Evaluating the impact of the eu emissions trading system on aviation supply: evidence from synthetic control methods

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BASED ON:

Kang, Y., Liao, S., Jiang, C., & 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

Online, March 17 2026

Industry background

- The **European Union Emissions Trading System (EU ETS)** represents the cornerstone of European climate policy and constitutes the world's first large-scale international carbon market.

- Introduced in **2005**, the EU ETS is designed to **reduce greenhouse gas emissions in a cost-effective manner by creating a market-based mechanism that assigns a price to carbon emissions.**

- The system operates under a **cap-and-trade framework in which a limit is placed on the total quantity of emissions permitted within the regulated sectors.** Firms covered by the system must surrender **emissions allowances corresponding to their verified emissions, while the total number of allowances available is progressively reduced over time to ensure declining emissions.**

- By allowing firms to trade emission allowances, the system creates **financial incentives for companies with low abatement costs to reduce emissions and sell excess allowances, while firms facing higher abatement costs may purchase additional permits on the market**. This flexibility ensures that **emissions reductions are achieved at the lowest possible overall cost while maintaining a binding environmental constraint**.

Industry background

- Although **auctioning has progressively become the default allocation mechanism within the EU ETS**, a substantial proportion of allowances has historically been distributed for free, particularly during the early phases of the program.

- **Free allocation was introduced to mitigate competitiveness concerns and reduce the risk of carbon leakage**, whereby firms might relocate production to jurisdictions with weaker environmental regulations. **Even when allowances are freely allocated, however, they still carry an opportunity cost equivalent to their market value**, implying that carbon pricing effectively increases firms' marginal production costs regardless of the allocation method.

- The **aviation sector was incorporated into the EU ETS in 2012**, marking the first instance of a carbon pricing mechanism applied to international aviation activities. **Under the system, airlines operating flights within the European Economic Area must account for their carbon dioxide emissions and surrender allowances accordingly**. The policy thus introduces **carbon emissions as an additional input cost in airline operations, with potential implications for pricing, route structure, and capacity decisions**.

Industry background

- **During Phase III of the EU ETS (2013–2020)**, the annual cap on aviation allowances was set at approximately 210 million allowances. These allowances were distributed according to a predefined allocation rule: approximately 82 percent were allocated free of charge to aircraft operators, 15 percent were auctioned, and 3 percent were reserved for new entrants and rapidly expanding airlines.

- **Phase IV, spanning 2021-2030**, strengthens carbon market rules to meet higher climate targets. Key features include
  - Reduced Cap: The total number of emission allowances decreases annually by 2.2% (previously 1.74%), accelerating the reduction path.
  - Free Allocation Update: Free allocation of allowances is maintained but revised to focus on sectors at the highest risk of carbon leakage, with updated benchmarks to reflect technological progress.
  - Support for Innovation & Modernization: Launch of the Innovation Fund (for innovative low-carbon technologies) and the Modernization Fund (for energy systems in lower-income EU Member States).
  - Market Stability Reserve (MSR): The MSR continues to operate to manage the surplus of allowances in the market, with enhanced mechanisms.
  - Target: The sector aims to achieve a 43% reduction in emissions by 2030 compared to 2005 levels, supporting the broader "Fit for 55" package goal

Our study

- This paper evaluates the **causal impact of EU ETS on aviation supply**. The introduction of aviation into the EU ETS provides a **natural policy experiment** to investigate **how airlines adjust supply decisions in response to carbon pricing**.

- The analysis focuses on **airline output measured at the airline-route level**, with the **number of seats supplied serving as the primary indicator of aviation supply**. This outcome reflects both **flight frequency and aircraft size, thereby capturing key operational decisions made by airlines in response to changes in marginal costs**.

- The empirical analysis exploits a **large panel dataset covering airline routes across multiple countries over the period 2007–2017, including five years before and five years after the introduction of the EU ETS for aviation**.

- The dataset includes **more than 315,000 routes in 48 countries, of which 31 fall within the regulatory scope of the policy**. This extensive dataset allows the study to explore heterogeneous effects across different market segments, including
    - airline business models (low-cost, regional, and full-service carriers)
    - route distances (short-haul versus medium- and long-haul flights)
    - airport network structures (hub versus non-hub routes)
    - and levels of market competition.

Our study

- The evaluation of policy interventions that operate at an aggregate level represents a central challenge in applied economic research. A widely used empirical approach in such contexts is the **comparative case study framework, where the evolution of outcomes for units exposed to a policy intervention is compared with those of unaffected units that serve as a control group.**

- The validity of this approach depends critically on the **ability of the control group to approximate the trajectory that the treated units would have followed in the absence of the intervention.**

- Traditional empirical strategies often rely on **propensity score matching techniques, which attempt to identify untreated units that resemble treated units based on observable characteristics**. These methods rely on the **existence of suitable control units that closely resemble treated units along relevant dimensions**.

- In many settings, however, no single untreated unit provides a satisfactory comparison. This limitation has motivated the development of **synthetic control methods, which construct a weighted combination of multiple untreated units to approximate the counterfactual trajectory of the treated unit**. By allowing the **control group to be composed of several units rather than a single comparator, synthetic control approaches often provide a more accurate representation of the counterfactual outcome**.

Literature

- The literature relevant to this study spans three main strands of research:

- **analyses of the economic impact of the EU ETS on airline strategies and performance**
- **studies examining airline operational decisions regarding aircraft size and flight frequency**
- **and research investigating the role of fuel prices in shaping airline market outcomes.**

- A **first stream of literature** focuses on **ex-ante evaluations of the policy based on theoretical models or simulations rather than empirical ex-post analysis**. These contributions examine how carbon pricing may affect airlines' cost structures, network configurations, and competitive dynamics. **Early studies suggested that the introduction of emissions trading would increase operating costs for airlines, potentially affecting ticket prices and route structures. However, the magnitude of these cost increases was generally predicted to be relatively modest.**
    - airlines' networks reconfiguration (e.g., Albers et al. 2009; Derigs & Illing 2013; Malina et al. 2012)
    - the additional costs and effects on fares (e.g., Morrell 2007; Scheelhaase & Grimme 2007; Scheelhaase et al. 2010)

Literature

- A **second strand of literature** examines **airlines' strategic choices regarding aircraft size and service frequency**. In the aviation industry, airlines face a trade-off between operating larger aircraft with lower frequency and smaller aircraft with higher frequency. **Economic theory suggests that frequency can be an important competitive instrument because passengers value schedule flexibility.** Empirical studies using structural models of airline competition find that **increasing flight frequency often generates greater market share gains than increasing aircraft size**, leading airlines to operate aircraft smaller than the cost-minimizing size in order to offer more frequent services.

- This trade-off between aircraft size and frequency has **important implications for the environmental impact of aviation**. **Larger aircraft tend to be more fuel-efficient on a per-seat basis, particularly on longer routes, whereas higher flight frequencies may increase overall fuel consumption**.

- Wei & Hansen (2007), Givoni & Rietveld (2009), Wei (2006), Wei & Hansen (2007), Givoni & Rietveld (2010), Fageda & Flores-Fillol (2015, 2016), Brueckner & Lin (2016), Wang & Wang (2019),

Literature

- A **third related literature** investigates the **role of fuel prices in shaping airline behavior**. Since **fuel costs constitute a major component of airlines' operating expenses**, fluctuations in fuel prices can significantly affect airline decisions regarding pricing, capacity, and network design. From an economic perspective, **carbon pricing mechanisms such as emissions trading systems can be interpreted as policies that effectively increase the price of fuel faced by airlines.**

- Several studies have analyzed how higher fuel prices influence airline market outcomes. These analyses suggest that **increases in fuel costs tend to raise airfares, reduce flight frequencies, and increase load factors, as airlines adjust their operations to maintain profitability. Importantly, theoretical models predict that higher fuel costs may not necessarily lead to significant changes in aircraft size, as fleet composition decisions are often determined by long-term investment cycles and technological constraints**.

- (Fukui & Miyoshi 2017; Hofer et al. 2010; Tol 2007).
- (Brueckner & Zhang 2010; Scotti & Volta 2018; Wadud 2015), Brueckner & Zhang (2010)

- Closely related (in parallel but independent) work: **Fageda and Teixedo (2022)**
- **difference-in-differences strategy on a sample based on all flights within Europe from 2010 to 2016 to examine the causal impact of the EU ETS on emissions and supply.**

Methods and data

- The empirical analysis in this study relies on the **synthetic control method to estimate the causal impact of the EU ETS on aviation supply.**

- In the context of this study, **the treated units correspond to airline routes that fall within the regulatory scope of the EU ETS, while untreated units consist of routes outside the European Economic Area that are not subject to the policy**.

- **The objective is to estimate how aviation supply on treated routes would have evolved if the EU ETS had not been implemented. This counterfactual trajectory is approximated using a synthetic control constructed from a weighted average of untreated routes.**

- The methodological framework builds on a model in which the **outcome variable — such as the number of seats supplied or the average aircraft size** — depends on several components. These include common time trends affecting all routes, observable route-specific characteristics such as **distance or economic conditions in origin and destination regions, and unobservable factors capturing latent heterogeneity across routes**.

Methods and data

- Comprehensive dataset of airline operations covering **flights within Europe over the period 2007–2017.**

- The data are obtained from the **Official Airline Guide (OAG):** contains detailed information at the carrier-route level, including the total number of seats supplied, flight frequencies, departure and arrival airports, and the operating airline for each route.

- The final sample consists of more than **790,000 airline-route observations organized as a panel dataset.** These observations are **divided into treated and control groups depending on whether the routes fall within the regulatory scope of the EU ETS**.

- Routes with **both origin and destination located within the European Economic Area are classified as treated units, since they are subject to the aviation component of the EU ETS**. **Routes involving at least one airport outside the EEA serve as the control group and are used to construct synthetic counterfactuals.**

- The dataset includes observations from 48 countries, of which 31 fall within the EEA and are therefore affected by the policy. **In total, approximately 573,000 observations correspond to routes subject to the EU ETS, while around 219,000 observations correspond to unaffected routes that serve as potential controls.**

Methods and data

- Two primary outcome variables are analyzed in the empirical study.
- **total number of seats supplied on a particular carrier-route in a given year**. This variable captures the **overall supply of air transport capacity and reflects airlines' decisions regarding both flight frequency and aircraft size**.
- **average aircraft size**, calculated as **the ratio of total seats to flight frequency**. This measure provides insight into **airlines' fleet deployment decisions and allows the analysis to distinguish between adjustments in frequency and changes in aircraft size**.

- Control variables capturing key determinants of air travel demand and supply. These variables are motivated by the **gravity model commonly used in transportation economics, which posits that traffic flows between two regions depend on their economic size and geographic distance**.
  - **population and per capita GDP of both the origin and destination countries**
  - **Geographic distance between airports**
  - **Herfindahl-Hirschman Index (HHI)**
- Segmentation according to
  - **airline business models, including full-service carriers, low-cost carriers, and regional airlines**
  - **short-haul and medium/long-haul routes based on distance**
  - **routes involving hub airports and those connecting non-hub airports.**

Results – Total seats

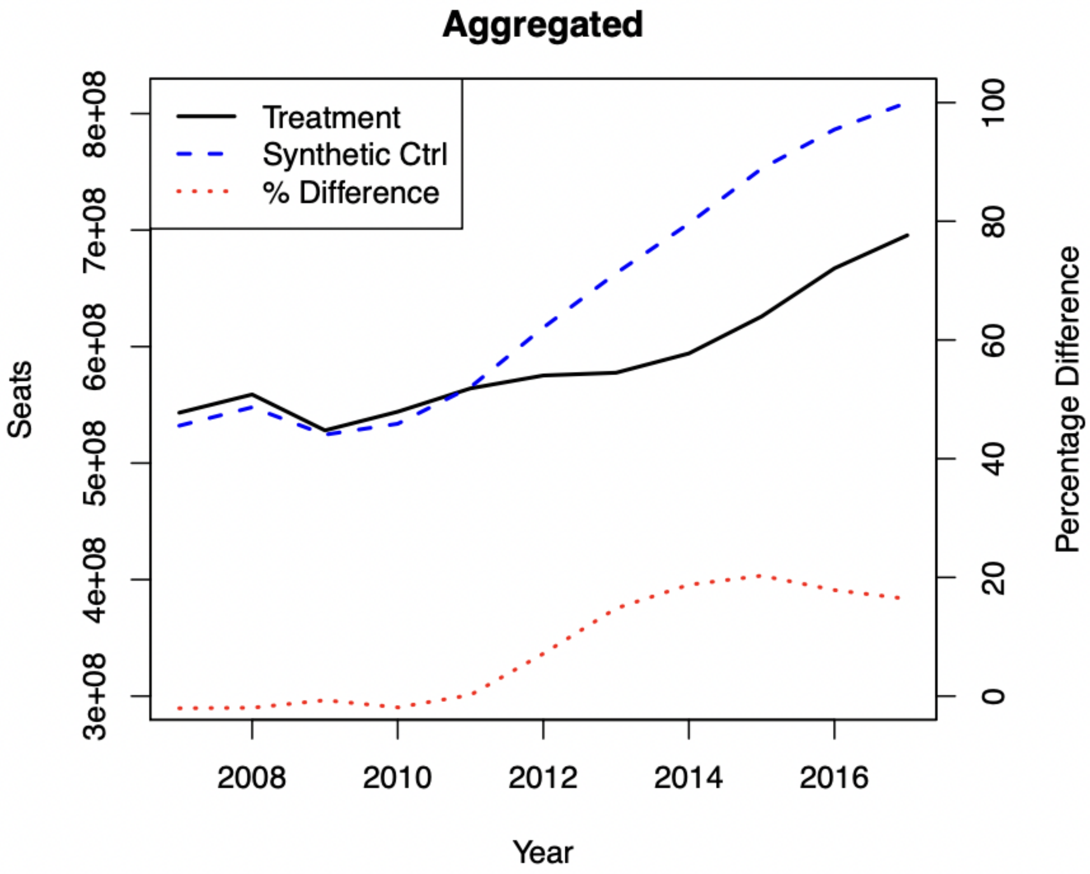

Figure 1: Total number of seats at the aggregated level.

Results – Seats by Carrier Type

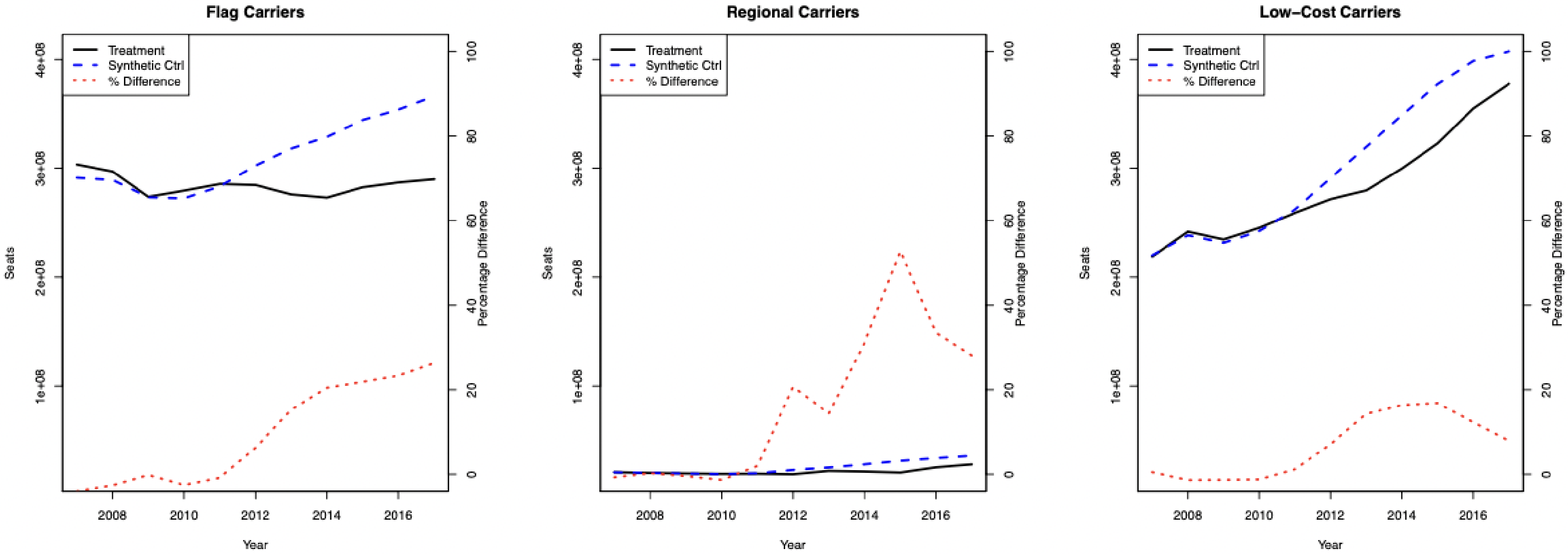

Figure 2: Total number of seats by different types of carriers.

Results – Seats by Distance

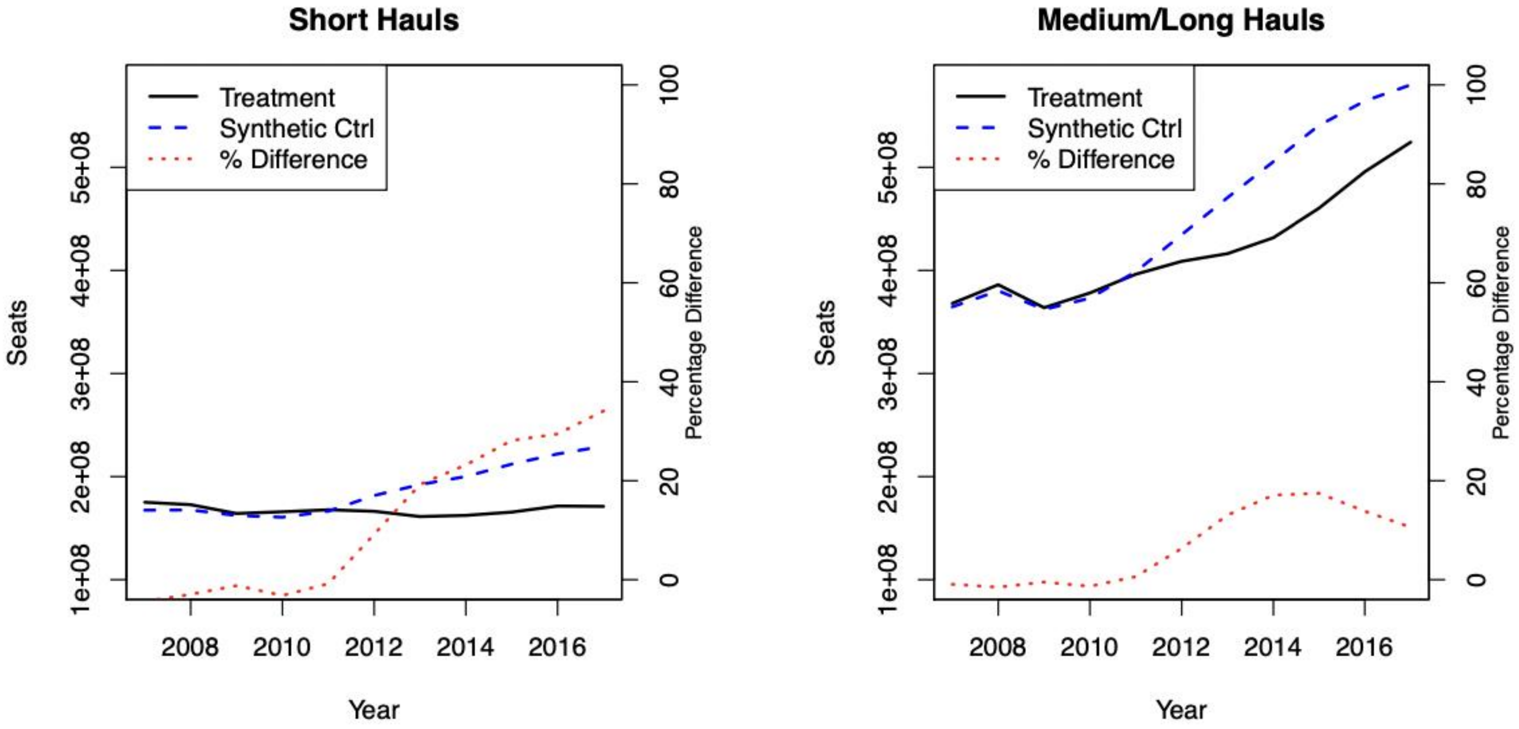

Figure 3: Total number of seats by different flight lengths.

Results – Seats by Market Type

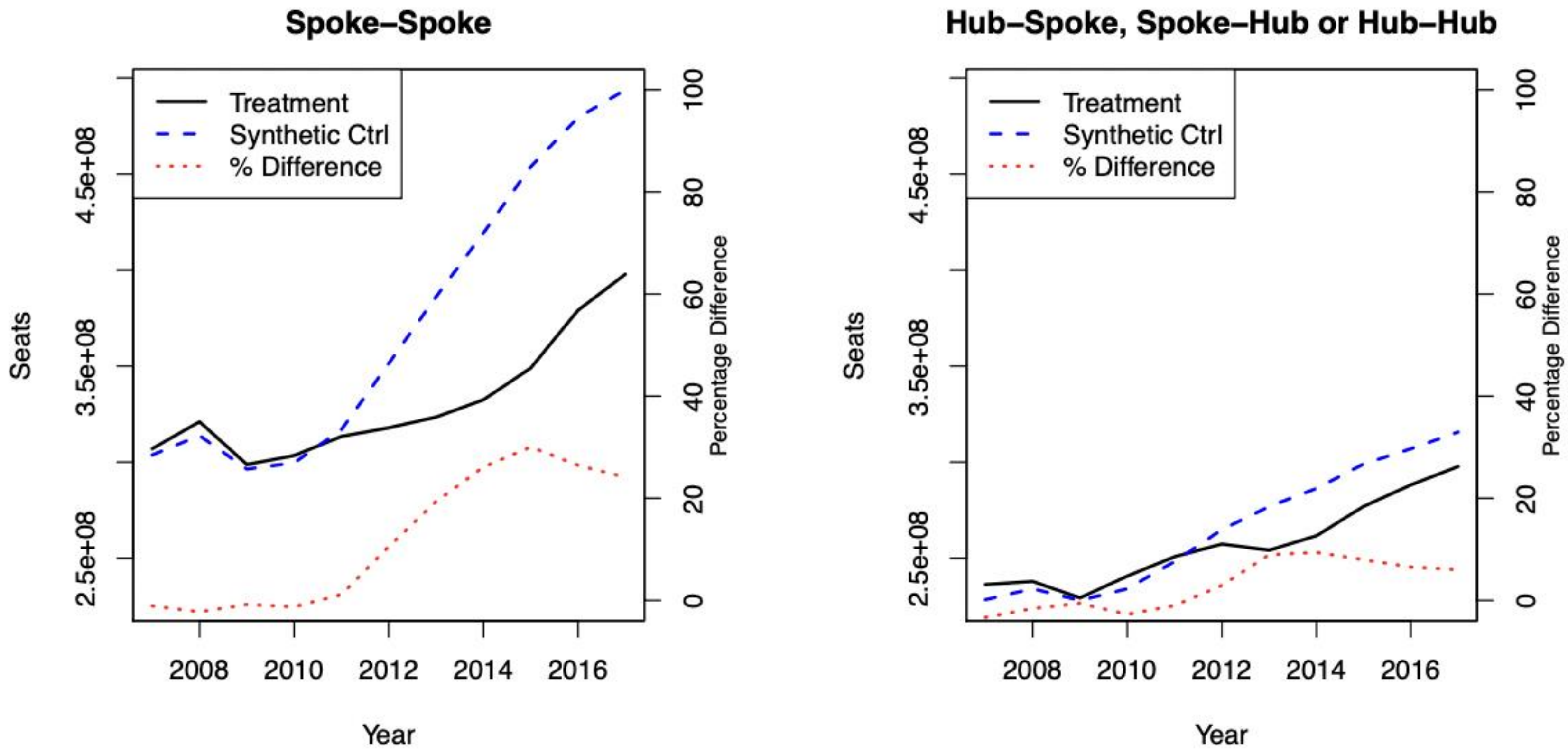

Figure 4: Total number of seats by different transport topologies.

Results – Average Aircraft Size

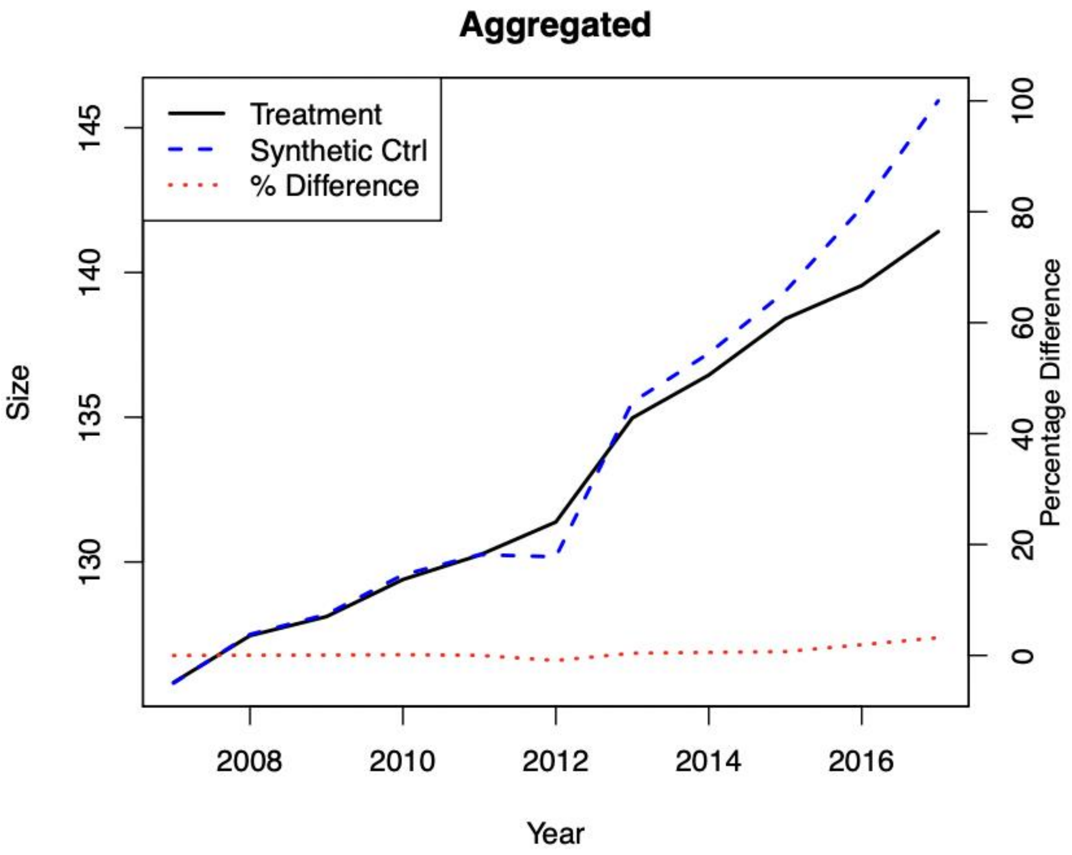

Figure 5: Average aircraft size at the aggregated level.

Results – Size by Carrier Type

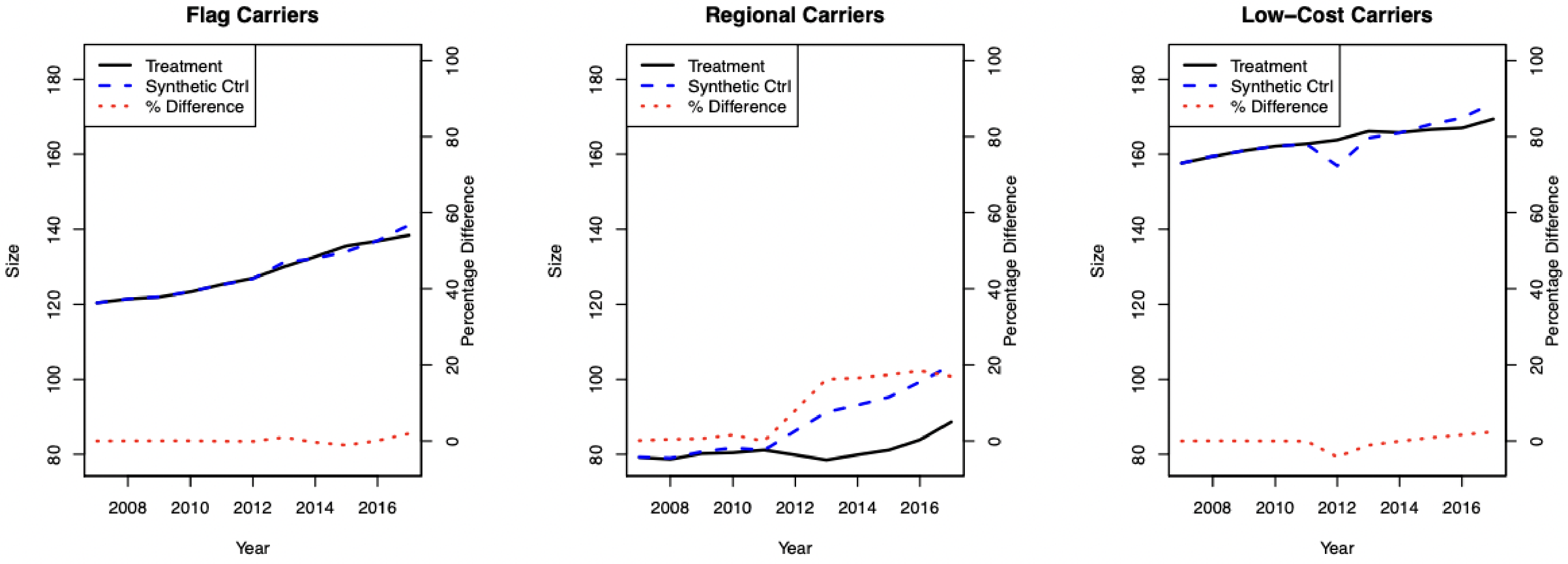

Figure 6: Average aircraft size by different types of carriers.

Results – Size by Distance

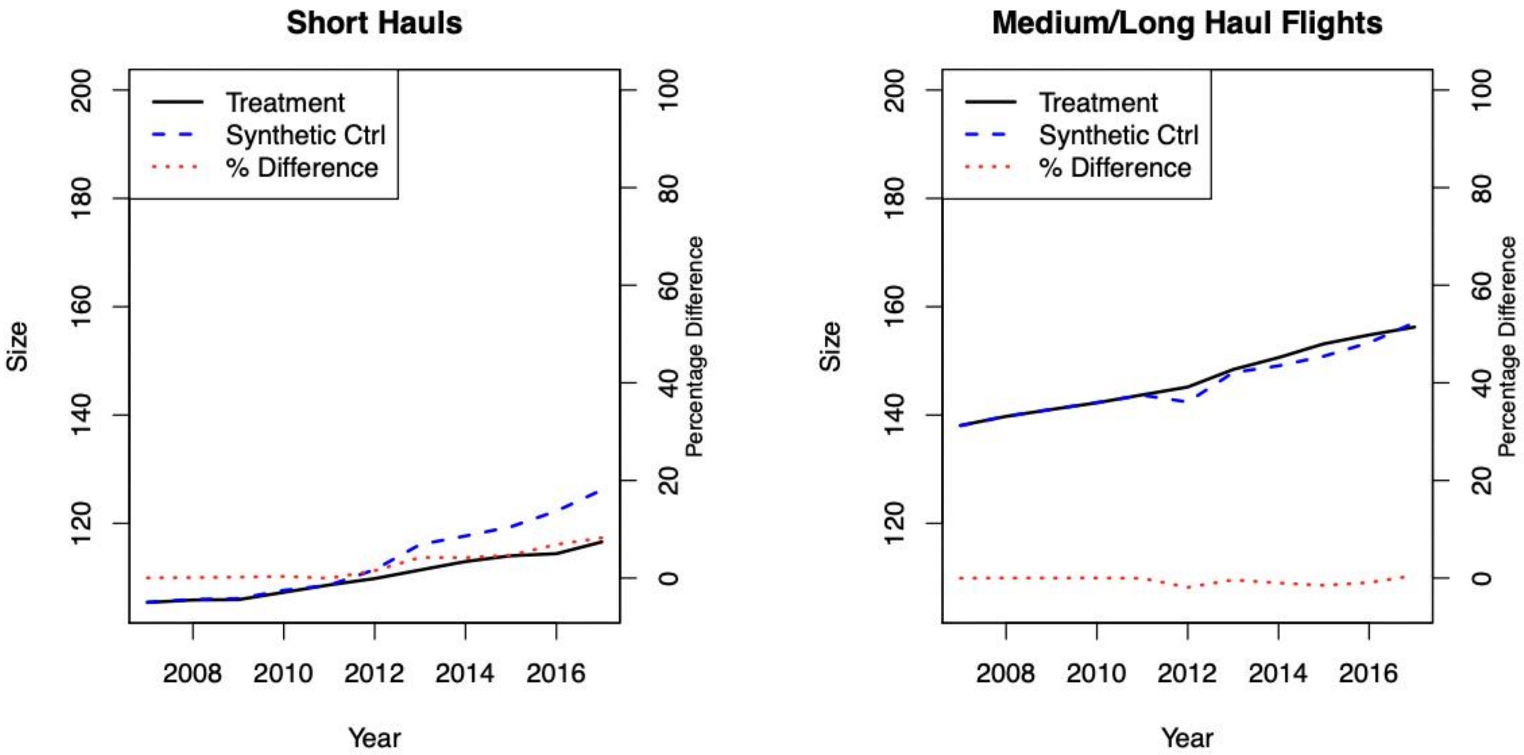

Figure 7: Average aircraft size by different flight lengths.

Results – Size by Market Type

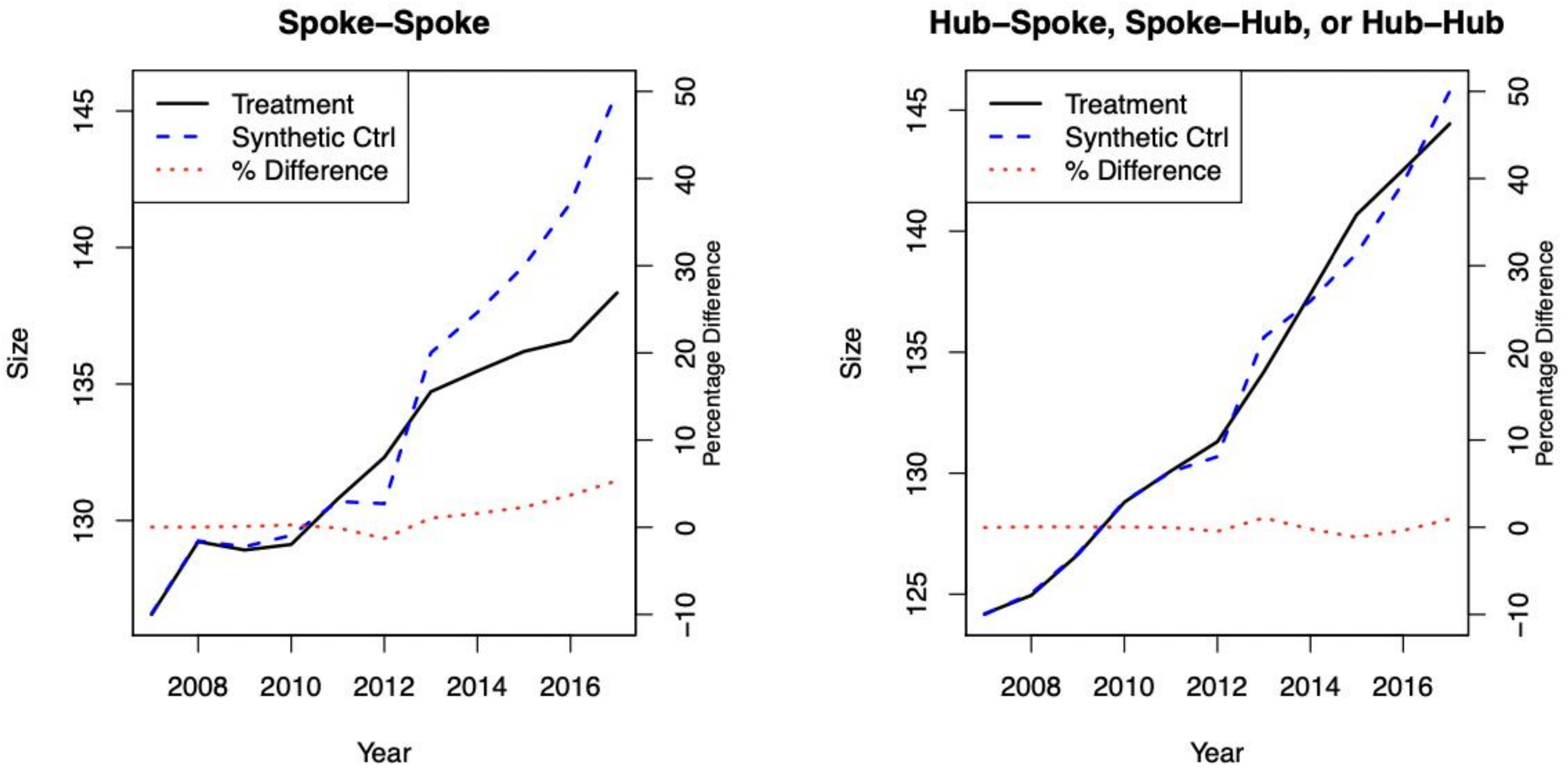

Figure 8: Average aircraft size by different transport topologies.

Conclusions

- **Carbon pricing significantly affects aviation supply.** The inclusion of aviation in the EU Emissions Trading System (EU ETS) produced a **measurable reduction in airline capacity on routes within the European Economic Area.**

- **Seat capacity declined relative to the counterfactual scenario.** Synthetic control estimates indicate that, following the introduction of the EU ETS, the growth trajectory of airline seat supply diverged substantially from what would have been expected in the absence of the policy.

- **The main adjustment channel is flight frequency.** Airlines primarily responded to carbon pricing by reducing the number of flights rather than altering the size of aircraft deployed on routes.

- **Aircraft size remained largely unchanged.** Consistent with theoretical predictions, the EU ETS had little systematic impact on average aircraft size, suggesting that fleet composition decisions are relatively rigid in the short to medium term.

- **The policy's impact varied across airline business models.** Low-cost and regional carriers appear to be more sensitive to carbon pricing than full-service airlines, likely reflecting differences in cost structures and pricing strategies.

Conclusions

- **Short-haul routes experienced stronger effects.** Capacity reductions were particularly pronounced on short-distance routes, where emissions per passenger are relatively higher due to the energy-intensive takeoff and landing phases.

- **Peripheral and spoke-to-spoke markets were more affected.** Routes connecting non-hub airports exhibited larger reductions in capacity, suggesting that thinner markets are more vulnerable to increases in operating costs.

- **Carbon pricing can influence airline operational behavior.** The findings provide empirical evidence that market-based environmental policies can affect firms' supply decisions even in highly competitive industries such as aviation.

- **Distributional implications should be considered.** While carbon pricing may contribute to emissions reductions, it may also reduce connectivity in smaller or less profitable markets, raising potential concerns about regional accessibility.

- **The results support the effectiveness of market-based climate policies.** Overall, the evidence suggests that emissions trading mechanisms can alter firms' operational decisions in ways that contribute to environmental policy objectives.