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Intercontinental air travel in the era of carbon pricing: demand and hub shifts

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In this paper, we investigate the causal relationship between carbon pricing and air travel demand in the intercontinental market. Using granular demand data for one-stop routes connecting airports in Europe with Asia and North America, we estimate regressions with multiple fixed effects to account for both time-invariant and time-varying factors that could confound the identification of policy effects. Our approach leverages variability in carbon prices in the European Union Emissions Trading System by comparing changes in routes subject to the policy (i.e., those involving European hubs) with routes unaffected by the policy (i.e., those involving non-European hubs). Our findings indicate that the carbon price variable is consistently negative and statistically significant across all regressions. A 100 % increase in the price of EU ETS allowances reduces passenger traffic through European hubs by 2–6 %. These results provide novel evidence of the policy's effectiveness in the long-haul market, while also highlighting the phenomenon of hub carbon leakage. Additionally, we find that joint ventures between European and non-European airlines mitigate the policy's impact.

1. Introduction

Carbon pricing is one of the primary instruments available to reduce carbon dioxide (CO_2) emissions. To address this challenge, emissions trading systems have been implemented or are under consideration in various countries worldwide. In particular, the European Union Emissions Trading System (EU ETS) for greenhouse gas emissions is the world's first international and the second largest ETS in the world and the cornerstone of EU environmental policy.[1] Since 2012, the aviation sector has been included within the EU ETS but it only covers flights within the European Economic Area (EEA, that is, the EU countries plus Norway, Iceland and Lichtenstein). Considering this reduced scope, we analyze possible passenger shifts associated with the increased costs of the policy in extra-EEA routes involving EEA and non-EEA hubs.

We examine the causal link between carbon pricing and air travel demand following the logic of a differences-in-differences strategy. Our sample is based on one-stop routes connecting airports in Europe with Asia and North America for the period 2010–2023. Data used consider both the origin and destination airports of passengers, as well as the stopover airports, including the operating airline, thus providing us with detailed information about connecting passengers. A regression model is estimated with

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[1] The scheme places a cap on total emissions but, within the cap, companies can buy or sell allowances on the EU carbon market while also receiving some free allocations.

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multiple fixed effects that allow us to control for time-invariant and time-varying factors that could confound the identification of the policy effects. The routes affected by the policy are those that involve EEA hubs, while the control routes involve non-EEA hubs.

A few studies have provided ex post econometric evidence of the expected supply reactions of airlines to the EU ETS in terms of lower frequencies and higher fares (i.e., Fageda and Teixidó, 2022; Kang et al., 2022, Santonja et al., 2023; Zhang and Wang, 2024). These previous studies have focused on the effects of the EU ETS on non-stop short-haul flights.[2] However, the analysis of the effectiveness of the policy on long-haul routes is also relevant given the intense competition between airlines to attract connecting passengers and the significant weight that this market segment has in the total emissions of the sector.[3] Here, we depart from previous studies of the effects of the EU ETS within the aviation sector in two important ways: First, our sample selection is based on the long-haul market where EEA airlines may be particularly exposed to competition from non-EEA airlines; and, second, while extant studies only consider supply data for non-stop services, we exploit granular demand data that allow us to analyze the effects of the policy on connecting passengers, who typically make up around half of the long-haul aviation market (Sabre, 2024).

In our context, a negative impact of carbon pricing on passenger traffic can be related to both policy effectiveness and hub carbon leakage. Hub passenger shifts may involve the displacement of passengers from regulated to unregulated routes. Such passenger shifts can result in carbon leakage, as it may simply change the source of emissions without necessarily reducing their total volume — which is what truly matters from a climate change perspective. Indeed, carbon leakage may arise if pollution-intensive activities (such as flying) shift to places with weaker environmental regulations to avoid the additional costs imposed by regulations at home.

Empirical studies to date find no evidence of any relevant carbon leakage attributable to the EU ETS (Sartor, 2013; Branger et al., 2017; Aus dem Moore et al. 2019; Koch and Basse, 2019; Naegele and Zaklan, 2019; Borghesi et al., 2020; Garnadt et al., 2021; Colmer and Martin, 2022; Dechezleprêtre et al., 2022). In this regard, these studies have been conducted within the energy and manufacturing sectors and for a period in which CO_2 prices were low. However, the issue of carbon leakage within aviation is clearly of some relevance given that it is one of the sectors with highest emission intensity (Copeland et al., 2022), and greater risks of cross-border effects given its strong international dimension and the mobility of its main capital asset. Compared to firms in other sectors, those of the aviation sector operate in relatively homogeneous technological conditions (Fageda and Teixidó, 2024). Finally, in contrast to previous studies, the final years of the period considered here are characterized by relatively high carbon prices. We also contribute to the literature on alliances and joint ventures (e.g., Brueckner, 2001, 2003; Calzaretta et al, 2017; Bilotkach, 2019; Bilotkach and Hüschelrath, 2019; Fageda et al., 2019) by examining how such agreements interact with the asymmetric costs imposed by environmental regulations in a sector with a strong international dimension.

Overall, the main goals of our analysis are to examine the direct and indirect effects of the EU ETS on the long-haul aviation market. Our findings indicate that the EU ETS has had a significant impact on passenger numbers. The carbon price variable is negative and statistically significant across all regressions. A 100 % increase in the price of EU ETS allowances reduces passenger traffic through European hubs by 2 %–6 %. Our results are consistent with both direct and indirect effects of the EU ETS. In this regard, part of the reduced traffic on routes transferring via an ETS hub can be attributed to lower traffic growth compared to non-ETS hubs (i.e., direct effect). Furthermore, this traffic reduction is also explained to some extent by the displacement of traffic from regulated to unregulated routes (i.e., indirect effect). Additionally, we find that joint ventures influence these effects.

The remainder of the paper is structured as follows: Section 2 reviews the literature on the EU ETS and explains the route network structure of the long-haul market. Section 3 details our empirical strategy, while Section 4 describes the data. Section 5 presents our main results, and Section 6 concludes.

2. Background

2.1. Impact of the EU ETS on the aviation sector

Carbon pricing increases costs for airlines, which, in conditions of imperfect competition, react by reducing supply and increasing prices to maximize their profits. Combined with price-demand elasticities, higher fares (and lower flight frequencies) should lead to less demand. Additionally, airlines affected by the EU ETS may have greater incentives to reduce aircraft emissions and, hence, operate newer, more efficient planes.[4] Ultimately, all these responses should bring about a reduction in emissions at least compared with those of the counterfactual.

As discussed, previous empirical studies find the expected supply reactions by airlines. Fageda and Teixidó (2022), for example, report a 5 % reduction in emissions on ETS routes compared to those of the counterfactual, while Kang et al. (2022) find that the EU system reduced total seat numbers by up to 20 %. In both cases, the effect is primarily driven by the decrease in flight frequencies.[5] Zhang and Wang (2024) also report a strong supply effect of the EU ETS in domestic markets.

Santonja et al. (2023) find evidence of full cost pass-through when analyzing the price responses of airlines to the increased costs

[2] Except for Oesingmann (2022) and Fageda and Oesignmann (2025), all previous studies focus on the supply effects of the policy.

[3] Looking at all passenger flights worldwide, Dobruszkes et al. (2024) show that flights longer than 4000 kms account for just 5.1 % of flights, but 39.0 % of fuel burnt. They also find that, since the mid-1990s, the long-haul segment has grown much more rapidly than the short-haul one.

[4] Brueckner and Zhang (2010), moreover, incorporate a load factor in their theoretical model, which predicts that the increased costs associated with the emissions market will encourage airlines to reduce flight frequency, keep aircraft sizes constant but increase the load factor of each flight.

[5] Fageda and Teixidó (2024) find that the EU ETS has led to a modest reduction in emission intensities due to greater incentives to use more efficient aircrafts and to instigate retrofit actions (e.g., winglets).

associated with the EU ETS. In contrast, evidence regarding the reaction of passengers is less clear as Oesingmann (2022) finds a non-significant effect of the emissions trading system on total passenger numbers.

Importantly, a reduction in emissions on ETS routes could be driven in part by a shift of traffic from regulated to unregulated routes. However, evidence regarding carbon leakage in the aviation sector is scarce. Dray and Doyne (2019) employ a network-based analysis to simulate the potentially strong carbon leakage effects that could be associated with an emissions market applied only to the United Kingdom. De Jong (2022) analyzes a specific case of carbon leakage by comparing the aircraft fleets of US and European network carriers over a long period. Given that the EU ETS only affects intra-European flights, its effects should be centered essentially on narrowbody aircraft, given that widebody planes are used for long-haul flights. Indeed, the author finds that the EU emissions trading system incentivizes a faster renewal of narrowbody aircraft, albeit at the expense of a slower renewal of widebody aircraft, which might imply an increase in emissions on long-haul flights. Borbely (2019) analyzes the cross-border effects of a tax on passengers departing from German airports. Drawing on a sample of German airports and airports near the German border, the author finds relevant cross-border effects of the tax with sizeable increases in passenger numbers in airports near German borders. Finally, Wei and Kallbekken (2024) simulate possible carbon leakage in aviation under the EU's Fit for 55 climate policies using both sectoral and general equilibrium models. Their results show only limited carbon leakage effects within the aviation sector but significant leakage in other sectors of the economy, indicating that concerns are more about overall climate policy efficiency than sector competitiveness.

In this paper, we focus on the demand effects of the EU ETS on routes from Europe to Asia and from Europe to North America, with one stopover in an ETS or non-ETS hub. More specifically, we examine the link between carbon prices and passenger numbers, considering both the effectiveness of the policy and passenger shifts from regulated to unregulated routes.

2.2. Airline competition in the long-haul market

The aviation market is dominated by two types of airlines operating different route structures (Berry et al., 1996; Brueckner and Zhang, 2001; Brueckner, 2004; Fageda and Flores-Fillol, 2012). Low-cost airlines, which operate point-to-point routes by exploiting their competitive advantages in non-stop, short-haul trips, and network airlines, which operate via hub-and-spoke systems taking advantage of the economies of traffic density that characterize the airline industry.[6] To this end, network airlines concentrate flights at their (few) hub airports, with passengers on short-haul flights feeding their long-haul services. This means a sizable proportion of passengers channeled by network airlines are connecting passengers who use the hub airport as a stopover to reach their final long-haul destination. Hence, network airlines dominate the long-haul segment of the market. Most of them are integrated into one of the three global airline alliances (Star, SkyTeam, oneworld).

In Europe, network airlines are generally the former flag carriers and are grouped around three major carriers: Lufthansa, Air France-KLM and IAG.[7] These three major carriers have cooperation agreements in the form of codeshare partnerships, price and frequency coordination schemes or joint venture agreements with other non-European network airlines.

Airlines within joint ventures lead the flows from Europe to North America. In this regard, joint venture agreements represent the deepest degree of cooperation. Airlines within joint ventures not only coordinate capacity and fares, but they may also share revenues and even costs and profits, being virtual mergers at the route-level (Calzaretta et al, 2017; Bilotkach and Hüschelrath, 2019; Fageda et al., 2019). Joint-ventures are usually called metal-neutral because revenues and costs are shared proportionally no matter which airline operates the flights on a route. However, on routes between Europe and Asia, the competition scenario is different. European network carriers are affected by fierce competition from growing airline carriers that include Emirates, Etihad Airways, Qatar Airways, Turkish Airlines and Asian Airlines.

The increased costs on legs affected by the EU ETS and which form part of a long-distance route reduce the profitability of European airlines and may undermine their competitiveness with respect to non-European network airlines. This is particularly the case in the context of fierce rivalry to attract connecting passengers. However, joint ventures may mitigate these potential negative effects given that airlines that are partners in these agreements share, at least partially, the additional costs imposed by the policy.

Fig. 1 illustrates a simplified version of the hub-and-spoke route structure typically operated by network airlines on routes with one stopover. These routes comprise a short leg (e.g., O1H) and a long leg (HD). The network in Fig. 1 is a hub-and-spoke network in which the points of origin (O1…O4) are connected to the destination (D) with a stopover at the hub airport (H).[8] If the short leg involves an intra-EEA flight, then it will be affected by the increased costs associated with the EU ETS and, in line with the literature, network airlines are likely to react by reducing flight frequencies and increasing fares on this route. The reduction in flight frequencies may increase travel times in terms of two important dimensions; i) the schedule delay cost, i.e. the difference between the actual and desired time of departure, and ii) the layover time, i.e. the waiting time in the connecting airport. Hence, the negative effect of carbon pricing on passenger numbers would be explained by higher prices and lower frequencies in the short leg affected by the policy. In this context, carbon pricing may play a critical role in shaping airlines' network structure decisions. Liao et al. (2024) demonstrate that, due to horizontal product differentiation, the hub-and-spoke network is suboptimal for airlines, and they recommend a gradual shift from a 2-hub system to a mixed network, and eventually to a direct-flight model as carbon costs increase, in order to optimize both operational costs and passenger satisfaction.

Fig. 2a shows an example that illustrates our identification strategy; the route Barcelona–Helsinki–Bangkok is affected by the EU

[6] For a more detailed discussion see Caves et al. (1984), Brueckner and Spiller (1994), and Berry et al. (2006).

[7] Smaller network carriers may be subsidiaries of these airlines or cooperate with them within alliances.

[8] The route will be affected by joint ventures if the long leg (HD) involves two hubs of partner airlines.

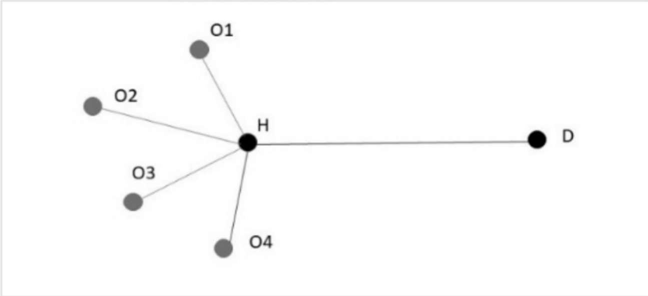

Fig. 1. Hub-and-spoke network. Notes: O = Origin; H = Hub; D = Destination.

ETS, but the route Barcelona–Dubai–Bangkok is not. Hence, an increase in the carbon price of the EU ETS should only have effects on the route Barcelona–Helsinki–Bangkok. In the example, if the route is operated simultaneously by Finnair (via Helsinki) and by Emirates (via Dubai), the passenger shifts from Helsinki to Bangkok could be indicative of hub carbon leakage. This is what we call the indirect effect of the EU ETS.

However, our sample also includes airport-pairs with one stopover that are only operated exclusively either through an EEA hub or through a non-EEA hub. For example, Milan–Amsterdam–Shanghai and Rome–Doha–Calcutta considering that Milan–Shanghai is only possible with a one-stop via EEA hubs and Rome–Calcutta is only possible with non-EEA hubs (refer to Fig. 2b). In such cases, the negative effect of the ETS on passenger numbers would not be linked to hub carbon leakage because the shift from regulated to non-regulated routes is not possible. The effect of the EU ETS on passenger numbers would be explained by changes in passenger numbers in policy-affected routes as compared to non-affected routes. This is what we call the direct effect of the EU ETS.

It is worth noting here that we focus on one-stop routes, as only 8.8 % of all passengers traveling from Europe to Asia or North America use itineraries with two or more stops. Moreover, the distinction between routes affected and unaffected by the EU ETS becomes more complex when itineraries involve multiple stops.

3. Empirical strategy

Aviation has officially been covered by the EU ETS since 2012, although the current scope of the system was not introduced until 2013. After initially covering all flights departing from the EEA, the scope of the EU ETS was later limited to intra-EEA flights only, due to strong opposition from non-EEA governments and airlines to its broader scope.[9] Moreover, in 2012, free allocations exceeded verified CO_2 emissions from the aviation sector, and airlines effectively did not have to buy additional allowances (European Environment Agency, 2023). We therefore take 2013 as the treatment year in our analysis.[10]

Our variable of interest identifies whether the route associated with each observation in our dataset falls under the scope of the EU ETS. When passengers originating from the EEA connect at EEA hubs, the EU ETS applies to the first leg of their journey, with airlines being required to surrender emission allowances to offset their associated CO_2 emissions. The group affected by the EU ETS therefore comprises all origin–destination airport pairs with a connecting airport located in countries participating in the EU ETS (including the UK and Switzerland). In contrast, the group not affected by the policy consists of all airport combinations in which passengers transfer in non-EU ETS countries. Considering this, we use granular air travel demand data at the route-airline level to estimate the following equation:

$$Y_{ikjh,t} = EUETS(allowanceprice)_{ik,t} + \eta_{i,t} + \lambda_{j,t} + \nu_{ikj} + \delta_{h,t} + \varepsilon_{ikjh,t} \tag{1}$$

Our dependent variable $Y_{ikjh,t}$ gives the number of passengers flows between airport of origin i and airport of destination j via a specific transfer airport k, with operating airline h and at time t. Time t refers to the years from 2010 to 2023, excluding the years 2020 and 2021 which had been affected most severely by the COVID-19 pandemic. As our main variable of interest, Eq. (1) contains the yearly average EU ETS allowance price. To reduce the skewness of the variable, we transform it to its square root, which allows us also to interpret the coefficients as elasticities. As the EU ETS only applies to the first leg of the route, the index of the EU ETS variable refers to airport of origin i and connecting airport k.

Eq. (1) also includes time-variant airport-year fixed effects at the origin and destination level $\eta_{i,t}$ and $\lambda_{j,t}$. These fixed effects replace variables such as GDP per capita and population and, moreover, control for additional observable and unobservable, time-variant factors that impact bilateral passenger flows at the origin and destination-level such as tourism attractiveness, business links, capacity restrictions at airports and airport charges. Additional route fixed effects (ν_{ikj}) substitute the time-invariant controls at the route level, including distance. The time-varying airline fixed effects, $\delta_{h,t}$ account for changes in the cost and productivity differences between airlines and airline-specific reactions and adaptations to the policy. To address the heteroskedasticity and autocorrelation that

[9] Since 2020 and respectively 2021, the EU ETS has been linked to the Swiss and UK ETS. Flights from EEA to Switzerland or the United Kingdom (UK) are subject to the EU ETS, while flights from Switzerland or the UK to the EEA are subject to their respective national ETS.

[10] As the Swiss ETS is linked to the EU ETS from 2020, the treatment year for flights connecting in Switzerland is set to 2020.

Fig. 2a. Routes affected and not affect by the EU ETS (hub competition). Notes: In this example, the route Barcelona-Helsinki-Bangkok is affected by the EU ETS but the route Barcelona-Dubai-Bangkok is not.

Fig. 2b. Routes affected and not affect by the EU ETS (without hub competition). Notes: In this example, the route Milan-Amsterdam-Shanghai is affected by the EU ETS but the route Rome-Doha-Calcutta is not.

impact standards errors, we include robust standard errors clustered at the route level. $\varepsilon_{ikjh,t}$ is the error term.

We also implement an augmented estimator to evaluate the impact of the policy measure in different years. D_{ik} in Eq. (2) is a dummy variable indicating whether the first leg of the route falls under the EU ETS, which is multiplied with t that indicates the year. The coefficient β' represents the impact of the EU ETS in each year.

$$Y_{ikjh,t} = \beta'(D_{ik}xt) + \eta_{i,t} + \lambda_{j,t} + \nu_{ikj} + \delta_{h,t} + \varepsilon_{ikjh,t} \quad (2)$$

To check model robustness, we vary the regressions with regards to the time horizon of the analysis. As the COVID-19 pandemic had a significant impact on aviation statistics due to travel bans, we calculate our main regressions without the data for 2020 and 2021, the two years most severely affected by the pandemic. Additionally, we also analyze data solely for the period before 2020, to avoid any impact of the COVID-19 pandemic and of Russia's war in Ukraine on passenger numbers in the analysis. The post-2022 rebound in air traffic, following the lifting of COVID-19-related travel bans, may partly reflect pent-up demand or operational adjustments unrelated to policy effects. We also use the full period, including the years 2020 and 2021, for comparison purposes. Note that all our regressions include origin-year and destination-year fixed effects, which control for unobservable time-varying factors affecting passenger numbers, such as differences in the intensity of the pandemic's evolution at the route's origin and destination. Without accounting for these pandemic-related distortions, estimated policy impacts could be biased or overstated.

Additionally, we split the sample into two groups. First, we restrict the sample to observations for which each airport-pair-year combination is present in the groups affected and not affected by the EU ETS. Second, we limit the sample to airport-pair-year combinations that exclusively include either routes influenced by the policy or routes not influenced by the policy. Therefore, the airport-year combinations containing both affected and unaffected routes are excluded in the second sub-sample.

This helps us identify how the EU ETS impacts passenger numbers. In the first sub-sample, the comparison has to do with, for example, Barcelona–Bangkok, which can be reached via Helsinki (affected by the policy) and via Dubai (not affected by the policy). Thus, we can test if the effect of carbon prices on demand is at least partially due to traffic shifting from regulated to non-regulated routes, indicating potential carbon leakage.

In the second sub-sample, the comparison would refer, as a hypothetical example, to the Milan-Amsterdam–Shanghai route (affected by the policy) and the Rome–Doha–Calcutta route (not affected by the policy), considering that Milan–Shanghai cannot be flown with one-stop via a non-EEA hub and Rome–Calcutta cannot be flown via an EEA hub. Here, non-EEA hubs are unaffected by the policy, showing the policy's direct effect.

As a further variation we include a set of control variables, $X_{ikj,t}$, which consist of time-variant aviation-specific variables, including the number of flights on the longer leg, a dummy that takes a value of one when the route competes with non-stop connections and a dummy indicating if the route includes two hubs of airlines within the same joint venture (JV).

We chose the number of flights on the longer leg as a control variable, as this segment of the route is not directly affected by the EU ETS.[11] Note also that the connecting passenger volume for any particular airport-pair in our sample will be negligible compared to the total volumes on the segment out of the connecting hub, which will include traffic in many other airport-pair markets. This allows us to treat the variable of flights on the longer leg as exogenous, although we also use lagged values of the variable to take into account a possible endogeneity bias.[12] We may expect a positive sign of the coefficient associated to this variable given that higher frequencies improve service quality due to lower schedule delay costs (which is the difference between the actual and desired time of departure) and lower layover time costs (which is the time spend at the airport waiting for the flight). Regarding the dummy variable for non-stop services, we may expect a negative sign because one-stop flights must compete with non-stop flights that have lower time costs.

The expected effect of the JV variable is not clear because the literature identifies potential pro-competitive and anti-competitive effects of alliances that may be operating simultaneously (Brueckner, 2001). On the one hand, there may be anticompetitive effects on the non-stop flight in the inter-hub market. On the other hand, pro-competitive effects may arise in connecting flights due to the elimination of the double mark-up and better coordination schedules. While there is ample evidence of the effects of alliances on fares, evidence on the demand effects of JVs is scarce. However, a few empirical studies provide evidence that JVs may reduce fares and lead to demand and capacity increases (Calzaretta et al, 2017; Bilotkach and Hüschelrath, 2019; Fageda et al., 2019).

4. Data

4.1. Data sources

The data for our analysis is mainly obtained from Sabre Market Intelligence (Sabre, 2024), a commercial database that provides various sets of air travel supply and demand data. For our analysis, we employ annual passenger volumes on an origin–destination basis at the operating airline and airport level. Data are in the form of marketing information data tapes (MIDT) that take into consideration the true origin and destination of the passengers and so provide detailed information about connecting passengers. This means that we can identify the number of passengers on each one-way route including their origin, connecting airport, destination, and operating airline.

To analyze the effects of the EU ETS on passenger numbers, we retrieve passenger flows originating in European countries covered by the EU ETS. The countries of origin in our dataset are therefore the European Union (EU) countries plus Norway and Iceland, Switzerland and the United Kingdom (UK). The airports of destination in our dataset include all those in the countries of North America, Central Asia, South Asia, East Asia and Southeast Asia as provided by Sabre. In our analysis of the EU ETS policy, the group affected by the policy includes all origin–destination pairs with a transfer airport in the EU ETS countries (plus the UK and Switzerland), while the group not affected consists of all airport combinations where passengers transfer in a non-EU ETS country. As we mention above, to ensure a clear distinction between both types of groups, our analytical framework focuses on one-stop routes only. Appendix A1 provides a full list of all the countries of origin and destination in our analysis.

Daily EU ETS allowance prices in EUR are obtained from Investing.com (2024) and converted to annual averages. The number of flights on each leg of the route and whether a non-stop connection exists on that route are variables that are also obtained from Sabre. The data obtained from Sabre also identify the connecting airport and, hence, the distances for each of the two legs of the journey, which also gives us the total distance of the route for each observation for the descriptive analysis. Information about airline joint ventures on our routes is obtained from internet research and information provided by the airlines. There are three different joint ventures in the North American market. One consists of the Lufthansa Group (Lufthansa, Swiss International Airlines, Austrian Airlines, Brussels Airlines, Eurowings) with United Airlines and Air Canada, another one of Iberia, British Airways and Finnair with

[11] For example, on a flight from Barcelona to Singapore via Frankfurt, only the first and shorter leg is affected by the EU ETS.

[12] Taking the sample example as in footnote 14, the number of passengers from Barcelona to Singapore via Frankfurt will represent a small percentage of total passengers in the flight from Frankfurt to Singapore that will include non-stop passengers and connecting passengers from/to multiple origins and destinations.

American Airlines. The third transatlantic joint venture is between KLM, Air France, Virgin Atlantic and Delta Airlines. The Lufthansa Group has three joint ventures on Asian routes, one with Singapore Airlines, one with All Nippon Airways and one with Air China. There are also joint ventures between Iberia, British Airways and Finnair with Japan Airlines and between Air France and Vietnam Airlines. Our analysis considers the different starting dates of the joint ventures and the entry of airlines into existing joint ventures.

Fig. 3 shows the evolution taken by EU emission allowance prices between 2010 and 2023 and the number of verified emissions and free allowances under the EU ETS for aviation. Under the EU ETS, airlines must surrender emission allowances for every ton of CO_2 they emit. The price of these allowances reflects the market price of CO_2 in the EU ETS and thus indicates the cost of acquiring a permit that allows a company or airline to emit one additional ton of CO_2. While allowance prices remained relatively low in the early years, since 2018 they have risen, peaking at a daily price of almost 100 EUR in 2022. By the end of 2023, daily prices had stabilized at around 70 euros per ton of CO_2. In the same year, the share of purchased emissions was about 58 %, which means 42 % of the emission allowances were allocated for free to the aviation sector. Due to the COVID-19 pandemic, allowance prices dipped slightly in 2020 but continued to rise thereafter, even though airlines purchased smaller numbers of allowances on the market. The severe decline in air traffic meant that freely allocated allowances were (nearly) sufficient to cover aviation emissions in 2020 and 2021. However, it is important to note that within the overall EU Emissions Trading System (EU ETS), aviation emissions account for only a small fraction of total emissions, so allowance prices are primarily driven by sectors such as energy and manufacturing.

The EU-wide cap on emissions is reduced annually in line with the EU's climate target. The reduction factor is applied to the reference cap value, namely the average total volume of allowances issued annually under the system over the 2008–2012 period. A reduction factor of 1.74 % per year applied until 2020. Starting in 2021, the factor increased to 2.2 % per year. Following the 2023 revision of the ETS Directive,[13] the EU ETS cap is set to bring emissions down by 62 % by 2030 compared to 2005 levels. To achieve this, the reduction factor has increased to 4.3 % per year over the period 2024–2027 and to 4.4 % per year from 2028. Furthermore, since 2024, the share of the aviation cap that is auctioned gradually increases. As a result, free allocation for aircraft operators will be phased out from 2026 (European Commission, 2023). Thus, we may expect that the allowance prices will remain relatively high in the coming years.

4.2. Dataset and descriptive analysis

Each observation in our dataset denotes the number of passengers travelling between an airport pair via a specific connecting airport and with a specific operating airline for each year. For reasons of data availability in Sabre, our dataset covers the years 2010–2023 and our final dataset consists of more than two million observations. Table 1 shows the descriptive statistics for our different variables, separated by the region of destination.

The average annual passenger flow per route (i.e., for example, passengers from Barcelona to Hong Kong via Frankfurt) is around 233 for the routes to Asia and about 130 for routes to North America. The average distance of the whole route is around 9500 km and 8000 km, respectively. The average number of flights per observation and flight stage is between almost 1300 and 1800 per year, which corresponds to an average of around 4–5 flights per day. About 20 % of the observations have a non-stop connection competing with the actual route. 48 % of the observations connect at an EU ETS airport for the Asian subsample and 43 % for the North America subsample. The average annual allowance price, considering only routes where the EU ETS applies, is between 26 and almost 31 euros, with a maximum of almost 85 euros.

Note also that JVs have a more relevant role in the sample for North America than for Asia. About 7 % of observations in the sample for Asia include routes with two hubs of airlines within the same joint venture, while this percentage increases to 27 % in the sample for North America.

In addition, Table 2 gives the summary statistics differentiated by whether the stop-over airport is covered by the EU ETS. Differences between routes affected and not affected by the EU ETS in terms of passengers and other route characteristics are small.

However, route distance differs when we look at each of the two legs of the route. When distinguishing between observations affected and unaffected by the EU ETS, the total journey distance remains almost constant when passengers choose to transfer at a non-EU ETS hub. In this regard, a possible source of carbon leakage could be related to the increase in the distance of the journey in case the connections via a non-ETS hub involve longer journeys. This possible source of carbon leakage does not seem to be relevant in our context. There is a discrepancy in the distribution between the two legs of the journey: when transferring at an EU ETS hub, the first leg is typically a short- or medium-haul flight, while the second leg is a long-haul flight. For the non-affected group, the first leg is longer on average than the second (see Fig. 4).

If we consider all passengers travelling to Asia from the European countries, 42 % take a non-stop flight. 35 % of passengers take a one-stop flight with transfer in the Gulf and Middle East or Asia regions, while just 16 % of passengers take a one-stop flight with transfer in an ETS hub (see Fig. 5). For passengers travelling to North America, 52 % fly non-stop from Europe, while 27 % transfer at an ETS hub and 19 % in North America.

By way of an initial descriptive analysis of the impact of the EU ETS, in Fig. 6 we plot the average number of passengers per route in each year. The analysis is carried out for the whole period and differentiated by region of destination. Note that routes via ETS hubs are thinner in the sample for Asia but are denser in the sample for North America. The analysis shows a similar trend for the variable passenger numbers before the treatment event in 2013 and a better performance of the routes not affected by the policy after

[13] Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU).

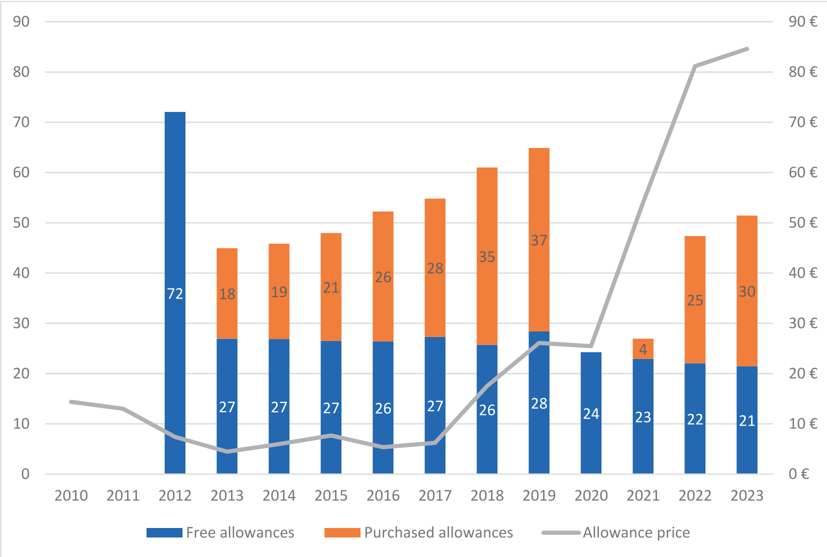

Fig. 3. Emissions/allowances (mil. tons of CO_2) of the aviation sector and allowance market prices (EUR), 2010–2023. Notes: The figure shows the verified emissions in mil. tons of CO_2 from the aviation sector covered by the EU ETS. In 2012, the aviation sector was officially subject to the full scope of the EU ETS. Sources: EEA, 2023; Investing.com, 2024.

Table 1
Descriptive statistics – by destination region.

Variable	Asia				North America			
	Obs.	Mean	Min.	Max.	Obs.	Mean	Min.	Max.
Passengers	746,695	233.20	0.02	51,628.54	1,332,633	132.11	0.01	20,123.49
Distance	701,332	9,426.87	1,842.00	23,240.00	1,276,365	8,017.26	3,425.00	26,274.00
Distance (leg 1)	744,747	3,803.46	39.00	14,573.00	1,324,939	4,077.64	17.00	11,953.00
Distance (leg 2)	703,123	5,550.68	41.00	15,354.00	1,283,549	3,849.74	39.00	15,354.00
Flights (leg 1)	744,758	1,280.03	1.00	18,714.00	1,324,940	1,259.52	1.00	18,714.00
Flights (leg 2)	703,131	1,401.01	0.00	24,996.00	1,283,549	1,766.82	1.00	20,516.00
Non_stop	746,695	0.18	0.00	1.00	1,332,633	0.20	0.00	1.00
JV	746,695	0.07	0.00	1.00	1,332,633	0.27	0.00	1.00
Treated	746,695	0.48	0.00	1.00	1,332,633	0.43	0.00	1.00
EU ETS (dummy)	746,695	0.37	0.00	1.00	1,332,633	0.35	0.00	1.00
EU ETS (allowance price)	279,210	26.45	4.47	84.60	462,136	30.83	4.47	84.60

Notes: The statistics for the EU ETS price variable are calculated for observations where the EU ETS applies.

Table 2
Descriptive statistics – by affected/ non-affected routes.

Variable	EU ETS routes				Non-EU ETS routes			
	Obs	Mean	Min	Max	Obs	Mean	Min	Max
Passengers	924,303	159.16	0.01	20,123.49	1,155,025	175.82	0.01	51,628.54
Distance	853,173	8,549.30	3,118.00	14,643.00	1,124,524	8,492.73	1,842.00	26,274.00
Distance (leg 1)	922,312	943.67	17.00	4,765.00	1,147,374	6,418.89	136.00	14,573.00
Distance (leg 2)	854,796	7,606.00	3,001.00	12,585.00	1,131,876	2,069.62	39.00	15,354.00
Flights (leg 1)	922,312	1,819.67	1.00	18,714.00	1,147,386	822.57	1.00	7,499.00
Flights (leg 2)	854,796	681.75	0.00	7,499.00	1,131,884	2,359.03	1.00	24,996.00
Non_stop	924,303	0.19	0.00	1.00	1,155,025	0.20	0.00	1.00
JV (Asia)	924,303	0.03	0.00	1.00	1,155,025	0.02	0.00	1.00
JV (North America)	924,303	0.16	0.00	1.00	1,155,025	0.19	0.00	1.00
Region_ID	924,303	0.39	0.00	1.00	1,155,025	0.34	0.00	1.00
EU ETS (dummy)	924,303	0.80	0.00	1.00	1,155,025	0.00	0.00	0.00
EU ETS (allowance price)	741,346	29.59	4.47	84.60				

Notes: The identifier variable region_ID is one if the destination region is Asia and zero if the destination region is North America. The statistics for the EU ETS price variable are calculated for observations where the EU ETS applies.

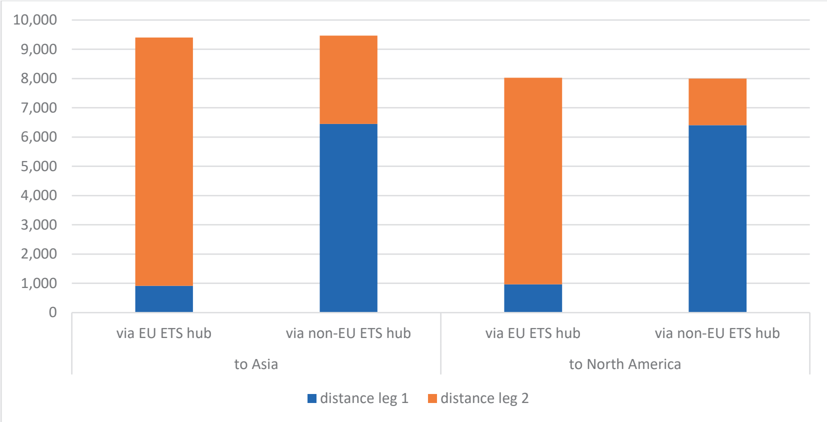

Fig. 4. Distances of routes to Asia and North America (in km), 2010–2023.

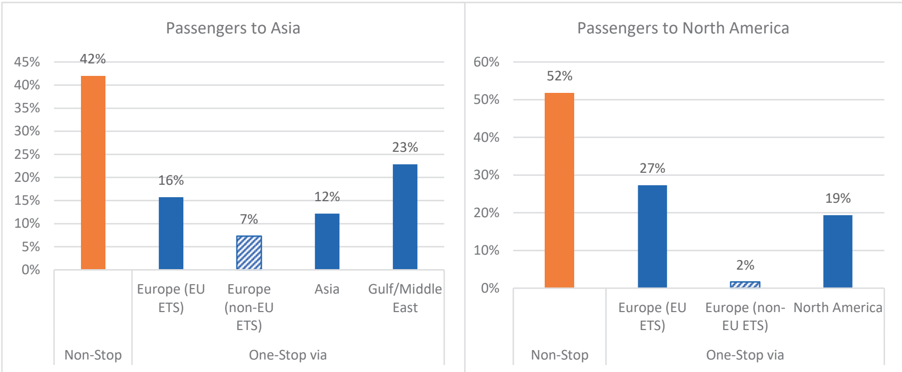

Fig. 5. Distribution of passengers to Asia and North America (in %), 2010–2023. Notes: The data refer to passengers originating in the EEA countries plus the UK with destinations in Asia and North America.

Fig. 6. Evolution of passenger numbers on routes affected and not affected by the EU ETS. Notes: In all graphs, the trend in the average number of passengers is shown for the routes affected by the EU ETS (line 1) and routes not affected by the EU ETS (line 0).

Table 3
Main estimation results.

	(1)	(2)	(3)
EU ETS (price)	−0.041***	−0.051***	−0.032***
	(0.002)	(0.004)	(0.003)
Observations	1,835,052	656,350	1,178,190
R-squared	0.398	0.477	0.354
Controls	NO	NO	NO
Route FE	YES	YES	YES
Destination-/Origin-Year FE	YES	YES	YES
Airline-Year FE	YES	YES	YES
Period	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023
Sample	Europe-Asia & NA	Europe-Asia	Europe-NA

Note: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is ln (passengers). NA = North America.

treatment, especially when carbon prices are relatively higher.

5. Results

Table 3 shows the results of our main regressions with the number of passengers travelling from Europe to destinations in Asia and North America as the dependent variable. All regressions include the full set of fixed effects but no additional control variables. The data covers the period from 2010 to 2023, excluding the years 2020 and 2021. Column (1) presents the results for the entire sample, while columns (2) and (3) report the estimates for the EU ETS variable, separated by the region of destination.

The EU ETS allowance price variable is negative and highly significant in all the regressions reported in Table 3. A one-hundred percent increase in the allowance price has led to a 4 % decrease in passenger numbers on routes transferring via an ETS hub.[14] Differentiating by destination region, the impact increases to −5.1 % for one-stop routings with a destination in Asia and decreases to −3.1 % for one-stop routings with a destination in North America.

It is remarkable that we find a negative and statistically significant effect of the allowance price in both the Asian and North American samples because there are substantial differences between both markets. For example, the regulatory environment is more liberal in the case of North America, since the United States and the European Union signed an open skies agreement in 2008, while air traffic between the EU and Asia is governed by more or less restrictive bilateral agreements. The Asian market is in a phase of greater growth than the North American one, considering also that Middle East airlines benefit from strong public support that airlines from the United States or Europe do not have. As we have mentioned above, cooperation between EEA and non-EEA airlines is particularly intense in the case of North America. Other factors that may be different are the specific characteristics of demand, or the relative geographical position of non-EEA hubs in competition with EEA hubs. Finding a significant effect of the allowance prices on passenger numbers in such heterogeneous destination regions reinforces the causality of the estimated effect.

To assess the impact of the EU ETS policy measure in different years, we also implemented an augmented estimator (see description in the methodology section). This provides us with an estimate of the impact of an EU ETS dummy variable for each year on our dataset in the form of a so-called event study. Fig. 7 shows the estimated coefficients of the EU ETS dummy variable for each year including the significance for a 95 % confidence interval (Fig. A1 in the appendix shows the same estimates for the Asia and North America samples). The ETS does not seem to have had any clear effect before 2018. However, the figure shows a significant reduction in passenger numbers due to the EU ETS since the year 2018. As shown in Fig. 3, the EU ETS allowance price rose to around 26 euros in 2018 and continued to rise in subsequent years. Prior to this period, the allowance price was quite low, which presumably did not affect passenger numbers. Thus, while we find a negative effect of the allowance price on passenger numbers for the entire period considered, this effect only seems to be relevant when such prices are high.

Note that Table A3 in the appendix shows the results of a regression in which the main explanatory variable is a dummy for routes affected by the EU ETS. The results of these regressions show a strong impact of the EU ETS, particularly in the case of Asia where the estimated effect is −13 %.

Table 4 gives the results for our regressions on different time frames. Due to the COVID-19 pandemic, we exclude the years 2020 and 2021 from our main regressions. The first three columns of Table 4 restrict the analysis to the period before 2020, and regressions (4)–(6) include the whole period in our dataset (2010–2023). The impact of the EU ETS is lower for the subsample when the years from 2020 onwards are excluded (−2.7 %). This can be explained by the relatively low price of EU ETS allowances in most years of the period 2010–2019 (cf. Fig. 3). Including the whole period, i.e. including the years 2021 and 2022, which also showed higher EU ETS allowance prices, slightly increases the impact of the EU ETS on passenger numbers from −4.1 % to −4.4 %. Although these regressions cover the entire period, including the COVID-19 pandemic which caused a significant drop in aviation demand, the time-varying year

[14] We also show the results using the real price level of the EU ETS variable in Table A2 in the Appendix. The results can be interpreted as the percentage change in passenger numbers due to a one unit (euro) change in the dependent variable. The differences between the non-transformed and transformed models are minimal.

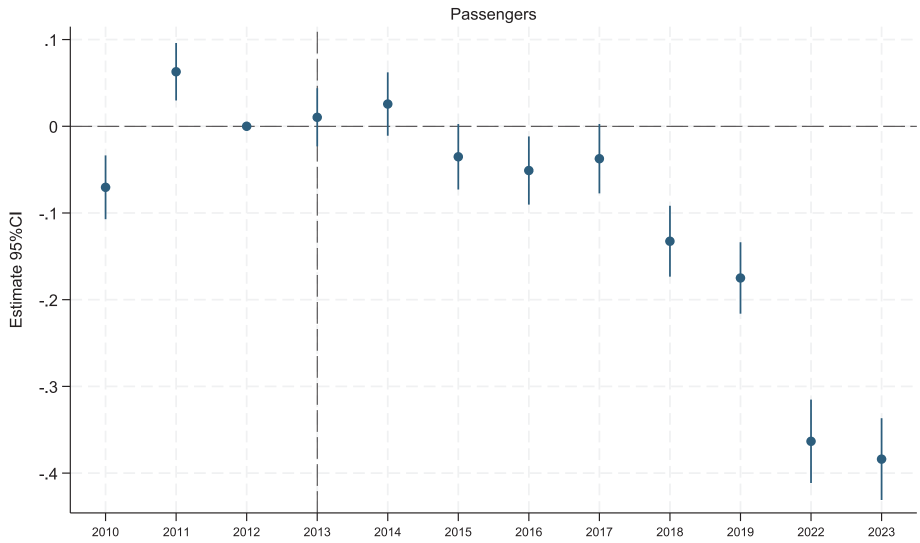

Fig. 7. Event study of the EU ETS impact on passenger numbers. Notes: The estimates show the impact of the EU ETS dummy variable on the number of passengers in each year, with 2012 as the base year. All regressions include origin-year, destination-year, route and airline-year fixed effects. The years 2020 and 2021 are excluded from the estimates.

Table 4
Estimation results – different time frames.

	(1)	(2)	(3)	(4)	(5)	(6)
EU ETS (price)	−0.027***	−0.018***	−0.022***	−0.044***	−0.057***	−0.033***
	(0.004)	(0.007)	(0.004)	(0.002)	(0.004)	(0.003)
Observations	1,538,467	565,484	972,534	2,041,177	728,324	1,312,245
R-squared	0.412	0.486	0.369	0.394	0.474	0.350
Controls	NO	NO	NO	NO	NO	NO
Route FE	YES	YES	YES	YES	YES	YES
Destination/Origin & Year FE	YES	YES	YES	YES	YES	YES
Airline-Year FE	YES	YES	YES	YES	YES	YES
Period	2010–2019	2010–2019	2010–2019	2010–2023	2010–2023	2010–2023
Sample	Europe-Asia & NA	Europe-Asia	Europe-NA	Europe-Asia & NA	Europe-Asia	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is ln (passengers). NA = North America.

fixed effects account for annual disturbances and exogenous shocks like the pandemic. Moreover, as shown in Fig. 3, allowance prices only decreased in 2020 and kept rising afterwards, likely because the still ongoing reduced demand in aviation had little impact on the overall allowance market. The EU ETS allowances market is primarily driven by the demand for allowances from the energy sector and energy-intensive manufacturing industries.

Tables 5 and 6 show the results for different subsamples and for specifications with different control variables. For comparative purposes, the first columns in both tables show the main regressions as reported previously in Table 3.

In Table 5, regressions (2), (5) and (8) restrict the sample to observations for which each airport-pair-year combination is present in both the treated and control groups to identify the indirect effects of the EU ETS (hub competition sample). Regressions (3), (6) and (9) limit the sample to airport-pair-year combinations that exclusively include either routes affected by the policy or unaffected ones to capture the direct effects of the EU ETS (no hub competition sample).

For the sample considering both destination regions, the negative impact of the EU ETS increases from 3 % in the subsample with hub competition, to 6 % in the subsample without hub competition. Fig. 8 shows the estimated coefficients of the EU ETS dummy variable for each year considering both sub-samples. Again, the effect seems to be clearer in the period with high carbon prices. For Asia, the impact of the EU ETS slightly increases for the sub-sample without hub competition. Thus, both direct and indirect effects seem to have a similar influence in explaining the impact of carbon prices on passenger numbers in the sample with Asia as destination region. For North America, the direct effect is much higher than the indirect effect. Indeed, the estimated impact is about −6% when using the subsample without hub competition. Such impact is about −2% in the subsample with hub competition. Hence, passenger shifts from regulated to unregulated routes play a more relevant role in the sample for Asia. At this point, joint ventures between US and European airlines could help in mitigating hub passenger shifts.

Adding controls for the number of flights (of the longer leg), non-stop connections, and joint ventures reduces the EU ETS impact from −5.1 % to −4.6 % in the Asian subsample, while the North American subsample remains largely unchanged. The control variables

Table 5
Estimation results – direct effect vs indirect effects.

	(1)	(2)	(3)	(4)	(5)	(6)	(6)	(8)	(9)
EU ETS (price)	−0.041***	−0.038***	−0.060***	−0.0506***	−0.0544***	−0.0664***	−0.0317***	−0.0241***	−0.0592***
	(0.002)	(0.002)	(0.012)	(0.004)	(0.004)	(0.021)	(0.003)	(0.003)	(0.018)
Observations	1,835,054	1,039,698	787,549	656,352	406,298	246,063	1,178,190	633,247	541,025
R-squared	0.398	0.379	0.430	0.477	0.454	0.522	0.354	0.337	0.385
Controls	NO	NO	NO	NO	NO	NO	NO	NO	NO
Route FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Destination/Origin & Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Airline-Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Other criteria	–	Hub competition	No hub competition	–	Hub competition	No hub competition	–	Hub competition	No hub competition
Sample	Europe-Asia & NA	Europe-Asia & NA	Europe-Asia & NA	Europe-Asia	Europe-Asia	Europe-Asia	Europe-NA	Europe-NA	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is ln (passengers). The period considered in all regressions is 2010–2019 & 2022–2023. NA = North America.

Table 6
Estimation results – different controls.

	(1)	(2)	(3)	(4)	(5)	(6)
EU ETS (price)	−0.051***	−0.046***	−0.051***	−0.032***	−0.030***	−0.040***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
ln (flights)		0.300***			0.169***	
		(0.008)			(0.007)	
ln (flights_lagged)			0.032***			0.026***
			(0.006)			(0.006)
Non_stop		−0.049***	−0.054***		−0.115***	−0.116***
		(0.017)	(0.018)		(0.013)	(0.013)
JV		−0.063***	−0.075***		0.303***	0.397***
		(0.021)	(0.022)		(0.027)	(0.033)
Observations	656,352	655,450	573,682	1,178,190	1,177,202	1,037,999
R-squared	0.477	0.479	0.481	0.354	0.355	0.357
Route FE	YES	YES	YES	YES	YES	YES
Destination/Origin & Year FE	YES	YES	YES	YES	YES	YES
Airline-Year FE	YES	YES	YES	YES	YES	YES
Period	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023
Sample	Europe-Asia	Europe-Asia	Europe-Asia	Europe-NA	Europe-NA	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is ln (passengers). NA = North America.

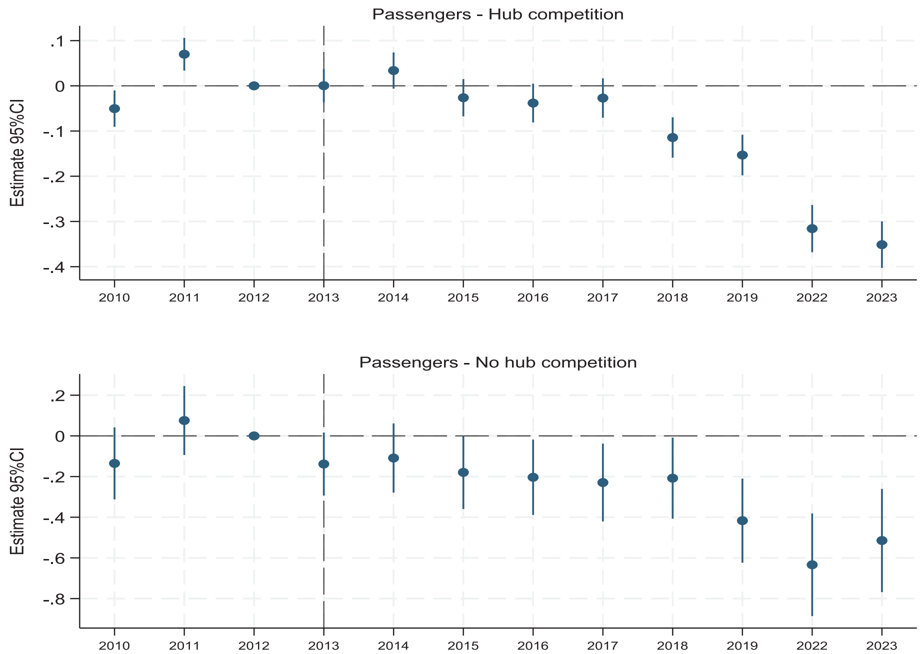

Fig. 8. Event study of the EU ETS impact on passenger numbers (hub and no hub competition samples). Notes: The estimates show the impact of the EU ETS dummy variable on the number of passengers in each year, with 2012 as the base year, considering the hub and no hub competition sample. All regressions include origin-year, destination-year, route and airline-year fixed effects. The years 2020 and 2021 are excluded from the estimates.

used in our estimates are highly significant in all regressions. While the presence of a non-stop connection reduces the number of passengers in our dataset, the number of flights covering the longer leg increases our dependent variable. Joint ventures increase passenger numbers on routes to North America by 30 %; however, for Asia, they have the opposite effect, decreasing passenger numbers by 6 %. It is important to note that only 7 % of observations for Asia are covered by joint ventures, mainly when the destination country is Japan, compared to 27 % for North America (refer to Table 2). Note also that the ties between airlines within the same JVs have been identified to be stronger on transatlantic routes (Grosche and Klophaus, 2024). To address potential endogeneity concerns arising from reverse causality between passenger numbers and supply measures, we extend the analysis by also including the lagged value (t-1) of the flights variable. The results are shown in columns (3) and (6) of Table 6. The impact of a 100 % increase in the

Table 7
Estimation results – impact of joint ventures.

	(1)	(2)	(3)
EU ETS (dummy)	−0.114***	−0.136***	−0.075***
	(0.013)	(0.023)	(0.017)
JV	0.038**	−0.096***	0.280***
	(0.016)	(0.027)	(0.027)
EU ETS # JV	0.106***	0.042	0.149***
	(0.015)	(0.036)	(0.017)
Observations	1,835,052	656,350	1,178,190
R-squared	0.398	0.477	0.355
Route FE	YES	YES	YES
Destination/Origin & Year FE	YES	YES	YES
Airline-Year FE	YES	YES	YES
Period	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023
Sample	Europe-Asia & NA	Europe-Asia	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$. The dependent variable is ln (passengers). NA = North America.

price of EU ETS allowances rises to −4.0 % for the North American subsample. For the Asian subsample, the impact of the EU ETS remains consistent with the main regression results in column (1). As observed previously, the effect of the EU ETS still is more pronounced on Asian routes compared to transatlantic routes. Importantly, the coefficient for the lagged flights variable is significantly smaller than that for the contemporaneous flights variable, suggesting that using the lagged value helps control for endogeneity by reverse causality.

Another issue to consider is the potential collinearity between the EU ETS and flight variables. In the regressions presented in Table 6, we control for the number of flights on the longer leg, which is not directly covered by the EU ETS. However, this segment may still be indirectly affected, as airlines might reduce frequencies on regulated short-haul flights, thereby influencing supply decisions on connecting long-haul segments. To further examine this relationship, we model the number of flights as the dependent variable and analyze the effects of the EU ETS on the first leg, second leg, and on total flights (refer to Table A4 in the Appendix). As expected, the EU ETS reduces flight frequencies on the first leg in both subsamples. Additionally, long-haul flights are significantly affected in the Asian subsample, while no such impact is observed for North American routes.

To further examine the effect of joint ventures on passenger numbers in connection with the EU ETS, we consider additional regressions that include as covariates the dummy variables for routes affected by the EU ETS and joint ventures, and an interaction term between both variables. Note that these additional regressions capture the EU ETS effect through a dummy variable that takes value one for routes with EEA hubs as connecting airports. We consider here a dummy variable instead of the EU ETS allowance price because this allows us to identify more clearly the existence of three groups of routes: (1) routes not affected by the EU ETS, (2) routes affected by the EU ETS but without influence from joint ventures, (3) routes affected by both the EU ETS and joint venture agreements.

The un-interacted term for the EU ETS variable shows the effect when joint ventures do not have any influence. The sum of the un-interacted term of the EU ETS variable and the interaction term with the joint venture variable shows the effect of the EU ETS for those routes that link two hubs of airlines within the same joint venture. A positive effect of the interaction term implies a lower effect of the EU ETS on passenger numbers on those routes affected by joint ventures.

The results, presented in Table 7, indicate that for the whole dataset and for the North America subsample, joint ventures dilute the negative impact of the EU ETS as the interaction term is positive and highly significant. For routes to Asia, the coefficient of the interaction is also positive but not statistically significant. Hence, our results suggest that JVs may have mitigated the effects of the EU ETS on passenger numbers, particularly when North America is the destination region. In this context it is important to acknowledge that joint ventures (JVs) have a strong baseline positive effect on passenger volumes on North American routes (refer to Table 6). The positive interaction term in Table 7 therefore reflects not only this intrinsic advantage but also an additional mitigating effect of JVs on the negative impact of the EU ETS on transatlantic routes. This distinction highlights that JVs help cushion the policy's adverse effects beyond their general traffic-enhancing role.

6. Concluding remarks

We provide novel evidence of the direct and indirect effects of the EU ETS on passenger traffic attributable to the reduced scope of the EU ETS as it is applied to the aviation sector. Such effects seem to be only relevant with high carbon prices. In this regard, the gradual reduction of the overall emissions cap implies that allowance prices are likely to remain high in the coming years.

On the one hand, the direct effects of the EU ETS on the long-haul aviation market shed light on its effectiveness complementing what has been found in previous studies focused on short-haul markets. On the other hand, the indirect effects are related to hub passenger shifts, which may harm the competitiveness of European airlines, particularly in the context of fierce competition with Gulf carriers when the destination is an Asian city. Hub passenger shifts may be associated with carbon leakage due to the displacement of a polluting activity, like flying, from regulated to unregulated routes.

One potential measure for reducing distortions in competition and the effects of carbon leakage would be to levy a tax (equivalent to CO_2 costs from the EU ETS in the European market) on connecting passengers that fly from/to a European airport but who make the connection in a non-EEA hub. However, this could generate the same level of opposition from non-European airlines as the initial ETS plan did unless the tax was small.[15]

Alternatively, the EU ETS could be extended to all flights taking off from or landing at an EEA airport in line with the EU's initial intentions. Expanding the scope of the EU ETS in this way would mean that c. 23 % of worldwide emissions from aviation would be covered by the scheme, while its current scope covers just 8 % (RDC aviation 2024, data for 2023). The decision to restrict the application of the EU ETS to flights within the EEA was justified on the grounds of the planned implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA, a global market-based mechanism to offset increases in emissions from international flights promoted by the International Civil Aviation Organization (ICAO), will be binding as of 2027. However, the scheme is less stringent, and its aims are more limited than those of the EU ETS and, as such, its effectiveness in reducing emissions has been called into question (Larsson et al., 2019; Scheelhaase et al., 2018, Gössling and Lyle, 2021, Mayer and Ding, 2023). In any case, an effective implementation of CORSIA would go a long way towards correcting the potential carbon leakage effects of the EU ETS.

In the transatlantic market, joint ventures may explain why the hub shifts associated with the EU ETS are small. Therefore, promoting cooperation agreements between European and non-European airlines can help to share the costs of the EU ETS on long-haul flights.[16]

In short, the analysis we report here shows that the EU ETS is an effective measure to contain traffic growth in the long-haul aviation market. However, some additional measures could mitigate those unintentional effects that may negatively impact businesses, employment and general well-being within the European Economic Area.

CRediT authorship contribution statement

Xavier Fageda: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Katrin Oesingmann:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Appendix

Table A1
Origin and destination countries.

Origin countries (EU, EEA, UK)	Destination regions	Destination countries
Austria	Asia Sub-Continent	Bangladesh
Belgium		Bhutan
Bulgaria		India
Croatia		Maldives
Cyprus		Nepal
Czech Republic		Pakistan
Denmark		Sri Lanka
Estonia	Central Asia	Kazakhstan
Finland		Mongolia
France	Far East Asia	China
Germany		Hong Kong – China
Greece		Japan

(*continued on next page*)

[15] To address the potential carbon leakage associated with its emissions trading system, the EU has introduced a carbon border adjustment mechanism (CBAM). The tool, which is to take full effect from 2026, is currently in a transitional reporting phase (2023–2025). Under the mechanism, EU importers of goods covered by the CBAM will be required to buy certificates for embedded emissions based on the auction price of EU ETS allowances. Yet, the aviation sector is not covered by CBAM, which applies solely to the carbon intensive sectors of cement, iron and steel, aluminum, fertilizers, electricity, and hydrogen. Clearly, one way to address carbon leakage in the aviation sector would be to include the latter in the CBAM, although various authors stress the challenges of doing so in practice (see Cosbey et al., 2019 and Fontagné and Schubert, 2023 for detailed reviews).

[16] However, it would likely be necessary to monitor that such agreements do not lead to anti-competitive effects in the inter-hub market.

Table A1 (*continued*)

Origin countries (EU, EEA, UK)	Destination regions	Destination countries
Hungary		Macau
Iceland		Singapore
Ireland		South Korea
Italy		Taiwan
Latvia	Southeast Asia	Brunei
Lithuania		Cambodia
Luxembourg		Indonesia
Malta		Laos
Netherlands		Malaysia
Norway		Myanmar (Burma)
Poland		Philippines
Portugal		Thailand
Romania		Vietnam
Slovakia	North America	Canada
Slovenia		Mexico
Spain		United States
Sweden		
Switzerland		
United Kingdom		

Notes: Destination regions defined as in Sabre (2024).

Table A2
Estimation results – EU ETS (real price) variable.

	(1)	(2)	(3)
EU ETS (real price)	−0.0044***	−0.0059***	−0.0035***
	(0.000)	(0.000)	(0.000)
Observations	1,835,054	656,352	1,178,190
R-squared	0.398	0.477	0.355
Controls	NO	NO	NO
Route FE	YES	YES	YES
Destination-/Origin-Year FE	YES	YES	YES
Airline-Year FE	YES	YES	YES
Period	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023
Sample	Europe-Asia & NA	Europe-Asia	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is ln (passengers). NA = North America.

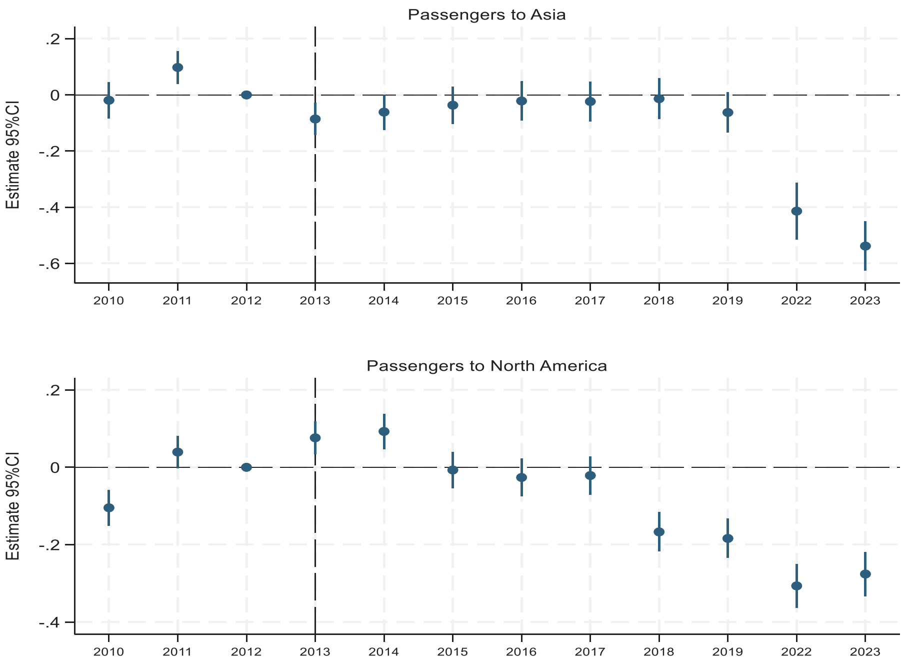

Fig. A1. Event study of the EU ETS impact on passenger numbers (Asia and North America samples). Notes: The estimates show the impact of the EU ETS dummy variable on the number of passengers in each year, with 2012 as the base year, considering the hub and no hub competition sample. All regressions include origin-year, destination-year, route and airline-year fixed effects. The years 2020 and 2021 are excluded from the estimates.

Table A3
Estimation results – EU ETS dummy variable.

	(1)	(2)	(3)
EUETS (dummy)	−0.092***	−0.134***	−0.037**
	(0.013)	(0.023)	(0.016)
Observations	1,835,052	656,350	1,178,190
R-squared	0.398	0.477	0.354
Controls	NO	NO	NO
Route FE	YES	YES	YES
Destination-/Origin-Year FE	YES	YES	YES
Airline-Year FE	YES	YES	YES
Period	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023
Sample	Europe-Asia & NA	Europe-Asia	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. The dependent variable is ln (passengers). NA = North America.

Table A4
Estimation results – Number of flights as dependent variable.

	(1) ln (flights) 1.leg	(2) ln (flights) 2. leg	(3) ln (flights) total	(4) ln (flights) 1.leg	(5) ln (flights) 2.leg	(6) ln (flights) total
EU ETS (price)	−0.011***	−0.016***	−0.010***	−0.031***	0.028***	−0.003***
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	655,452	618,875	618,021	1,177,202	1,137,992	1,137,112
R-squared	0.949	0.956	0.967	0.966	0.965	0.970
Route FE	YES	YES	YES	YES	YES	YES
Destination/Origin & Year FE	YES	YES	YES	YES	YES	YES
Airline-Year FE	YES	YES	YES	YES	YES	YES
Period	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023	2010–2019 & 2022–2023
Sample	Europe-Asia	Europe-Asia	Europe-Asia	Europe-NA	Europe-NA	Europe-NA

Notes: (Robust) standard errors, clustered by route, are given in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. NA = North America.

Data availability

The authors do not have permission to share data.

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