missing piece to the literature by studying carbon cost pass-through in aviation, an important and under-researched sector characterized by imperfect competition. Our setting with highly granular data in the cross-sectional dimension – at the airline-route level across Europe – further allows us to contribute an analysis of heterogeneity in pass-through rates extending well beyond the possibilities for the analysis of heterogeneous effects available to the setting in power markets, e.g. Fabra and Reguant (2014).

Our analysis uses highly granular data on the aviation industry provided by RDC Aviation, a provider of data services to stakeholders in the aviation industry. Specifically, we use monthly data for the period 2017-2019 on scheduled flights, CO_2 emissions and fares for all airport routes covered under the EU ETS during the sample period, i.e. all flights between any two airports inside the European Economic Area, which includes the current 27 member states of the European Union and Norway, Iceland and the United Kingdom. We categorize airlines into three airline types: low-cost airlines, network airlines and other airlines. Our empirical analysis focuses on low-cost airlines offering point-to-point connections that are fully under the EU ETS. We combine these data with additional information on relevant input prices in the aviation industry, namely EU ETS allowance prices and jet fuel prices from Bloomberg.

The baseline empirical analysis relates data on ticket prices one month ahead of departure to carbon costs per passenger seat imposed under the EU ETS for all airline-route combinations offered by low-cost carriers. We then consider heterogeneity in several dimensions, e.g. by competition intensity – e.g. routes with only one carrier and those with several competitors –, the availability of modal shifts – e.g. routes where train connection is a realistic alternative vs. routes where this is not the case – or market segments – tickets bought early vs. shortly before departure. Another potentially interesting dimension of heterogeneity is whether pass-through rates differ depending on the allowance price level. Due to the length of the time series dimension in our data we can estimate pass-through rates both during periods of very low and fairly high allowance prices.[1]

Preliminary results indicate that airlines pass through more than 100% of CO_2 costs, with pass-through rates ranging between 100% and 200%. This result is in line with results in other sectors with limited

---

[1] The full analysis of heterogeneity in pass-through rates is underway and will be provided in time for the conference.

competition (Miller et al., 2017) and suggests that a rise in the carbon cost per airplane seat by one euro leads to an increase in air fares by about 1 to 2 euro. In addition, pass-through seems to be particularly high for oligopolistic routes (i.e. routes where more than one airline provides services but still presenting substantial market concentration) and short distances (i.e. routes of less than 500 km).[2]

Since airlines pass through carbon costs at least fully, the current practice of substantial free allocation, with about 82% of allowances earmarked for aviation distributed for free during EU ETS Trading Phase 3 (2013-2020), might have lead to the creation of windfall profits for airlines subject to the EU ETS. As carbon leakage on intra-EU flights is not a concern, free allocation to airlines hardly seems justified on the grounds of preventing such leakage. Our analysis contributes to understanding to what extent windfall profits have been realized in the European aviation sector and will support policy-makers in the design of free allocation rules for this sector.[3]

This paper fills an important gap in the literature, as to our knowledge currently there exists no empirical evidence on carbon cost pass-through in the aviation sector and very limited evidence on the transport sector in general. The latter includes analysis of environmental taxes and other carbon pricing schemes in the vehicle transport sector (Knittel et al., 2015; Stitzing, 2017; Erutku, 2019) and the maritime sector (Nolan and Mantin, 2021). The existing literature on carbon cost pass-through focuses mainly on the power sector (Fabra and Reguant, 2014; Hintermann, 2016), with some evidence also emerging for industrial sectors (Cludius et al., 2020). Moreover, we also contribute to the broader literature on cost pass-through in markets characterized by imperfect competition, where cost pass-through can be an important indicator of market power (e.g. Duso and Szücs, 2017; Miller et al., 2017). Finally, we add to the scarce and recent literature on the empirical evaluation of the EU ETS on the European aviation sector (Kang et al., 2022; de Jong, 2022; Fageda and Teixidó, 2022; Oesingmann, 2022) and expand the empirical literature on airline pricing in the aviation sector, which due to better data availability has been mainly focused on the US (Berry and Jia, 2010; Sengupta and Wiggins, 2014; Bradley and Feldman,

---

[2] This additional analysis will be deepened and expanded along a range of dimensions and will be available for presentation at the conference.

[3] The analysis on the extent of windfall profits will be available in time for the presentation at the conference.

2020).

This paper is structured as follows. Section 2 provides an overview of the policy framework, describing the design of the EU ETS in relation to the aviation sector. Section 3 describes our data sources and provides a descriptive overview of the European aviation sector. Section 4 provides details on our identification strategy and research design, while Section 5 presents the empirical analysis. Finally, Section 6 concludes.

2. Background

2.1. The inclusion of aviation in the EU ETS

Including the impact of non-CO_2 emissions in high altitudes, aviation accounts today for 6% of the global climate impact (Lee et al., 2021), a share that, given the sector's projected growth, is expected to triple by 2050 (IATA, 2022; Graver et al., 2019). However, to be consistent with the 2ºC threshold, aviation emissions in 2050 need to be between 41 and 96% lower than they were in 2005 (Cames et al., 2015).

Against this backdrop, the EU decided to include CO_2 emissions from the aviation sector into the EU ETS, starting on January 1st 2012 (Directive 2008/101/EC by the European Council & Parliament (2009)). From then on, all airlines operating in the European Economic Area (EEA) would need to monitor, report and verify their emissions, and surrender allowances against these. However, this decision met considerable resistance from foreign carriers who deemed the EU regulation a breach of non-EU countries' sovereignty. Although the Court of Justice of the EU, in response to a case brought by US airlines, ruled that the EU ETS regulation was fully consistent with international law, the European Commission decided retrospectively on April 2013 to limit the carbon pricing scheme to flights within EEA airports, leaving out flights from and to third countries. This was the so called "stop-the-clock" decision (Decision 377/2013/EU by the European Council & Parliament (2013)).

This derogation, conceived as a temporary measure, has been extended indefinitely on the grounds of allowing the international community to develop a global market-based instrument that would deal with emissions internationally under the supervision of the International Civil Aviation Organization (ICAO). The proposed instrument is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) agreed in 2016, which is currently in its pilot phase. In response, the exemption of extra-EEA flights from the EU ETS is now extended at least until 2026, when the European Commission will carry out an assessment of CORSIA's effectiveness and the extent to which it is consistent with the Paris Agreement and the European Green Deal, i.e. carbon neutrality by 2050. Depending on the outcome of this assessment, the European Commission could propose an extension of the EU ETS to also include non-EEA flights. However, since 2013 until nowadays, all airlines – regardless of their nationality – need to surrender allowances only against the emissions of the flights they operate between EEA airports.

2.2. Allowance allocation

The overall emissions that can be emitted by sectors under the EU ETS, including aviation, is capped by the number of emission allowances. A key issue in any cap-and-trade system is therefore the way emissions allowances are allocated. Allowances are typically allocated either for free or auctioned, the EU ETS being no exception. Since the beginning of EU ETS Trading Period 3 (2013-2020), the default method of allocating allowances has been auctioning. However, 43% of allowances were still granted for free during Phase 3. In general, the amount of free allowances per installation are determined in terms of their historical emissions, the sectoral benchmark and the estimated risk of carbon leakage.

The main rationale of free allocation is to address potential competitiveness impacts when regulated firms face relevant international competition. Importantly, if allowances imply an actual cost for regulated and internationally competing firms, in the short run it can lead to a loss of market share in favor of non-ETS firms and, in the longer run, a reduction of investments in the ETS-area in favor of non-ETS area. Overall, instead of in a reduction of global emissions, this results in a displacement of emissions to regions with a weaker or no carbon price, i.e., to carbon leakage. In the aviation sector, given that airlines compete at the route level, the risk of carbon leakage is not a concern. However, a second argument to grant free allowances is to gain political acceptance by emitting firms and their governments.

Total aviation allowances, the so-called aviation cap, was determined as 95% of the average total emissions in the baseline period 2004-2006, which after the "stop-the-clock" derogation resulted in about 38 million allowances: 82% of those are allocated for free, 15% auctioned and 3% reserved for new entrants. The number of free allowances an airline receives is based on the transport volume (in tonnes-km) in 2010, the benchmark year, which was set as 0.6422 allowances for every 1,000 tonne-km flown during that year. However, the air traffic has grown on average uninterruptedly until the pandemic crisis at a pace of about 5% annually, leading to the consequent growth in emissions. In 2013 aviation verified emissions in the EU ETS were 45 million tons of CO_2. In 2019 these climbed up 65 million (a 44% increase). Given the sector's growth, the allowances received for free only cover about half of the sector's allowance demand. Thus the sector needs to purchase extra allowances year after year, mainly from other ETS sectors.

3. Data

3.1. Data sources

Schedules, emissions and fares

The core dataset used in this analysis was provided by RDC Aviation, a provider of data and consulting services to stakeholders in the aviation industry. The dataset used in the main analysis of this paper covers the period 2017-2019[4] and provides monthly information on three key dimensions in our setting: scheduled flights, CO_2 emissions and fares. First, the dataset contains the monthly number of scheduled departures and the associated number of airplane seats between any two European airports, disaggregated by airline and aircraft model. As an illustration, we observe the number of scheduled flights and total seats from Munich airport to London Gatwick airport offered by Ryanair on a Boeing 737-800 in June 2019. We restrict the dataset to airport routes that were covered under the EU ETS. This comprises

---

[4] The obtained data covers the period 2013-2022. However, we leave out years prior to 2017, as data on CO_2 emissions estimated by RDC is only available from 2017 onward. We leave data after 2019 out of the core analysis, as the aviation sector faced great disruptions during the Covid period. We will use data before 2017 and after 2019 for robustness checks that will be incorporated in time for the conference presentation.

all flights between any two airports inside the European Economic Area, which during our sample period included the current 27 Member States of the European Union but also Norway, Iceland and the United Kingdom.[5] Second, RDC also provides an estimation of CO_2 emissions. This estimate takes into account not only the distance between the origin and destination airports, but additionally adjusts emissions based on aircraft type as well as typical aircraft age and seat configuration by airline. We use these CO_2 emissions data to infer fuel consumption and subsequently aggregate our data across aircraft types in order to end up with a monthly dataset on the route-airline level. Third, RDC provides information on monthly average fares at the route-airline level for a large subset of airlines during the sample period 2017-2019.[6] For each available route-airline combination, average monthly fares (incl. all airport charges and taxes) are based on round trips and further disaggregated by cabin type. Given that ticket prices vary by the amount of time in advance that they are purchased, the dataset provides average three-month-ahead, one-month-ahead and one-week-ahead fares. In addition, RDC applies an algorithm to estimate average weighted fares by airline-route and month based on an estimated distribution of the time of sale by route. We only focus on economy fares and combine the schedules and fares datasets at the route by airline by month of sample level.

In addition, we categorize all airlines in our dataset into three airline types: low-cost airlines, network airlines and other airlines. Network airlines have to be members of one of the three airline alliances worldwide (Star Alliance, Oneworld, SkyTeam). These airlines focus on long-haul flights to non-European destinations. Therefore, a substantial share of their European routes serve connecting passengers flying from/to hub airports (Fageda and Teixidó, 2022). In contrast, the International Civil Aviation Organization (ICAO) publishes a list of low-cost airlines fitting the description of a carrier "that has a relatively low-cost structure in comparison with other comparable carriers and offers low fares and rates" (ICAO, 2016).[7] These airlines mainly operate point-to-point services. Finally, the remaining airlines include airlines operating with a mixed business model or charter airlines offering scheduled flights

---

[5] We adjust our sample for the fact that a small subset of aviation routes inside the European Economic Area are excluded from EU ETS coverage. The list of excluded routes can be found here.

[6] The list of airlines for which fare information is available is presented in Table 4.

[7] The list of low-cost airlines as defined by ICAO can be found here.

(Fageda and Teixidó, 2022). The categorization of airlines into the three categories for our sample period is presented in Table 4.

Input prices and costs

We combine the above-mentioned dataset with additional information on relevant input prices in the aviation industry. In particular, we add information on daily EU ETS allowance prices and New York Harbor kerosene spot prices sourced from Bloomberg. We aggregate these prices to the monthly level and combine them with the dataset on monthly schedules, emissions and fares. Given these input prices, we are able to construct estimates of CO_2 and fuel costs per airline-route. For each airline-route, we multiply total tonnes of CO_2 and fuel with the current monthly allowance price and fuel price, respectively.

3.2. Descriptive overview

Table 1 provides summary statistics for our main estimation sample. The sample includes all monthly route-airline combinations that were covered under the EU ETS and for which we have fare information available at some point during our sample period from January 2017 until December 2019. However, we only have fare information for 75% of route-airline combinations (equivalent to 83% of seats supplied) during this period. Therefore, Table 5 provides analogous information on the full sample of airline-routes, including the ones for which we have no fare information.

Table 1 provides information on three different layers. First, it starts by depicting total quantities at the airline-route level. On average, a route-airline combination in our estimation sample presents 40 departures per month translating into 6,000 seats. The average distance flown is 1,270 km, although we observe routes with a distance of up to 3,800 km. The flights in our estimation sample amount to an average of 423 tonnes of CO_2 emitted and 134 tonnes of jet fuel consumed per month and airline-route. Second, the information on seats, CO_2 emissions, fuel consumption and associated costs are presented by flight departure and by airplane seat. Finally, Table 1 presents information on the different fare variables in our dataset. The average weighted fare amounts to 81 euro. Moreover, we observe that fares are higher the less time in advance of departure ticket purchases are made.

VARIABLES	(1) N	(2) mean	(3) min	(4) p50	(5) max
Departures	341,349	39.4	4	21	752
Departing seats (total)	341,349	6,019	32	3,213	147,999
Route distance (km)	341,349	1,268	2.97	1,188	3,881
CO2 tonnes (total)	341,349	423	0.40	256	7,650
Jet fuel tonnes (total)	341,349	134	0.13	81.1	2,421
Seats per departure	341,349	163	8	180	345
CO2t per departure	341,349	13.8	0.078	13.2	62.4
Cost CO2t per departure	341,349	226	1.13	180	1,409
Fuel t. per departure	341,349	4.37	0.025	4.18	19.8
Cost Fuel t. per departure	341,349	2,507	14.8	2,365	11,853
CO2t per seat	341,349	0.083	0.0098	0.079	0.25
Cost CO2t per seat	341,349	1.35	0.059	1.16	6.40
Fuel t. per seat	341,349	0.026	0.0031	0.025	0.079
Cost Fuel t. per seat	341,349	15.0	1.69	14.2	50.9
Avg. weighted fare	341,349	81.2	6	73.2	781
Avg. one-week-ahead fare	341,343	111	2.91	101	677
Avg. one-month-ahead fare	341,349	86.1	2.49	77.5	793
Avg. three-month-ahead fare	341,349	74.5	4.36	65.5	793
Avg. six-month-ahead fare	261,038	72.4	4.75	63.7	526

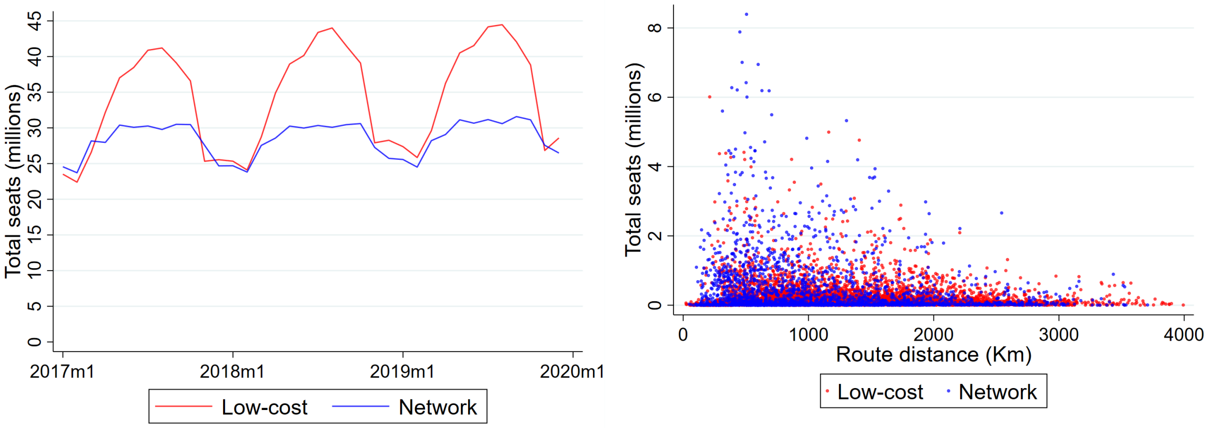
Table 1: Summary statistics

Summary statistics of the main estimation sample based on the time period January 2017 to December 2019. The underlying sample only includes route-airline observations with available fare information on one-month-ahead fares.

Finally, Table 6 provides analogous information to Table 1 but disaggregated by low-cost and network airlines. Given that our main analysis focuses on low-cost carriers, it is noteworthy that average one-month-ahead fares are around 30% lower for low-cost carriers compared to network carriers. The difference is not only driven by the type of airline but also the different routes that these two different airline types cater to.

We now turn to some descriptive visualizations of our dataset. In order to do so, we will focus on the full sample including observations with missing fare values. In this way we avoid changes in the sample composition resulting from expansions in fare information coverage over time.

Figure 1 presents information on the total supply of seats for network and low-cost airlines. When focusing on the evolution over time (Figure 1a), it is noteworthy that not only do low-cost carriers supply more seats than network airlines, but the supply of seats by low-cost airlines also follows a much more seasonal pattern. While the total supply of seats by network airlines increases by around 20% in the summer compared to the winter, the increase reaches up to 60% for low-cost airlines. This finding relates to the strong reliance on tourist destinations by low-cost carriers. In addition, low-cost and network airlines cover a very similar range of distances with their routes, although network airlines tend to focus on routes covered under the EU ETS of less than 1,000 km (Figure 1b). This might be related to the business model of network airlines, as their routes within Europe often aim at providing services to passengers that want to reach hub airports to continue on long-haul flights.



(a) Total seats over time

(b) Seats by route distance

Figure 1: Supply of routes under the EU ETS by low-cost vs. network airlines

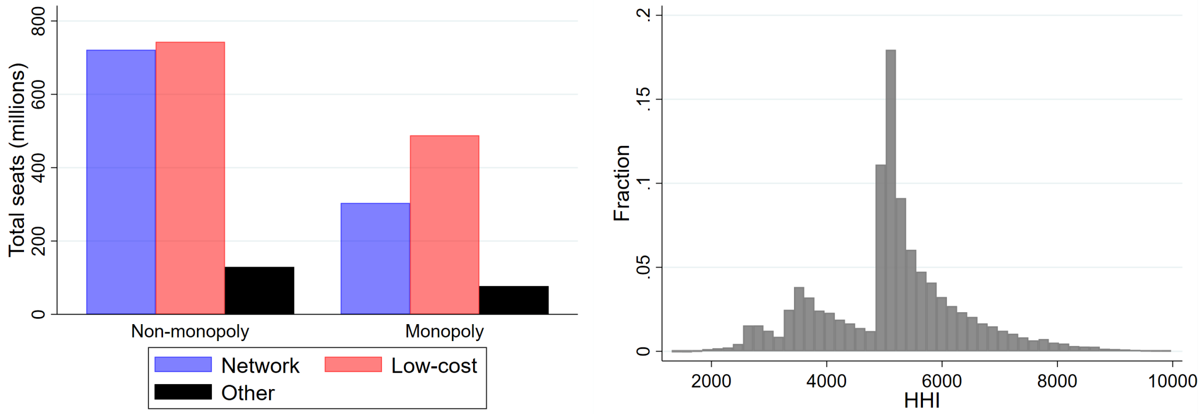
Sources: RDC Aviation, own calculations.
Note: The figure is based on monthly data on bilateral airport connections from January 2017 until December 2019.

In order to shed some light on the market structure of routes under the EU ETS, Figure 2a presents information on the total seats supplied on monopoly routes vs. non-monopoly routes by airline type. Three aspects are worth noting. First, despite most seats under the EU ETS being supplied on non-monopoly routes, a substantial share of 35% of the seats are supplied on routes where one airline acts as a monopolist.[8] Second, low-cost airlines offer more seats on monopoly routes than network airlines, while the same does not hold for non-monopoly routes where the amounts of seats supplied is approximately equal. Third, airlines that cannot be classified as either low-cost or network play a minor role in terms of seats supplied during our sample period. In addition to the substantial share of monopoly routes, Figure 2b shows that the HHI index on non-monopoly routes is often well in excess of 2500, which is deemed to indicate that a market is highly concentrated (DOJ, 2010). We will therefore refer to these routes as

---

[8] We define a monopoly route when a single airline supplies more than 99% of the seats during a particular year.

non-monopoly routes instead of *competitive* routes.

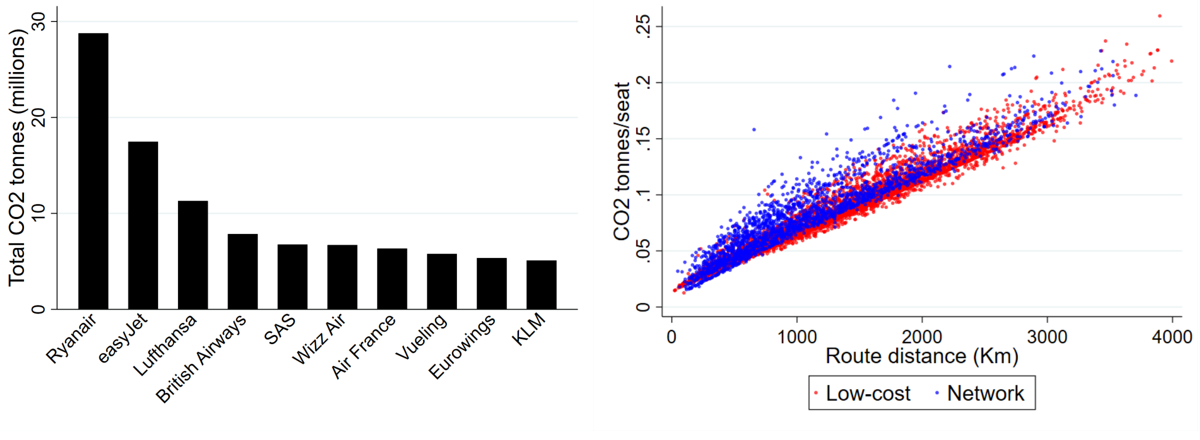


(a) Share monopolistic routes **(b)** Herfindahl-Hirschman index, non-monopoly routes

Figure 2: Competition on flight routes covered by the EU ETS

Sources: RDC Aviation, own calculations.
Note: The figure is based on monthly data on bilateral airport connections from January 2017 until December 2019.

In relation to CO_2 emissions and in line with their strong market share, low-cost carriers are strongly represented among the top emitters, with Ryanair and Easyjet by far the largest emitting airlines under the EU ETS (Figure 3a). However, the relevance of low-cost airlines in terms of total CO_2 emissions is not driven by their CO_2 intensity, as Figure 3b shows higher emissions per airplane seat for network airlines when comparing routes of a similar distance.



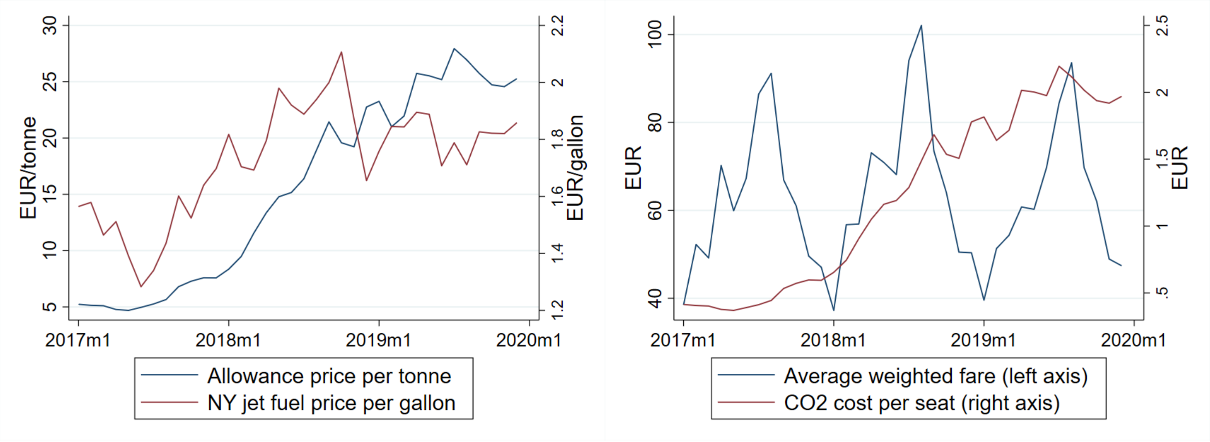
(a) Top CO_2 emitting airlines **(b)** CO_2 emissions per seat

Figure 3: CO_2 emitters and annual CO_2 costs

Sources: RDC Aviation, own calculations.
Note: The figure is based on monthly data on bilateral airport connections from January 2017 until December 2019.

Lastly, we focus on the evolution of input prices and costs during our sample period. Figure 4a depicts the evolution of the EU ETS allowance price per tonne of CO_2 as well as the New York jet fuel price per gallon. Allowance prices started at a relatively low level in early 2017, with prices per tonne of CO_2 around 5 euro. However, they experienced a continuous increase until reaching 25 euro per tonne in late 2019. This implies a substantial increase in allowance prices, by 400% over 36 months. In contrast, fuel prices present more variability. They increased substantially during 2017 and remained around 1.8 euro per gallon for the rest of our sample period. The evolution of allowance prices maps into the evolution of CO_2 costs per airplane seat, as depicted in Figure 4b. The sample for this figure is restricted to route-airline combinations by low-cost airlines for which we observe average fares throughout our sample period. In this way, we can circumvent distortions due to changes in sample composition over time arising from the inclusion of more airlines with fare information available. CO_2 costs per airplane seat gradually increase from 0.5 euro per seat to around 2 euro per seat. Also depicted is the average weighted fares for routes in this sample, which present a seasonal pattern with fares being often twice as high during the summer months compared to the winter months.

The changes in allowance and fuel prices also translate into the distribution of CO_2 and fuel costs at the airline-route level, as depicted in Figure 5. The figures present the distribution of CO_2 costs (Figure 5a) and fuel costs (Figure 5b) separately for the years 2017, 2018 and 2019. We now focus on the airline-route combinations with available fare information, as the distribution of costs depcited in this Figure represents the variation that we will exploit in later sections for identification. The increase in CO_2 prices over the sample period increased the mean of the distribution of CO_2 emissions by departure and also led to a greater spread. While almost all routes faced CO_2 costs of less than 200 euro per departure in 2017, by 2019 many airlines were facing costs of more than 400 euro per departure. On the other hand, fuel costs represent a higher expense per departure, with estimated fuel costs often over 2000 euro per departing flight. However, the changes over time in the distribution of the costs do not change as noticeably as for CO_2 costs.



(a) Input price evolution

(b) Fares and CO$_2$ costs

Figure 4: Input prices and fare evolution 2017-2019

Sources: Bloomberg, RDC Aviation, own calculations.
Note: Panel (a) is based on daily prices aggregated to the monthly level. Panel (b) is based on the subset of airline-route combinations for low-cost carriers for which we observe fares throughout our sample period.

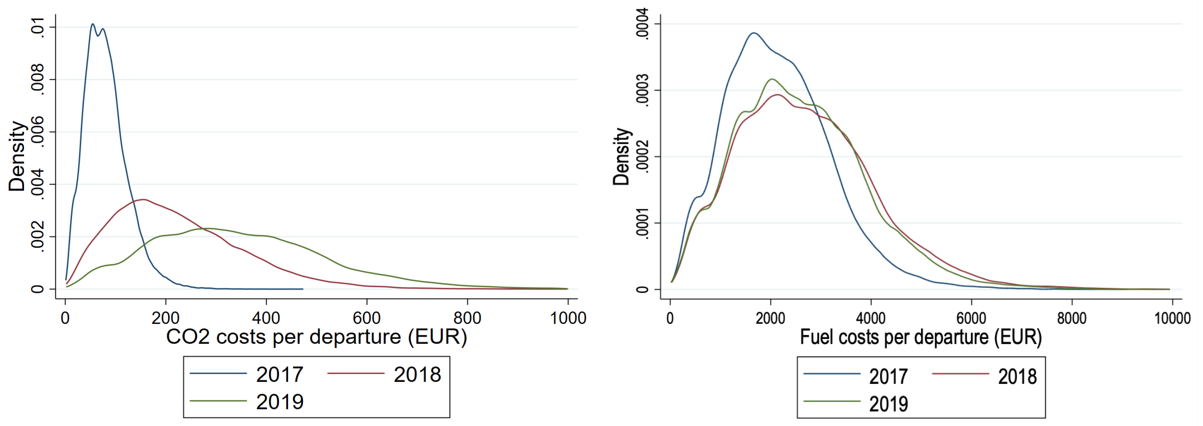
4. Research design

In order to quantify pass-trough rates, we estimate the following model:

$$y_{iat} = \beta_0 + \delta_1 fuelcost_{iat} + \delta_2 co2cost_{iat} + \beta X_{iat} + \lambda_{ia} + \varepsilon_{iat}, \tag{1}$$

Our outcome y_{iat} is the average fare in month-of-sample t for route i and airline a. We regress this outcome on route-airline-month of sample specific estimates of fuel costs per airplane seat and CO$_2$ costs per airplane seat. In addition, we control for month-of-year fixed effects as well as year fixed effects in X_{iat} and route-airline fixed effects λ_{ia}. Given that we only exploit within-route-airline variation, we are able to include all routes in our estimation sample regardless of whether we observe fares for the full sample period. The month-of-year fixed effects and year fixed effects allow us to capture time-varying common demand shocks. Finally, δ_1 identifies the equilibrium pass-through of fuel costs, while δ_2 identifies the equivalent for CO$_2$ costs.

We restrict our analysis to low-cost carriers and the one-month-ahead average fare. We disregard network and other airlines, as these tend to focus on connecting passengers to an airport hub for them to



(a) CO_2 cost per departure **(b)** Fuel cost per departure

Figure 5: Input costs over time

Sources: RDC Aviation, own calculations.
Note: The figure is based on monthly data on bilateral airport connections from January 2017 until December 2019. CO_2 costs are trimmed at 1,000 Euro per departure and fuel costs are trimmed at 10,000 Euro per departure.

continue on intercontinental flights. Given that the fares we observe only reflect point-to-point connections (i.e. without any continuation of the flight), they will only reflect the prices faced by a relatively low share of passengers on routes by network airlines. However, the observed fares are a good proxy for the average fares paid by customers on low-cost carriers with a clear focus on point-to-point connections. In addition, we focus on the one-month-ahead price to be able to link time of ticket purchase with EU ETS allowance and fuel price. Our CO_2 pass-through estimates mainly reflect two different kinds of costs. On the one hand, a fraction of the CO_2 emissions have to be purchased on the allowance market, which has a direct impact on airlines' marginal costs. On the other hand, regardless of the amount of allowances airlines receive under free allocation, rational firms factor into their decisions the opportunity costs of holding EU ETS allowances that have a market value at a given market price. We disregard one-week-ahead fares as they might be driven by last-minute pricing strategies and other unobserved factors.

Finally, in our main specifications we divide total CO_2 costs per flight by the number of seats per airplane in order to estimate quantities from a ticket price perspective. However, note that this assumption implies a load factor of 100%. If the real load factor is lower, the estimated coefficients will be biased upwards. For example, a pass-through of 100% when only 50% of the seats are occupied by passengers would be mistakenly estimated as a pass-through of 200% when doing the calculations by airplane seat, as a given change in ticket prices is associated with a smaller increase in CO_2 per passenger if more passengers are assumed on the plane. Given that we have no information on route by airline specific load factors, we will show results assuming a load factor of 100%. Results can be rescaled to other average load factors by multiplying the estimated coefficient for δ_2 with the new assumed load factor (between 0 and 100%).

5. Results

This section presents the estimated pass-through rates in the aviation sector for low-cost airlines under the EU ETS based on Equation 1. Table 2 presents pass-through rates for the full sample and for short- and long-haul routes separately. Table 3 presents analogous results but now differentiating between monopoly routes and non-monopoly routes.

Our first result is that average CO_2 pass-through is estimated to be very close to the full pass-through rate of 1 (Column 1 in Table 2). Our coefficient of 1.09 implies that average one-month-ahead ticket prices increased by 1.09 euro for each one euro increase in CO_2 costs per seat. Scaling our parameter to an average load factor during our sample period of 80% – in line with European load factors for 2019 (IATA, 2019) – still yields a considerably high average pass-through rate of 0.87. It might seem surprising that we do not estimate significant pass-through rates for fuel costs. However, this finding is in line with the theoretical predictions of pas-through in the aviation sector if airlines engage in substantial fuel hedging (Gayle and Lin, 2021). The authors conclude that “a greater percentage of fuel hedging has a weakening effect on a positive pass-through, reducing the direct pass-on effect from crude oil price changes to airfare”. Given the substantial amount of fuel hedging in the European aviation sector, our finding is in line with previous literature.[9]

In a next step, we split our sample by short-haul routes (<500 km, Column 2 of Table 2) and long-

---

[9] The percentage of fuel consumption hedged is reported by airlines in their annual reports. See this overview by the International Air Transport Association (IATA) on fuel hedging behaviour in 2019 for selected airlines.

haul routes (>500 km, Column 3 of Table 2). While the fuel pass-through rate remains insignificant, CO_2 pass-through is now much higher than the previously estimated average pass-through for short-haul routes and slightly lower for long-haul routes. The high pass-through for short-haul flights is consistent with the particularly stark reductions in the supply of flights of around 10% for these routes as a reaction to the EU ETS (see Fageda and Teixidó (2022)). This reduction in supply, if not met with a contemporaneous reduction in demand, might lead to substantially higher fares. In our case, given that we observe an increase in the CO_2 costs per seat of around 1.5 euro during our sample period (see Figure 4b), this would translate into an fare increase of 9.7 euro for short-haul routes assuming a 100% load factor or 7.7 euro assuming an 80% load factor.

	(1) Full sample	(2) Short-haul	(3) Long-haul
Cost Fuel t. per seat	0.10	-1.28	0.14
	(0.09)	(0.84)	(0.09)
Cost CO2t per seat	1.09^{**}	6.48^{*}	0.87^{+}
	(0.41)	(2.77)	(0.44)
Route by airline FE	Yes	Yes	Yes
Month FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	243208	16787	226421
R^2	0.655	0.753	0.651

Standard errors in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2: Main results

Notes: Coefficients are based on the estimation of Equation 1 on the full sample (Column 1), routes with a distance of less than 500 km (Column 2) and routes with a distance of more than 500 km (Column 3). All models include route-airline fixed effects, month-of-year fixed effects and year fixed effects. Standard errors are clustered at the route level.

In a final step, we observe that the pass-through rates depicted in Table 3 for monopoly and non-monopoly routes separately provide additional insights. Fuel pass-through rates remain consistently insignificant, and CO_2 pass-through rates remain larger than average pass-through rates. However, we now observe that pass-through rates are higher for routes with more competition intensity (non-monopoly routes), where the average pass-through is estimated to be 1.61, in contrast to 1.14 for monopoly routes.

This finding is in line with previous research suggesting that the degree of competition is associated with a higher pass-through of industry-wide cost shocks (Sijm et al., 2012; Gayle and Lin, 2021). All in all, the results in this section are the first to estimate high degrees of carbon cost pass-through in the aviation sector.

	Monopoly			Non-Monopoly		
	(1) Full sample	(2) Short-haul	(3) Long-haul	(4) Full sample	(5) Short-haul	(6) Long-haul
Cost Fuel t. per seat	0.06 (0.12)	-0.46 (0.62)	0.08 (0.13)	0.06 (0.14)	-2.59 (1.60)	0.11 (0.14)
Cost CO2t per seat	1.14^{*} (0.53)	4.53^{+} (2.72)	0.76 (0.56)	1.61^{**} (0.61)	6.73 (4.47)	1.30^{+} (0.66)
Route by airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	127427	8199	119228	115781	8588	107193
R^2	0.647	0.765	0.647	0.656	0.766	0.647

Standard errors in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Pass-through rates by competition intensity

Notes: Coefficients are based on the estimation of Equation 1 on the subset of monopoly routes (Columns 1-3) and non-monopoly routes (Columns 4-6). Coefficients are then reported separately for all routes (Columns 1 and 3), routes with a distance of less than 500 km (Columns 2 and 4) and routes with a distance of more than 500 km (Columns 3 and 6). All models include route-airline fixed effects, month-of-year fixed effects and year fixed effects. Standard errors are clustered at the route level.

6. Conclusion

This paper studies the pass-through of carbon emission costs in the European aviation sector covered by the European Union's Emission Trading System (EU ETS). To our knowledge, our study is the first to consider carbon cost pass-through in the aviation sector, a setting with highly fragmented markets and limited competition a large number of routes.

We combine highly granular data on the aviation industry obtained from RDC Aviation, a provider of data services to the aviation industry, with data on emission allowance and jet fuel prices. Our core analysis uses monthly data on scheduled flights, CO_2 emissions and airfares for all airport routes covered under the EU ETS during the period 2017-2019. In a preliminary baseline empirical analysis we regress data on ticket prices one month ahead of departure to carbon costs per passenger seat imposed under the EU ETS for all airline-route combinations offered by low-cost carriers. In a further step, we split our sample based on short-haul vs. long-haul flight and the degree of competition at the route level.

Preliminary results show that airlines regulated under the EU ETS fully pass through increases in allowance prices on average. Carbon costs are more than fully passed through in short-haul routes and routes with a higher degree of competition intensity. While these findings are in line with theoretical predictions and results for other sectors with limited competition, they deviate from the existing evidence on the EU ETS, which finds at most full pass-through for the power sector.

References

Berry S. and Jia P. (2010) Tracing the Woes: An Empirical Analysis of the Airline Industry. *American Economic Journal: Microeconomics*, 2(3): 1–43.

Bradley S. and Feldman N. E. (2020) Hidden Baggage: Behavioral Responses to Changes in Airline Ticket Tax Disclosure. *American Economic Journal: Economic Policy*, 12(4): 58–87.

Cames M., Graichen J., Siemons A., and Cook V. (2015) Study on Emission Reduction Targets for International Aviation and Shipping.Technical report, European Parliament.

Cludius J., de Bruyn S., Schumacher K., and Vergeer R. (2020) Ex-post Investigation of Cost Pass-Through in the EU ETS: An Analysis for Six Industry Sectors. *Energy Economics*, 91: 104883.

DOJ (2010) U.S. Department of Justice and Federal Trade Commission, Horizontal Merger Guidelines. *Issued August 19, 2010*.

Duso T. and Szücs F. (2017) Market Power and Heterogeneous Pass-Through in German Electricity Retail. *European Economic Review*, 98: 354–372.

Erutku C. (2019) Carbon pricing pass-through: Evidence from Ontario and Quebec's wholesale gasoline markets. *Energy Policy*, 132: 106–112.

European Commission (2021) Proposal for a Directive of the European Parliament and of the Council Amending Directive 2003/87/EC as regards aviation's contribution to the Union's economy-wide emission reduction target and appropriately implementing a global market-based measure. *COM(2021) 552 final*, URL: `https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0552`.

European Council & Parliament (2009) Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. *Official*

Journal of the European Union, URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0101.

——— (2013) Decision No 377/2013/EU of the European Parliament and of the Council of 24 April 2013 derogating temporarily from Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community. *Official Journal of the European Union*, URL: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32013D0377.

Fabra N. and Reguant M. (2014) Pass-Through of Emissions Costs in Electricity Markets. *American Economic Review*, 104(9): 2872–99.

Fageda X. and Teixidó J. J. (2022) Pricing carbon in the aviation sector: Evidence from the European emissions trading system. *Journal of Environmental Economics and Management*, 111: 102591.

Gayle P. G. and Lin Y. (2021) COST PASS-THROUGH IN COMMERCIAL AVIATION: THEORY AND EVIDENCE. *Economic Inquiry*, 59(2): 803–828.

Graver B., Zhang K., and Rutherford D. (2019) CO2 emissions from commercial aviation, 2018. *ICCT Working Paper 2019-16*.

Hintermann B. (2016) Pass-Through of CO2 Emission Costs to Hourly Electricity Prices in Germany. *Journal of the Association of Environmental and Resource Economists*, 3(4): 857–891.

IATA (2019) State of the region: Europe. *Regional brifiengs*, URL: https://www.iata.org/en/iata-repository/publications/economic-reports/regional-briefing---europe---dec-2019/.

——— (2022) Air Passenger Numbers to Recover in 2024. *Press Release*, URL: https://www.iata.org/en/pressroom/2022-releases/2022-03-01-01/.

ICAO (2016) Manual on the Regulation of International Air Transport.

de Jong G. (2022) Emission Pricing and Capital Replacement: Evidence from Aircraft Fleet Renewal. *Tinbergen Institute Discussion Paper, No. TI 2022-060/VIII*: 42.

Kang Y., Liao S., Jiang C., and D'Alfonso T. (2022) Synthetic control methods for policy analysis: Evaluating the effect of the European Emission Trading System on aviation supply. *Transportation Research Part A: Policy and Practice*, 162: 236–252.

Knittel C. R., Meiselman B., and Stock J. (2015) The Pass-THrough of rin Prices to Wholesale and Retail Fuels under the Renewable Fuel Standard. *NBER Working Paper 21343*.

Lee D., Fahey D., Skowron A., Allen M., Burkhardt U., Chen Q., Doherty S., Freeman S., Forster P., Fuglestvedt J., Gettelman A., De León R., Lim L., Lund M., Millar R., Owen B., Penner J., Pitari G., Prather M., Sausen R., and Wilcox L. (2021) The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment*, 244: 117834.

Miller N. H., Osborne M., and Sheu G. (2017) Pass-through in a concentrated industry: empirical evidence and regulatory implications. *The RAND Journal of Economics*, 48(1): 69–93.

Nolan J. and Mantin B. (2021) Who Pays the Piper? Assessing the Incidence for Pass-through of Environmental Taxes Within the Maritime Shipping Industry. *Transportation Research Board - Working Paper*.

Oesingmann K. (2022) The effect of the European Emissions Trading System (EU ETS) on aviation demand: An empirical comparison with the impact of ticket taxes. *Energy Policy*, 160: 112657.

Sengupta A. and Wiggins S. N. (2014) Airline Pricing, Price Dispersion, and Ticket Characteristics On and Off the Internet. *American Economic Journal: Economic Policy*, 6(1): 272–307.

Sijm J., Chen Y., and Hobbs B. F. (2012) The impact of power market structure on CO2 cost pass-through to electricity prices under quantity competition – A theoretical approach. *Energy Economics*, 34(4): 1143–1152.

Stitzing R. (2017) Distributional and Environmental Effects of an Emissions-Differentiated Car Sales Tax. *SSRN Electronic Journal*.

A. Appendix

Low-cost airlines	Blue Air, Eurowings, Flybe, Jet2, Laudamotion, Moarch Airlines, Norwegian Air Shuttle, Ryanair, SmartWings, Transavia, Volotea, Vueling, WOW Air, Wizz Air, easyJet
Network airlines	Aegean Airlines, Aer Lingus, Air China, Air France, Alitalia, Austrian, British Airways, Brussels Airlines, CSA, Finnair, Iberia, KLM, LOT Polisch Airlines, Lufthansa, SAS, TAP Air Portugal, TAROM, airberlin
Other airlines	Air Baltic, Air Corsica, Air Malta, Bulgarian Air, CityJet, Hainan Airlines, Hop!, Loganair, Olympic Air

Table 4: List of airlines with fare information available by airline type

This table lists the airlines in our dataset for which fares are available at some point in time during our sample period. Note that fare coverage expands over time, so that fare information might be only available for a subset of months in our sample. In addition, all airlines are categorized into low-cost, network or other sub-categories.

VARIABLES	(1) N	(2) mean	(3) min	(4) p50	(5) max
Departures	466,095	36.3	4	18	785
Departing seats (total)	466,095	5,281	16	2,585	151,152
Route distance (km)	466,095	1,284	2.97	1,201	4,652
CO2 tonnes (total)	466,095	377	0.36	222	7,650
Jet fuel tonnes (total)	466,095	119	0.11	70.3	2,421
Seats per departure	466,095	158	3	180	408
CO2t per departure	466,095	14.1	0.078	13.4	76.5
Cost CO2t per departure	466,095	224	0.37	166	1,969
Fuel t. per departure	466,095	4.45	0.025	4.24	24.2
Cost Fuel t. per departure	466,095	2,541	10.5	2,383	15,976
CO2t per seat	466,095	0.085	0.0074	0.081	0.52
Cost CO2t per seat	466,095	1.34	0.038	1.08	11.9
Fuel t. per seat	466,095	0.027	0.0023	0.026	0.17
Cost Fuel t. per seat	466,095	15.3	1.13	14.3	109
Avg. weighted fare	341,349	81.2	6	73.2	781
Avg. one-week-ahead fare	341,343	111	2.91	101	677
Avg. one-month-ahead fare	341,349	86.1	2.49	77.5	793
Avg. three-month-ahead fare	341,349	74.5	4.36	65.5	793
Avg. six-month-ahead fare	261,038	72.4	4.75	63.7	526

Table 5: Summary statistics - including observation with missing fares

Summary statistics of the main sample based on the time period January 2017 to December 2019. The underlying sample include all route-airline observations regardless of whether fare information is available.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Low-cost					Network				
VARIABLES	N	mean	min	p50	max	N	mean	min	p50	max
Departures	243,208	26.4	4	15	455	87,335	75.2	4	57	752
Departing seats (total)	243,208	4,537	136	2,604	81,254	87,335	10,352	90	6,552	147,999
Route distance (km)	243,208	1,348	96.4	1,290	3,881	87,335	1,086	106	931	3,707
CO2 tonnes (total)	243,208	331	5.56	223	3,888	87,335	698	6.99	509	7,650
Jet fuel tonnes (total)	243,208	105	1.76	70.6	1,230	87,335	221	2.21	161	2,421
Seats per departure	243,208	176	19	186	345	87,335	134	18	144	301
CO2t per departure	243,208	14.9	0.24	14.4	54.5	87,335	11.3	0.68	9.75	62.4
Cost CO2t per departure	243,208	243	1.13	205	1,409	87,335	186	3.43	139	1,105
Fuel t. per departure	243,208	4.73	0.076	4.56	17.2	87,335	3.58	0.22	3.09	19.8
Cost Fuel t. per departure	243,208	2,709	32.2	2,575	11,374	87,335	2,056	94.8	1,760	11,853
CO2t per seat	243,208	0.084	0.013	0.081	0.25	87,335	0.081	0.014	0.075	0.25
Cost CO2t per seat	243,208	1.36	0.059	1.18	6.40	87,335	1.32	0.075	1.09	6.25
Fuel t. per seat	243,208	0.027	0.0040	0.026	0.079	87,335	0.026	0.0045	0.024	0.078
Cost Fuel t. per seat	243,208	15.2	1.69	14.4	50.4	87,335	14.7	2.16	13.6	50.9
Avg. weighted fare	243,208	71.1	6	62.2	477	87,335	108	17.4	99.8	781
Avg. one-week-ahead fare	243,202	95.9	2.91	87.5	677	87,335	151	24.6	144	631
Avg. one-month-ahead fare	243,208	75.3	2.49	66.5	513	87,335	114	17.2	105	793
Avg. three-month-ahead fare	243,208	66.1	4.36	55.8	507	87,335	96.0	16.4	86.7	793
Avg. six-month-ahead fare	183,297	66.2	4.75	55.3	405	71,963	87.8	19.7	80.4	526

Table 6: Summary statistics by airline type

Summary statistics of the samples for low-cost and network airlines based on the time period January 2017 to December 2019. The underlying sample includes only route-airline observations with available fare information.