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Fewer seats, resilient frequencies: Impacts of large-scale high-speed rail liberalisation on air transport supply☆

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ABSTRACT

This paper examines how the liberalisation of high-speed rail (HSR) services affects competing air transport supply in short-haul markets. While previous research has focused mainly on HSR infrastructure expansion, less is known about how opening HSR markets to new entrants reshapes intermodal competition. Using the large-scale liberalisation of Spanish HSR in 2021 as a quasi-natural experiment, we estimate its causal impact on airline supply across major domestic corridors. Our results show that liberalisation led to a significant reduction in airline seat capacity (around 10–16%), while flight frequencies remained broadly stable. Airlines adjusted mainly by deploying smaller aircraft rather than by cutting flights, indicating a reduction in capacity with limited effects on route connectivity. These findings provide new evidence on how liberalisation reshapes intermodal competition and highlight its relevance for policymakers considering market opening as a tool to strengthen rail competitiveness and influence airline market outcomes.

1. Introduction

High-speed rail (HSR hereafter) has emerged in recent decades as a modern mode of transportation, garnering increasing interest and presence worldwide, and contributing to the global transportation landscape as an efficient alternative for medium- to long-distance travel. Due to its operating speeds exceeding 250 km/h, HSR transforms the dynamics of transport markets, offering a competitive alternative to traditional modes such as aviation, conventional rail, and road transport.[1]

Despite its high capital costs, supportive policies for HSR have been implemented in Europe, as many national governments and the European Commission have promoted HSR as a more sustainable mode of transportation, contrasting with road and air transportation. On the latter, authorities are concerned about the large growth rates experienced (66% between 2005 and 2019 in air traffic – excluding the UK-) (European Commission, 2023) and the projected traffic (global air transport over the long term is expected to grow by around 5% annually until 2030). As a low-carbon transportation option, once built, it is expected to reduce greenhouse gas (GHG) emissions compared to these modes (See Prussi & Lonza, 2018; Tang, Wang, & Wu, 2023; among others). Nonetheless, some scholars have warned that the net balance could be negative if this results in greater mobility demand, rather than just a modal diversion (Chen, Lu, Wan, & Zhang, 2021; D'Alfonso, Jiang, & Bracaglia, 2015; Jiang, Wan, Yang, & Zhang, 2021).

The EU promotes HSR on several fronts. First, it committed to an ambitious action plan in 2021 intended to double high-speed rail traffic by 2030 and triple it by 2050.[2] Second, it contributes to financing

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[1] Throughout the manuscript we refer by HSR to the rail infrastructure and rail services able to accommodate and travel at speeds for 250 km/h or higher.

[2] The EU Sustainable and Smart Mobility Strategy (COM(2020) 789 final) set these ambitious milestones to HSR developments due to the pivotal role of HSR in achieving Sustainable and efficient transport.

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investments in the Trans-European Transport Network (TEN-T) initiative, which aims to increase the HSR network in Europe from 11,000 km to 32,000 km by 2050 under the Green Deal Agenda. Third, it promotes competition by supporting the opening of the rail market and encouraging private-sector participation to increase service quality and reduce costs. This latter EU strategy aimed to boost rail passenger transport by completing the liberalisation process, as outlined in the Fourth Railway Package in December 2016.[3] Its approval marked the final step in the liberalisation of rail services across Europe. However, outcomes of this market pillar were still disappointing by 2020, with only 6.6% of passengers-km of commercial services under new entrants' operations (CNMC, 2024a).

Indeed, very few markets have been liberalised and opened to both competition and private participation in the case of classic HSR ($\geq$ 250 Km/h). We only find large-scale liberalisations in Italy (2012) and Spain (2021), and at a much lower scale in France (late 2021, on the Paris-Lyon line).[4] Outside Europe, HSR liberalisation is rare, with only Japan (1990s) and South Korea (2016) offering relevant experiences that hardly resemble the European model.[5]

In this paper, we focus specifically on the liberalisation of HSR services—namely, the opening of rail markets to new entrants—rather than on infrastructure expansion. This distinction is important because service liberalisation may reshape intermodal competition even in the absence of new infrastructure, by affecting prices, frequencies, and service differentiation. Accordingly, we examine how market opening influences competing short-haul air transport supply.

We empirically evaluate the causal impact of the recent liberalisation of Spanish HSR on domestic (short-haul) air transport supply using the quasi-experimental regression discontinuity method. Therefore, our contributions are threefold. First, we evaluate the impacts of large-scale HSR liberalisation ($\geq$ 250 km/h) on intermodal competition with air transportation by focusing on how new entrants shifted the equilibrium on treated routes. So far, the literature has examined only HSR openings, new connectivity/accessibility (routes), rail liberalisations for services and rail infrastructure standards for lower speeds (<250 km/h). Second, we are also the first to provide causal estimates on the intermodal impact of a large-scale HSR liberalisation on short-haul airline supply, using a quasi-experimental method. Previous literature had mainly focused on pre-post comparisons and other non-causal methods (see the review by Givoni & Dobruszkes, 2013). To our knowledge, only Wang, Sun, Teunter, Wu, and Hua (2020) employed a quasi-experimental differences-in-differences strategy. Still, they evaluate the case of a single entry in a single route by the low-cost commercial unit of the State-owned incumbent in a non-liberalised French market. Our analysis differs in evaluating several entries, including companies unrelated to the incumbent, across various corridors of a larger-scale liberalised market. Third, by considering the effects of different entries over time, we are the first to examine the heterogeneous effects of HSR market structure changes from monopoly to duopoly and triopoly).

Finally, we utilise data for the Spanish domestic (short-haul) air transport and HSR markets for the following reasons. First, it is the market with the largest number of competitors among the countries that liberalised HSR, comprising three companies and four commercial brands, making it a suitable case for obtaining insights into the potential of liberalisation. Second, it has one of the largest domestic air transport markets in Europe, only behind France and the United Kingdom. Third, Spain has the most extensive HSR network in Europe, and route distances between the most relevant cities are in a suitable range for HSR-air direct competition.[6] Moreover, the radial structure of the HSR network linking Madrid (core) with the dense coastal urban agglomerations overlaps several dense air routes.

The remainder of this manuscript is structured as follows. Section 2 summarises the related literature. Section 3 describes the liberalisation of high-speed rail services in Spain. Section 4 presents our empirical strategy, describing the methods, variables, and data. Section 5 presents our main results, discussed in Section 6. The manuscript briefly concludes in Section 7.

2. Related literature on the effects of HSR liberalisation

This section reviews the literature on HSR liberalisation and air-rail intermodal competition. First, we briefly review the literature that conceptualises intermodal competition between HSR and air transport, emphasising the role of travel time, prices, frequencies, and service quality. Second, we examine how liberalisation has affected these dimensions within rail markets, which constitute the main channels through which effects on air transport are expected to operate. Finally, we position our study within this literature on HSR liberalisation and air transport supply.

2.1. Intermodal competition between high-speed rail and air transportation

Intense intermodal competition between high-speed rail (HSR) and air transport has been widely documented in the literature (see Givoni & Dobruszkes, 2013). The entrance of HSR often reduces air travel demand – and consequently air travel supply (see Albalate, Bel, & Fageda, 2015)-, but the magnitude of substitution varies substantially across corridors. Outcomes depend strongly on contextual factors such as travel time, relative prices, market size, network configuration, and service quality. As a result, intermodal competition cannot be generalised across settings and must be assessed case by case. Recent reviews (Sun et al., 2024) confirm that the interaction between HSR and aviation is complex and context-dependent, involving both substitution and coexistence, with outcomes shaped by corridor characteristics and network structure.

However, the evidence on the effects of HSR competition on airlines' pricing has been broadly documented as well, what indicates that airlines face increasing intermodal competition when HSR services are available along their routes. On this regard, Bergantino, Capozza, & Capurso, 2015 find domestic flights' price reductions with higher degrees of HSR competition for Italian routes. Similar results were obtained by Wei, Chen, and Zhang (2017) for the Jing-hu HSRs and by Sun et al. (2024) in China. Furthermore, Su, Luan, Fu, Yang, and Zhang (2020) uncovered that airlines adjust the structure and timing of fare changes when facing HSR, rather than cutting fares uniformly; and Abrate, Viglia, Sánchez-García, and Forgas-Coll (2016) showed that airlines appear to react more aggressively than rail in intermodal price competition, suggesting asymmetric competitive behaviour.

Competition also operates through multiple other strategic margins beyond prices, including capacity, frequencies, scheduling, and product differentiation. Several studies highlight how higher rail service quality and frequency improvements have driven demand growth across European HSR markets (Beria et al., 2025). These mechanisms suggest that HSR expansion and service improvements can reshape airline behaviour even without fully displacing air transport.

Taken together, this literature suggests that most core dimensions of

[3] The EU has historically led the liberalisation process of rail transport since 2001 with a gradual opening to competition to increase railways' modal share and increasing integration of national markets towards a single EU railway market.

[4] France allowed for the the entry of a private operator in the Paris-Lyon route at the end of 2021, as part of the Paris-Milan route.

[5] Japan fragmented the State-owned operator Japanese National Railways (JNR) into regional and functional monopolies in the late 1980s that were privatized in the 90s. South Korea separated Super Rapid Train (SR corporation) in 2016, which competes with Korail, both publicly owned companies.

[6] Route distance is the most distinctive and decisive feature of HSR relative (dis)advantage against aviation and road transport (Albalate & Bel, 2012).

air-rail intermodal competition—prices, frequencies, and service quality—are precisely those most likely to be affected by HSR liberalisation, providing a key motivation for examining its broader intermodal effects. The next subsection reviews the literature on these within-rail effects of liberalisations.

2.2. HSR liberalisation and within-rail impacts on prices, frequencies and service quality

The literature on rail services liberalisation is clear on its effects on prices. Opening the market to competition has decreased prices across Europe, including Sweden (Vigren, 2017; 13%), the Czech Republic (Tomeš, Kvizda, Jandová, & Rederer, 2016; 46%), and Austria (Tomeš & Jankova, 2017; 20–25%), among others. Yet, few articles address classic HSR liberalisation (≥250 Km/h).

The Italian case, the first and the most studied HSR liberalisation, shows significant price reductions (between 10 and 40%) (See the review by Beria, Lunkar, Tolentino, Paril, & Kvasnicka, 2023). Bergantino et al. (2015) finds that open-access competition had substantial intramodal competitive effects. Operators reacted through strategic pricing, while capacity and frequency also emerged as important strategic variables. Beria, Tolentino, Bertolin, and Filippini (2019) qualified results by showing that liberalisation not only reduced prices, but changed the structure of pricing in a measurable and economically significant way.

Bergantino et al. (2015) show that, following the liberalisation, competition in the Italian market operated through strategic pricing as well as through capacity and frequency adjustments, indicating that operators competed on both price and service density. This view is consistent with Beria et al. (2019), who document that head-on competition affected both price levels and price dispersion across Italian long-distance routes. More broadly, the Italian experience is often described as having improved the overall service offering, with denser timetables, greater product differentiation, and enhanced passenger-oriented service attributes, (see Bergantino et al., 2015; Beria et al., 2019; Beria, Redondi, & Malighetti, 2016; Beria, Tolentino, Shtele, & Lunkar, 2022 and Cascetta & Coppola, 2015).

Similar results on prices were recently confirmed by Brenna (2024) through a quasi-experiment on two liberalised routes in Spain. The outcomes on the prices charged by the incumbent operator (RENFE-AVE) on the routes Madrid-Alicante and Madrid-Sevilla/Málaga decreased by an average of 28–30%. The entry of low-cost rail services (sometimes with brands owned by incumbent operators) was also assessed. Brenna (2024) found no statistically significant price reductions on AVE (full-service) in the Madrid-Alicante route with the entrance of AVLO (owned by RENFE). Nonetheless, a 21% short-term average decrease in second-class AVE prices was causally associated with the entry of OUIGO. This suggests that only independent new entrants exert real price pressure in HSR. Because low-cost brands are expected to offer lower-priced services, this is typically associated to a more competitive HSR, potentially affecting intermodal competition in the low-willingness-to-pay market segment.

In sum, this literature shows that HSR liberalisation strongly affects prices, service levels, and product differentiation within rail markets, but provides limited evidence on how these changes translate into intermodal outcomes for aviation.

2.3. Intermodal effects of HSR liberalisation: Positioning this study

Despite growing interest in intermodal competition, empirical evidence on the effects of HSR liberalisation on aviation remains limited. Most existing studies focus on within-rail (intramodal) outcomes or evaluate changes in modal shares, with comparatively little attention to airline responses. Moreover, the literature examining air–HSR interactions relies largely on descriptive or reduced-form approaches, and there is little quasi-experimental evidence on how large-scale HSR liberalisation affects competing air transport markets.

One partial exception is Wang et al. (2020), who document a substantial decline in air traffic following the introduction of low-cost rail services on the Paris–Marseille corridor using a differences-in-differences approach. However, such evidence remains scarce and largely corridor-specific, leaving open important questions about how airlines adjust supply in response to intensified intermodal competition in a full-scale liberalisation with the entry of third-party operators, such in Spain.

Our study complements the above literature by providing causal evidence from the Spanish case, where a large-scale liberalisation occurred across multiple dense corridors directly overlapping with major short-haul air routes and involving multiple entrants, two of them unrelated with the incumbent's ownership. Methodologically, we contribute by applying a quasi-experimental regression discontinuity design to examine how airline supply adjusts following large-scale HSR market opening. In doing so, we address an important gap in the literature regarding airline strategic responses to intensified intermodal competition in a quasi-experimental setting.

3. High-speed rail liberalisation in Spain as a source of intermodal competition

3.1. Policy framework and the liberalisation process

Since 2000, high-speed rail (HSR) has become a central component of Spanish transport policy, supported by sustained public investment and resulting in one of the largest HSR networks in the world (Albalate & Bel, 2011, 2012; Beria, Albalate, Bel, & Grimaldi, 2018). By 2023, Spain's HSR network exceeded 3100 km of lines with operating speeds of at least 250 km/h. However, the scale of investment also generated concerns about low infrastructure utilisation and weak socioeconomic returns (AIReF, 2020; Beria et al., 2018; Betancor & Llobet, 2016; European Court of Auditors, 2018). In this context, increasing occupancy and making more intensive use of existing infrastructure became a policy priority.

Low demand and the financial burden of both the publicly owned infrastructure developer ADIF and operator RENFE encouraged actions to limit the costs of new investments in low-density corridors. They boosted efforts to increase occupancy factors and infrastructure utilisation, both of which are essential to improving the socioeconomic return (UIC Brochure, 2018). One of the most influential policies was the recent liberalisation of HSR services in the densest corridors, which took place in 2021.

Following the transposition of EU Directive 2016/2370,[7] Spain opened its domestic passenger rail market to competition in 2020, with effective entry of new operators beginning in 2021. This reform concerned service liberalisation rather than infrastructure expansion: the key change was the opening of existing HSR corridors to new operators. Liberalisation covered the main dense corridors radiating from Madrid, notably Madrid–Barcelona, Madrid–Levante (Valencia and Alicante), and Madrid–South (Sevilla and Málaga).

The model chosen optimised the existing capacity, which increased by 60% - with an integrated cadenced timetable (Montero & Ramos Melero, 2022). Six companies applied in 2019 for the three asymmetric framework agreements at stake. They included joint capacities across the three corridors to avoid the expected cherry-peaking effect on the single densest Madrid-Barcelona route. Due to the excess of bidders, a tender was organised, and agreements were signed between the infrastructure manager and three capacity-awarded operators (RENFE,

[7] Directive (EU) 2016/2370 of the European Parliament and the Council of 14 December 2016 amending Directive 2012/34/EU as regards the opening of the market for domèstic passenger transport servicies by rail and the governance of the railway infrastructure. Note EU Directive 2012/34 already imposed the liberalisation of railway services in Europe by December 2020.

Ouigo and Iryo) in May 2020 (Stojadinovic, Boskovic, Trifunovic, & Jankovic, 2019). The Competition Authority, *Comisión Nacional de los Mercados y la Competencia* (CNMC), monitored the process and oversees the market.

Framework capacity was allocated for ten years to the three corridors: Madrid-Barcelona, Madrid-Levante (branch lines to Valencia and Alicante), and Madrid-South (branches to Sevilla and Málaga). Liberalisation was feasible in this short period due to the existing excess capacity and modern infrastructure, which enabled interoperability (CNMC, 2024a).

OUIGO, a subsidiary of the French state-owned *Société Nationale des Chemins de Fers* (SNCF), obtained the smallest package (10%) but became the first new operator to enter the Madrid-Barcelona route in May 2021. Soon after, it started operations on the Madrid-Valencia line and connected Madrid to Alicante in 2023. Finally, it also served the corridor Madrid-Sevilla/Malaga in January 2025.

IRYO, owned by a mix of Italian and Spanish corporations, among which Trenitalia is the main shareholder, was awarded the second package (30%) and initiated operations on the Madrid-Barcelona and the Madrid-Valencia links in late 2022. They finally offered the first train services on the Madrid-Seville/Málaga lines in 2023. Finally, IRYO connected Madrid to Alicante with their services the same year.

RENFE, the publicly owned and incumbent operator, which received the most extensive package (70%), responded to this competition by launching its low-cost brand, AVLO, which was set to operate in the Madrid-French border corridor in 2021, just one month after OUIGO's entry. Later, AVLO was extended to several lines (Madrid-Valencia, Madrid-Alicante, Madrid-Sevilla/Málaga, and Valladolid-Alicante). Also, RENFE added the AVLO commercial service on routes not subject to competition in 2024. In all, RENFE increased its capacity by 20% (Brenna, 2024).

Fig. 1 displays the chronology of the increasing number of commercial operators by main Origin-Destination. Table 1 presents information on company entry dates for the main liberalised routes competing with air transportation. Fig. 2 displays the 2025 HSR network map in Spain by commercial operators, and Fig. 3 the split of HSR passengers and seats available by route.

3.2. Outcomes of the liberalisation on the HSR market

A preliminary evaluation of the liberalisation process appears positive from both demand and supply performance perspectives. Indeed, liberalisation contributed to both passenger (demand) and capacity growth (supply). Fig. 4 shows the monthly change in long-distance passengers by mode over time, indicating that HSR is the mode performing best, with high growth rates and traveller volumes exceeding pre-COVID-19 levels. Fig. 5 illustrates the growth in demand and supply for the specific liberalised corridors.

Table 1
HSR liberalisation chronology by main OD routes.

Route	Company	Brand	Entry
Madrid-Barcelona	Ouigo	Ouigo	10/05/2021
	Renfe	Avlo	23/06/2021
	Iryo	Iryo	25/11/2022
Madrid-Valencia	Ouigo	Ouigo	08/10/2022
	Iryo	Iryo	26/12/2022
	Renfe	Avlo	21/02/2022
Madrid-Sevilla/Málaga	Iryo	Iryo	30/03/2023
	Renfe	Avlo	01/06/2023
	Ouigo	Ouigo	16/01/2025
Madrid-Alicante	Renfe	Avlo	27/03/2023
	Ouigo	Ouigo	23/04/2023
	Iryo	Iryo	02/06/2023
Valladolid-Alicante	Renfe	Avlo	08/04/2024
	Ouigo	Ouigo	19/04/2024
Madrid-Murcia	Renfe	Avlo	10/12/2023
	Ouigo	Ouigo	03/09/2024

Source: Own elaboration.

According to CNMC (2024a), daily average frequencies in the three main corridors rose from 78 to 115 per direction, and seats increased by more than 60% compared to 2019. It also favoured a new range of commercial offers, such as differentiated tariffs by seat/class, greater flexibility, and personalised services, among others. There was a 47% increase in seats offered just between 2022 and 2023 (CNMC, 2024b).

The liberalisation boosted high-speed rail demand. The regulator estimates a consumer surplus of 343 MEUR due to lower prices and induced new demand (CNMC, 2024a). Overall, rail transport accounted for most of the growth in long-distance demand since 2019, increasing by 5 percentage points and reaching a 56% market share (among interurban buses and air travel). The regulator (CNMC, 2024a) attributes the increase in railway passenger numbers to the liberalisation process, reaching ten million by the end of 2023, up from 2019. Demand figures were about 45% higher than in 2019, with an annual growth rate of 36.6% between 2022 and 2023 (CNMC, 2024b).

The liberalisation was reflected almost immediately in cheaper tickets. The European Commission (2024) reports fare cuts ranging from 20% to 50%. On the Barcelona route, RENFE even moved ahead of

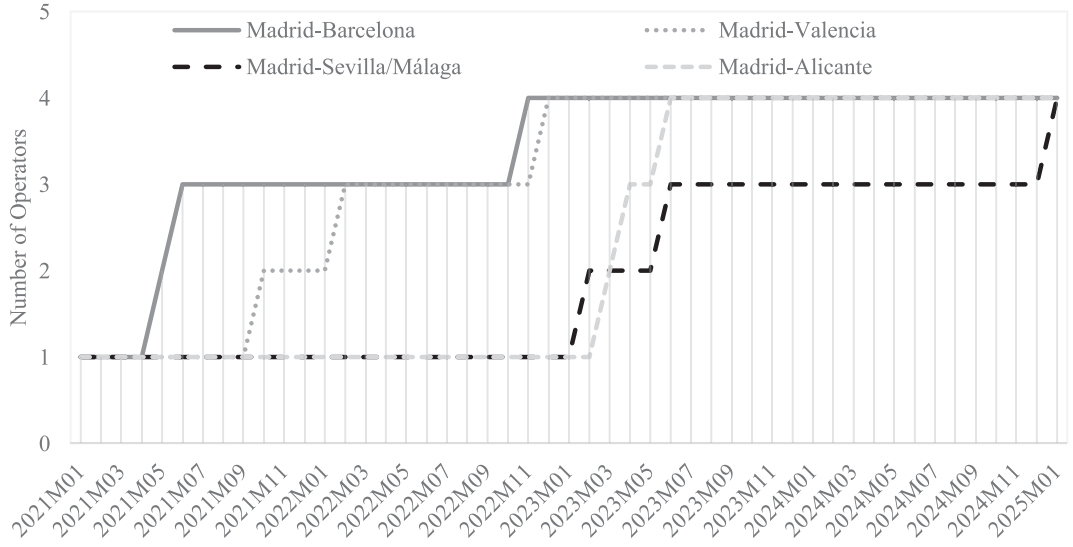


Fig. 1. Chronology of the market structure by commercial brands of the main liberalised HSR lines in Spain.

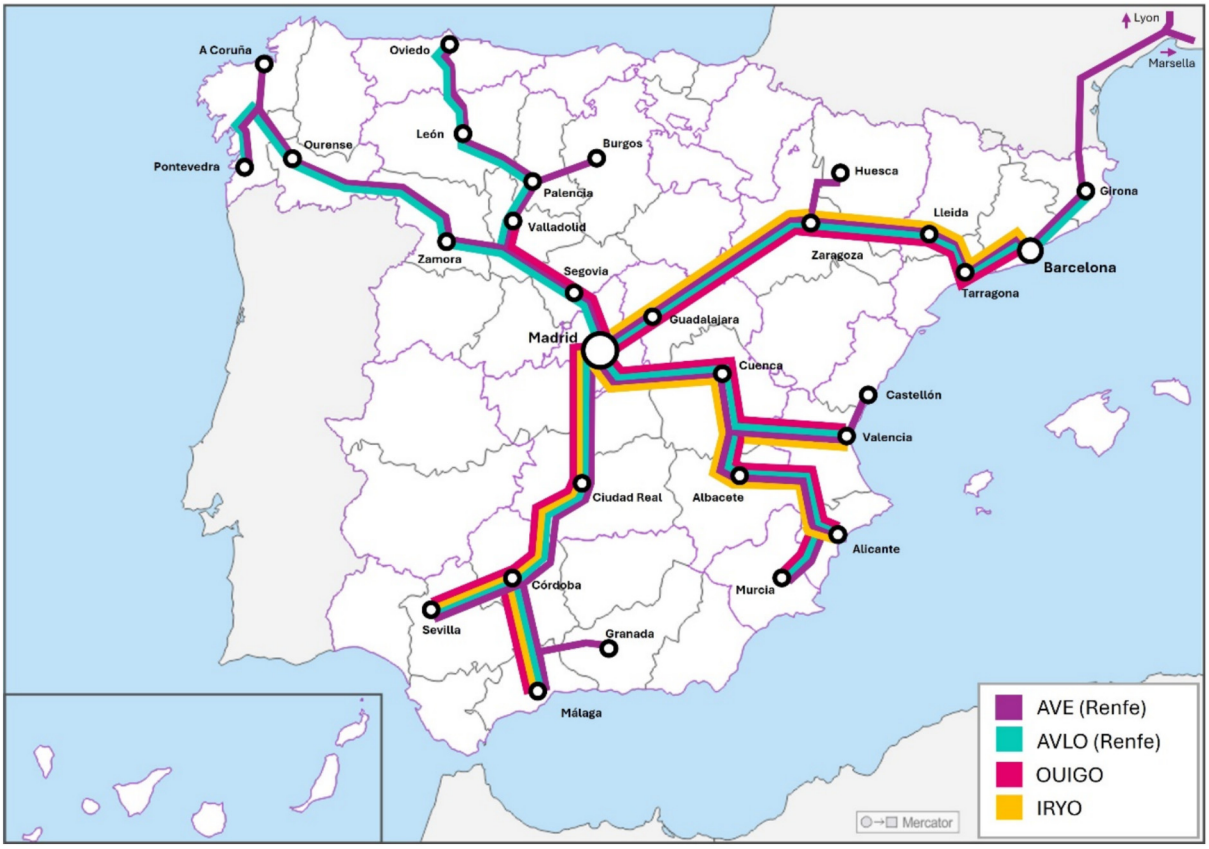


Fig. 2. Map of the HSR liberalised network and operators.
Source: Own elaboration.

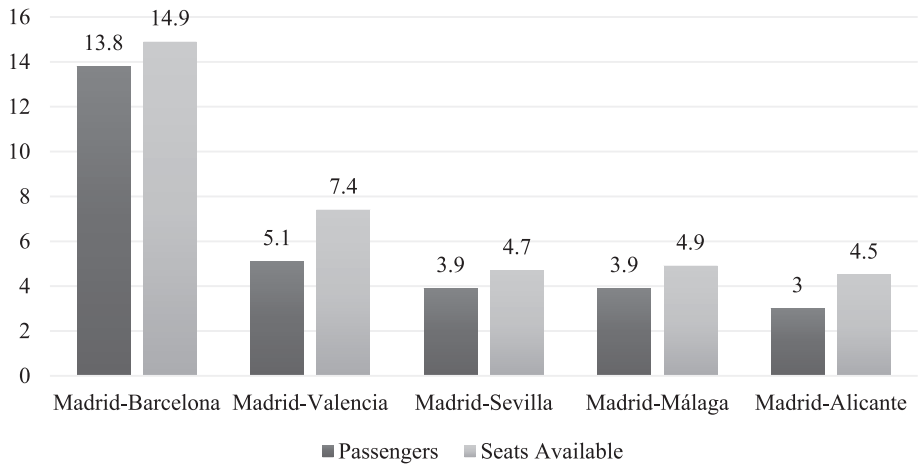


Fig. 3. HSR Passengers and seats available (in millions) by main liberalised routes in 2023.
Source: CNMC.

OUIGO's entry by lowering AVE fares months before the new competitor arrived (García-Samaniego & Campos, 2024). Brenna (2024) confirms this overall picture, estimating average reductions of around 28–30% on the Madrid–Alicante and the Madrid–Sevilla/Málaga corridors. The pattern, however, was not uniform. OUIGO's aggressive low-cost strategy drove sharp, immediate price drops (over 20% in second class), whereas IRYO mainly pushed down first-class fares, with more moderate cuts of about 16%. By contrast, RENFE's own low-cost brand, AVLO, barely altered the incumbent's pricing behaviour.

3.3. *Intermodal competition and airlines' reactions*

From the airline perspective the relevant competitive margin is concentrated in short-haul domestic air markets, where HSR constitutes a close substitute and can directly affect airline supply decisions. Accordingly, the intermodal interaction analysed here is best understood as taking place in domestic corridors where substitution between air and rail is most likely to occur.

HSR demand growth, driven by lower prices, increased frequencies, and a more varied commercial offer, is the source of its growing market

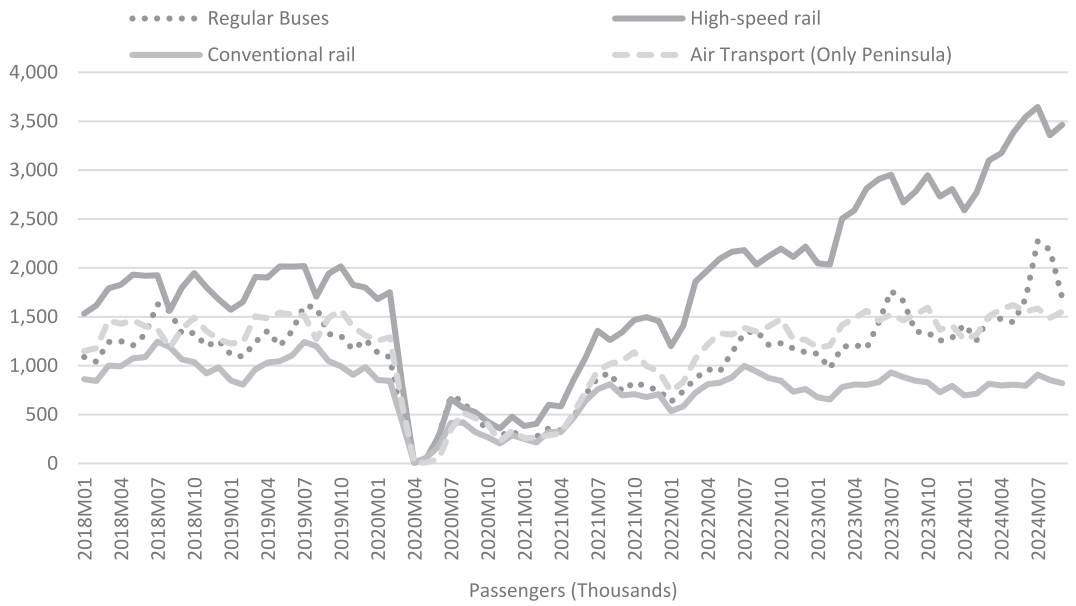


Fig. 4. Monthly passengers by long-distance mode in Spain, January 2018–July 2024.
Source: Spanish National Statistics Institute (INE), Passenger transport statistics.

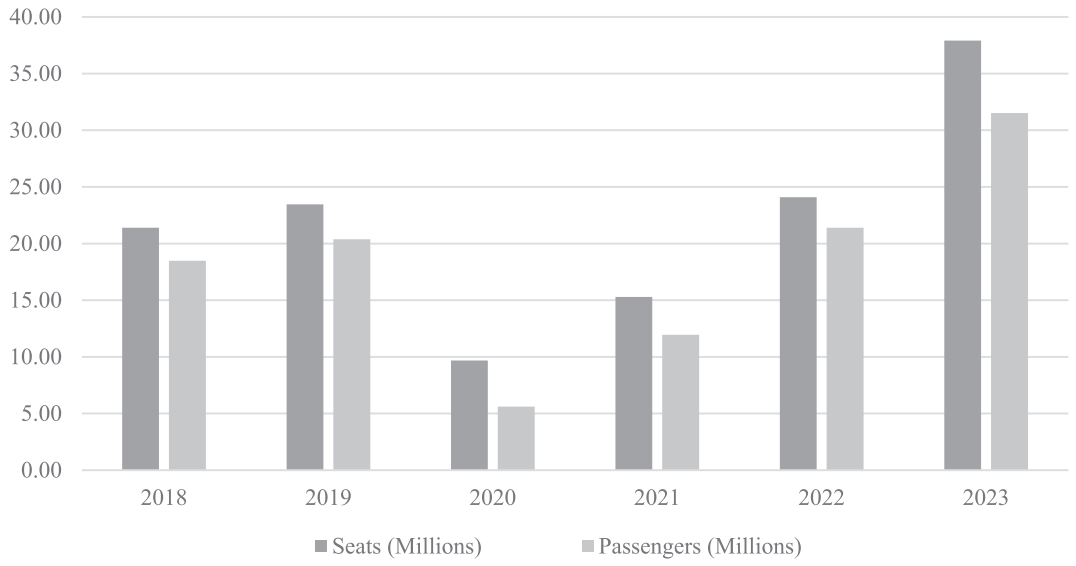


Fig. 5. Annual high-speed rail passengers and seats available in Spain (2018-2023).
Source: CNMC.

share against the two modes most directly impacted: air transportation and conventional rail. Fig. 4 confirms a redistribution effect in favour of HSR. Recent empirical evidence suggests that road transport has experienced only a limited impact from HSR services in Spain and no effect from its liberalisation (Albalate & León-Gómez, 2024).

Low-cost carriers dominate the domestic (short-haul) air transport market in Spain, with few full-service airlines remaining, primarily as feeder services for long-distance flights from Madrid or Barcelona. The empirical literature shows that HSR is a fierce competitor for both conventional and low-cost airlines (see Behrens and Pels (2012), Xia, Wang, and Zhang (2018), Li, Strauss, and Lu (2019), among others). Indeed, the evidence by Su et al. (2020) suggests that HSR can bring significantly more competition than low-cost carriers, especially on short-distance routes of less than 1000 km.

The competitive context of the analysed air routes is central to understanding the effects of HSR liberalisation. By 2023, HSR had already achieved very high market shares in the main Spanish air–rail corridors, exceeding 75% in all liberalised routes (Table 2). According to CNMC (2024a), rail's modal share relative to air increased further after liberalisation, especially in Madrid–Barcelona.

In the analysed corridors, the airline market was dominated by two groups: IAG (through Iberia and Vueling) and Air Europa. A common feature of these routes is that all airlines offered connection options through Madrid-Barajas Airport, underlining their strategic role in feeding hub-and-spoke networks. This is relevant because a stronger orientation towards connecting traffic may require airlines to accept lower passenger volumes and, in some cases, sustain fewer frequencies than would be viable in markets with a larger point-to-point segment (D'Alfonso et al., 2015). At the same time, the airlines serving these corridors represented two distinct business models: Iberia and Air Europa operated primarily as full-service network carriers, whereas Vueling, despite also offering connections, remained more focused on

Table 2
Distance and travel times by O—D routes by HSR and air transport, 2023.

Route	Distance by HSR (Km)	Travel time by HSR[a]	Travel time by Air[a]	Market share HSR
Madrid-Barcelona	621	2 h:30 min	1 h:15 min	82%
Madrid-Valencia	391	1 h:50 min	1 h:00 min	92%
Madrid-Alicante	422	2 h:15 min	1 h:00 min	87%
Madrid-Sevilla	471	2 h:30 min	1 h:05 min	87%
Madrid-Málaga	513	2 h:30 min	1 h:10 min	78%
Madrid-Murcia	473	2 h:45 min	1 h:05 min	n.a.[b]

[a] Travel times from HSR station to HSR station or from main airport to main airport.
[b] Data on the modal share on the Madrid-Murcia is not available yet.

high-density point-to-point traffic. This strategic divide suggests that airlines may respond differently to the competitive shock generated by HSR liberalisation, a point we return to in Section 6.

4. Empirical strategy

In this section, we describe the empirical strategy we follow to assess the causal impact of High-Speed Rail (HSR) liberalisation on short-haul domestic flights in Spain.

To construct our panel dataset of air transport supply, we use data from the OAG (Official Airline Guide) Schedules Analyser. OAG's schedule database is a widely used standard source in academic air transport research. Our database contains detailed information on all planned flights, including origin and destination airports, operating carrier, aircraft type, departure and arrival times, seat availability, and flight frequency. Our dataset covers the daily supply of flights from 2016 to 2024 for each corridor in our sample.

We use different outcome variables to define air travel supply for each HSR equivalent corridor at the daily level. We use the daily total number of seats, the daily flight frequency and the average number of seats per flight for each corridor. Given that airlines can adapt supply through different behavioural strategies, we use each outcome variable to explore these strategies. The total number of seats offered at the corridor level provides a rough measure of the total capacity deployed by airlines, yet changes in this variable can be achieved either through changes in flight frequency or by changing aircraft (with different capacities). Models for the impact of HSR liberalisation on total corridor frequency and the average seats per flight are estimated to explore how airlines achieve supply adaptations, which could be either by reducing the number of flights in the affected corridors (frequency) or using smaller aircraft (seats per flight), down-gauging the fleet serving the affected corridors.

Overall, our empirical analysis is conducted at the corridor aggregate level and does not distinguish responses by airline type. Accordingly, the estimated effects should be interpreted as aggregate supply adjustments rather than airline-specific responses.

Descriptive statistics for the outcome variables are reported in Table 3, including pre- and post-liberalisation periods. As an example of this temporal variation, Fig. 6 shows the evolution of total daily seats during the analysis period. This suggests that a naïve pre/post comparison using the descriptives in Table 3 won't yield any trustworthy results, as many things are changing over time beyond the policy intervention.

Our empirical strategy is based on a regression discontinuity in time design because the liberalisation of HSR services introduced a sharp temporal threshold in all corridors exposed to direct air–rail competition. At the same time, no comparable untreated corridors exist that could credibly serve as a control group, which limits the applicability of alternative quasi-experimental approaches. In this context, identification comes from testing whether airline supply exhibits a discrete break at the time of market opening, while controlling for the broader time path of the outcome variables.

Table 3
Descriptive statistics (outcome variables).

Full sample	Mean	Std. Dev.	Min	Max
Seats (total)	2521.35	3104.11	72	17,749
Frequency	15,97	14,96	1	93
Av. Seats per flight	138.82	45.57	62.15	234.93
Pre-liberalisation	Mean	Std. Dev.	Min	Max
Seats (total)	2357.84	3354.22	72	17,749
Frequency	15.86	16.38	1	93
Av. Seats per flight	127.17	43.59	62.15	232
Post-liberalisation	Mean	Std. Dev.	Min	Max
Seats (total)	2966.79	2228.29	672	8547
Frequency	16.28	10.11	4	43
Av. Seats per flight	170.54	34.34	84	234.93

Our baseline specification follows a global RDiT approach, which is well suited to settings where the intervention affects all relevant units simultaneously and the researcher must rely on temporal discontinuity rather than cross-sectional variation. The identifying assumption is that absent liberalisation, airline supply would have evolved smoothly through the threshold, so that any discontinuous change at that point can be attributed to the policy intervention rather than to underlying trends. The main advantage of this approach is that it allows us to exploit the timing of liberalisation directly in the absence of untreated corridors. Its main limitation is that identification may be threatened by other discontinuous shocks occurring at the same time, and that the results remain conditional on the functional form used to model the underlying time trend.

Descriptive statistics revealed substantial heterogeneity in the main outcome variables across corridors and over time, with dispersion measures that in some cases exceed the corresponding means. This reinforces the limitations of relying on simple unconditional comparisons in our setting and motivates the use of a quasi-experimental design based on local variation around the timing of liberalisation. Our empirical strategy does not identify effects from cross-corridor differences in levels, but from within-corridor changes around the entry threshold. In addition, the main outcome variables are modelled in logarithms, which helps mitigate the influence of extreme values and improves comparability across corridors with very different traffic volumes. For these reasons, the observed heterogeneity does not undermine the analysis, but instead highlights the need for an identification strategy capable of isolating the effect of liberalisation from broader variation in market size and temporal dynamics.

We first tried to somewhat correct this with a fixed effect model (FE) as a baseline for estimating the conditional correlation between HSR liberalisation and air travel outcomes, as depicted in (1). Each outcome variable is introduced in the model as the daily figure at the corridor level in logs (Y_{it}), so we use a semilogarithmic specification. We define a treatment variable dummy (T_t) that equals 1 for all air travel routes from the date HSR liberalisation is implemented in that specific corridor (and onwards) and 0 before that. This means that δ, the impact measure, should be interpreted as the percentage change in each specific air-travel outcome variable attributable to the liberalisation of HSR services.

$$Y_{it} = \beta_0 + \delta \bullet T_t + \beta_1 \bullet X_{it} + \alpha_i + \varepsilon_{it} \quad (1)$$

In (1), we are still undertaking a pre/post comparison while controlling for potential confounding factors through (X_{it}) by including time-specific effects, allowing for differences in air travel outcomes based on the day of the week, week of the year, season and year fixed effects. This is aimed at controlling for seasonality in travel patterns, changes in air traffic taxes, and fuel price fluctuations that could have

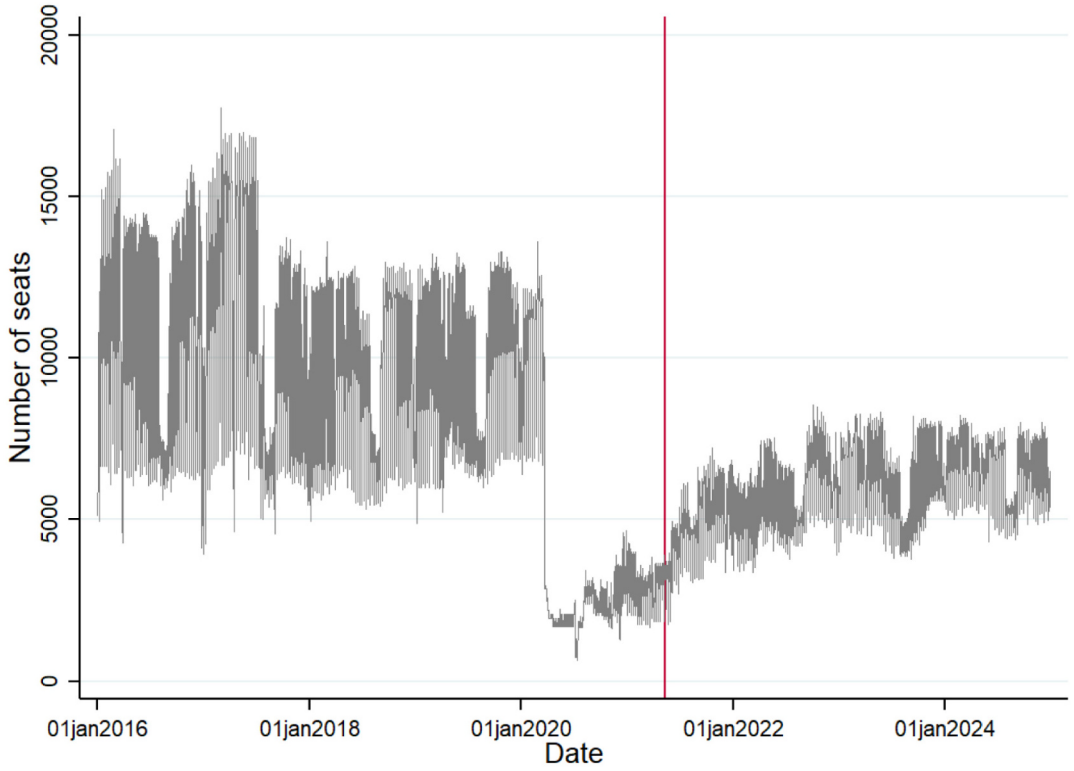


Fig. 6. Example of the evolution the of daily total number of seats supplied in the corridor Barcelona – Madrid.
Note: The red vertical line is the date of the first competitor entering this corridor after the liberalisation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

affected airlines' supply. Additionally, we also include the interaction between year- and week-specific effects to control for COVID-related lockdowns that limited travel in Spain during part of the period included in our sample, as well as other potential shifts in business and leisure travel patterns after the Pandemic or HSR liberalisation. We also include corridor-level fixed effects to account for potential unobserved heterogeneity across HSR-equivalent corridors, as their flight demand levels may differ systematically by connectivity, size, and presence of competing transportation modes. The fixed-effects model (FE) described in (1) utilises within-corridor variation over time to obtain δ as an average treatment effect (ATE) estimate.

A potential limitation with the model described in (1) is that unobserved factors changing over time could simultaneously drive short-haul flight supply up or down, leading to a correlation between the error term and time, biasing the estimation of the parameter of interest (δ). Some of these factors include changing traveller preferences, reduced business travel due to the rise of teleconferencing, or any underlying trends affecting air travel demand and supply independently of HSR liberalisation, beyond what we can control with the interaction between year- and week-specific effects.

To address these endogeneity concerns, we estimate the policy impact around the HSR liberalisation date in each corridor while flexibly controlling for nonlinearities in air travel demand through the inclusion of a global polynomial time trend $f\left(\widetilde{x}_t\right)$, where $\widetilde{x}_t$ is the running variable centred at the date of entrance of the new competitor in each corridor (libearlization date).[8] This allows us to isolate changes in air travel supply driven solely by HSR liberalisation by estimating a global polynomial regression discontinuity in time model (RDiT-global), as described in (2), where δ represents a local estimate of the average treatment effect (ATE) around the liberalisation date.

$$Y_{it} = \beta_0 + \delta \bullet T_t + f\left(\widetilde{x}_t\right) + \beta_1 \bullet X_{it} + \alpha_i + \varepsilon_{it} \quad (2)$$

The identification strategy in (2) relies on the key assumption of local randomisation around the liberalisation date, meaning that in the absence of the policy, short-haul flight travel outcome variables would not have changed discontinuously on the implementation date. This assumption ensures that HSR liberalisation is exogenous to flight supply and that no manipulation of the running variable (time) biases our estimates.

Relying on *RDiT-global* comes with challenges, as it inherently departs from the local randomisation assumption by including observations far from the liberalisation date. Additionally, the true functional form of the underlying trend is unknown, and misspecification can lead to biased estimates. When dealing with noisy data, low-order polynomials may oversmooth the trend, prompting statistical tests to recommend high-order polynomials, as suggested by Lee and Lemieux (2010). However, high-order polynomials have been criticised by Gelman and Imbens (2019) for assigning disproportionate weight to

[8] For this polynomial we assume continuity (no slope changes or structural break) in the relation between the outcome and the running variable across the date of liberalisation. Discontinuity can be accounted for by simply including interaction terms between the treatment and the running variable terms. The polynomial specification captures the underlying trend of the outcome variable (over time) due to unobservable factors.

observations distant from the cutoff, making estimates highly sensitive to the chosen polynomial order.

To further strengthen our identification strategy, we follow the approach suggested by Gragera, Matas, and Perdiguero (2024), which estimates a semi-parametric version of the previous RDiT-global model. This approach introduces K-2 bins (to avoid collinearity) into the model specified in eq. (2), termed *RDiT-global + bins*. These bins divide the running variable (time) into K equal-sized intervals on each side of the cutoff, with widths optimally selected using the data-driven approach proposed by Calonico, Cattaneo, and Titiunik (2015). This strategy accounts for deviations from the underlying trend that fall outside the cutoff for each outcome variable, ensuring the effect is primarily captured within bins contiguous to the liberalisation date and reducing sensitivity to polynomial order selection. The estimate from RDiT-global + bins gives a somewhat more local estimation of the Average Treatment Effect (ATE).

Additionally, we estimate a local regression on the residualised outcome variable (RDiT-local), restricting the analysis solely to the vicinity of the liberalisation date. In this case, we obtain the residualised outcome variable by subtracting the predicted values based on eq. (1) from the flight demand figures. This local regression is also commonly described in the regression discontinuity literature as a non-parametric approach. By applying it to the residualised outcome variable, we effectively control for seasonality patterns and other time-varying confounders while still focusing exclusively on the immediate (short-run) impact of HSR liberalisation on short-haul flights. It is essential to note that focusing solely on the immediate vicinity of the implementation date can reduce estimation bias, albeit at the expense of lower precision due to a significantly reduced sample size.

All previous models give estimates that implicitly assume δ is a constant treatment effect. However, each of their estimates gives somewhat more weight to observations within different ranges around the discontinuity, meaning they provide estimates that are closer or farther from the long- and short-run effects. On the one hand, FE and RDiT global models give approximations to the long-run treatment effect under the assumption that it is constant over time. For instance, the FE model provides an estimate of the impact as the mean difference between the pre- and post-intervention periods. RDiT global provides an

Table 4
Estimation results for the total number of seats supplied.

	Panel A - FE (static and dynamic)				
Treatment	0.247***	−0.298***	−0.298***	−0.298**	−0.068***
	(0.008)	(0.011)	(0.011)	(0.106)	(0.013)
Log(# of seats) t-1					0.774***
					(0.044)
R^2	0.062	0.646	0.646	0.646	0.852
Corridor FE	Yes	Yes	Yes	Yes	Yes
Time-specific FE	No	Yes	Yes	Yes	Yes
Interactions	No	No	Yes	Yes	Yes
Clustered S.E.	No	No	No	Yes	Yes
Lagged dep. Variable	No	No	No	No	Yes

	Panel B - RDiT global (variable slope)				
	p = 1	*p* = 2	*p* = 3	*p* = 4	p = 5
Treatment	−0.298***	−0.0645***	−0.0732***	−0.0255**	−0.0277**
	(0.0107)	(0.00978)	(0.0101)	(0.0118)	(0.0120)
R^2	0.646	0.737	0.737	0.738	0.738

	Panel C - RDiT + bins (variable slope)				
	p = 1	p = 2	p = 3	p = 4	p = 5
Treatment	−0.151***	−0.111***	−0.112***	−0.106***	−0.107***
	(0.0211)	(0.0222)	(0.0225)	(0.0234)	(0.0234)
R^2	0.749	0.749	0.749	0.749	0.749

	Panel D - RDiT local			
	p = 0	p = 1	p = 0	p = 1
Treatment	−0.0636	−0.0901	−0.0622	−0.0998
	(0.0611)	(0.0811)	(0.0595)	(0.0859)
Kernel Type	Triangular	Triangular	Uniform	Uniform
BW Loc. Poly. (h)	145.4	244.8	113.6	178
BW Bias (b)	343	390	313.5	328.2
Non-treated obs.	725	1220	565	890
Treated obs.	730	1225	570	895

Note: The units of observation for all specifications are the 5 corridors connecting Madrid to Alicante, Barcelona, Málaga, Sevilla and Valencia, during the period January 2016 to December 2024 (16,044 observations). The dependent variable is daily total number of seats in logs offered by airlines in each corridor. Panel A reports estimates from FE regressions fitting Eq. 1, sequentially including different sets of covariates. Panel B reports estimates from RDiT global depicted in Eq. 2 for the linear ($p = 1$) to quintic ($p = 5$) polynomial time trend, with AIC suggesting even higher order polynomials as better fits with wild variations in the estimates. Panel C reports estimates from RDiT global depicted in Eq. 2, including time-specific bins common to all corridors, for specifications linear (p = 1) to quintic (p = 5) polynomial time trend. All specifications include 26 bin dummies pre-intervention and 16 bins post-intervention (98 and 78 days, respectively), following the data-driven procedure of Calonico et al. (2015). Panel D reports estimates from a non-parametric RDiT local regression for a combination of zero and linear degree polynomials with triangular and homogeneous kernel weights. Estimates in panel D are computed using the data-driven MSE optimal bandwidth choice and the robust bias-corrected statistics proposed in Calonico et al. (2018, 2022). Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

estimate based on the difference around the discontinuity, calculated using the adjusted polynomial relation between the outcome and the running variable, incorporating all observations in the sample, which may be affected by data noise. RDiT global + bins smooths out such noise and provides a similar estimate, correcting for the bias due to the polynomial trend and assigning arbitrary weights to observations far from the discontinuity. RDiT local also assumes a constant treatment effect, but estimates it only in the immediate vicinity of the liberalisation date, thereby capturing the short-run treatment effect.

As a further robustness check to verify whether models align with the short-run estimate, we also estimate a dynamic FE model that includes the lagged outcome variable on the right-hand side of (1). This will yield the model described in (3), from which we can retrieve the estimates for both the short-run (δ) and long-run ($\frac{\delta}{1-\gamma}$) treatment effects.

$$Y_{it} = \beta_0 + \gamma \bullet Y_{it-1} + \delta \bullet T_t + \beta_1 \bullet X_{it} + \alpha_i + \varepsilon_{it} \quad (3)$$

Short-run estimates from the FE dynamic model should be equivalent to the RDiT local ones; however, long-run estimates from it will be equivalent to the FE static model and may differ from RDiT global ones due to bias introduced by unobserved factors that change over time. As pointed out in Hausman and Rapson (2018), RDiT tends to yield treatment effect coefficients that approach the long-run treatment effect, which is the relevant policy figure rather than short-run adaptations.

5. Results

Table 4 reports the results for the impact of liberalisation on the total number of seats supplied by airlines in the five corridors affected by it, for the alternative specifications described in section 4. Panel A reports FE models where we successively incorporate different sets of covariates. The first column, which includes only corridor fixed effects, shows a large positive impact, but it does not adequately control for confounders, such as the ridership plunge caused by COVID-related lockdowns. On the contrary, the most comprehensive models indicate a negative impact of liberalisation, with a 29.8% reduction in the number of aircraft seats supplied, failing to account for potential underlying trends driven by other factors that vary over time during the period of analysis. Panel A also reports the FE dynamic results,

Table 5
Estimation results for the daily frequency of flights.

	Panel A - FE (static and dynamic)				
Treatment	−0.037***	−0.243***	−0.243***	−0.243**	−0.068**
	(0.007)	(0.009)	(0.009)	(0.054)	(0.016)
Log(Total # of seats supplied) t-1					0.721***
					(0.040)
R2	0.002	0.700	0.700	0.700	0.850
Corridor FE	Yes	Yes	Yes	Yes	Yes
Time-specific FE	No	Yes	Yes	Yes	Yes
Interactions	No	No	Yes	Yes	Yes
Clustered S.E.	No	No	No	Yes	Yes
Lagged dep. Variable	No	No	No	No	Yes

	Panel B - RDiT global (variable slope)				
	p = 1	p = 2	p = 3	p = 4	p = 5
Treatment	−0.243***	−0.0909***	−0.0512***	−0.00706	−0.0152
	(0.00904)	(0.00879)	(0.00901)	(0.0105)	(0.0107)
R2	0.700	0.747	0.751	0.752	0.753

	Panel C - RDiT + bins (variable slope)				
	p = 1	p = 2	p = 3	p = 4	p = 5
Treatment	−0.0452**	−0.0266	−0.0182	−0.0183	−0.0166
	(0.0188)	(0.0191)	(0.0194)	(0.0201)	(0.0201)
R2	0.760	0.760	0.760	0.760	0.760

	Panel D - RDiT local			
	p = 0	p = 1	p = 0	p = 1
Treatment	−0.0133	−0.0223	−0.0162	−0.0311
	(0.0403)	(0.0581)	(0.0445)	(0.0606)
Kernel Type	Triangular	Triangular	Uniform	Uniform
BW Loc. Poly. (h)	176.6	245.6	100.2	184.6
BW Bias (b)	370.2	381.3	257.9	329.7
Non-treated obs.	880	1225	500	920
Treated obs.	885	1230	505	925

Note: The units of observation for all specifications are 5 corridors during the period January 2016 to December 2024 (16,044 observations) covering the relations Madrid, Alicante, Madrid-Barcelona, Madrid-Málaga, Madrid-Sevilla and Madrid-Valencia. The dependent variable is the daily flight frequency in logs offered by airlines in each corridor. Panel A reports estimates from FE regressions fitting Eq. 1, sequentially including different sets of covariates. Panel B reports estimates from RDiT global, depicted in Eq. 2, for the linear (p = 1) to quintic ($p = 5$) polynomial time trend, with AIC suggesting that higher-order polynomials provide a better fit. Panel C reports estimates from RDiT global, depicted in Eq. 2, including time-specific bins common to all corridors, for polynomial time trends from linear (p = 1) to quintic (p = 5). All specifications include 28 bin dummies pre-intervention and 14 bins post-intervention (91 and 88 days, respectively), following the data-driven procedure of Calonico et al. (2015). Panel D reports estimates from a non-parametric RDiT local regression for a combination of zero and linear degree polynomials with triangular and homogeneous kernel weights. Estimates in panel D are computed using the data-driven MSE optimal bandwidth choice and the robust bias-corrected statistics proposed in Calonico et al. (2018, 2022). Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

suggesting that the short-run impact of liberalisation on the total number of aircraft seats supplied is a reduction of around 6.8%.

Panel B, in an attempt to correct this, reports the RDiT global estimates for a range of polynomial-order specifications for such a trend, as described in (2). Noisy data suggest that even high-order specifications fit the data better under the AIC criterion, with substantial variation in the estimates across them. This occurs because the polynomial order introduces an arbitrarily high weight to observations far from the date of liberalisation. This introduces sensitivity in the estimates, with the total number of aircraft seat reductions fluctuating between 2.5% and 29.8%.

Panel C addresses the noise in the data and reports estimates for RDiT global + bins, showing more stable estimates across polynomial specifications, with a total reduction in aircraft seats of 10.6–15.1%. This gives us an estimate of the long-run effect (within the time frame we analyse) of HSR liberalisation on airline supply. Panel D reports RDiT local results, which confirm that the short-run effect of liberalisation on the total number of seats supplied is a reduction of around 6% to 9%, similar in magnitude to the FE dynamic model. However, these estimates are not statistically significant due to the reduced sample size.

To gain insight into the mechanism by which airlines reduce supply when facing competition by HSR, we replicate the same analysis for the daily frequency of flights and the average number of seats per flight offered each day across affected corridors, as total seat capacity could be reduced either by decreasing the frequency of flights, down-gauging (using smaller aircrafts) or some combination of both.

Table 5 shows the results for the impact of HSR liberalisation on the daily flight frequency. Panels A (FE models) and B (RDiT global) show results very similar to those for the total number of daily seats supplied, with variations due to data noise. Panel C (RDiT global + bins) addresses previous issues and suggests that flight frequency has experienced a small reduction due to HSR liberalisation. Only the linear model shows a statistically significant reduction of about 4.5%, yet the point estimates across polynomial specifications agree on the direction and the general magnitude of the change (ranging from −4.5% to −1.6%), even though lower orders should be preferred. Panel D (RDiT local) confirms this small impact with non-statistically significant estimates ranging from −3.1% to −1.1% in the daily frequency of flights, due to larger standard errors in a heavily reduced sample.

Table 6
Estimation results for the daily average number of seats per flight.

	Panel A - FE (static and dynamic)				
Treatment	0.284***	−0.055***	−0.055***	−0.055***	−0.007
	(0.003)	(0.005)	(0.005)	(0.019)	(0.006)
Log(Av. Seats per flight) t-1					0.875***
					(0.029)
R^2	0.349	0.615	0.615	0.615	0.910
Corridor FE	Yes	Yes	Yes	Yes	Yes
Time-specific FE	No	Yes	Yes	Yes	Yes
Interactions	No	No	Yes	Yes	Yes
Clustered S.E.	No	No	No	Yes	Yes
Lagged dep. Variable	No	No	No	No	Yes

	Panel B - RDiT global (variable slope)				
	p = 1	p = 2	p = 3	*p* = 4	p = 5
Treatment	−0.0547***	0.0264***	−0.0220***	−0.0184***	−0.0125**
	(0.00542)	(0.00537)	(0.00535)	(0.00626)	(0.00635)
R^2	0.615	0.662	0.687	0.687	0.687

	Panel C - RDiT + bins (variable slope)				
	p = 1	p = 2	p = 3	p = 4	p = 5
Treatment	−0.0845***	−0.0631***	−0.0634***	−0.0569***	−0.0684***
	(0.0112)	(0.0118)	(0.0118)	(0.0124)	(0.0128)
R^2	0.704	0.705	0.705	0.705	0.706

	Panel D - RDiT local			
	p = 0	p = 1	*p* = 0	*p* = 1
Treatment	−0.0545*	−0.0652**	−0.0545*	−0.0715**
	(0.0323)	(0.0324)	(0.0322)	(0.0358)
Kernel Type	Triangular	Triangular	Uniform	Uniform
BW Loc. Poly. (h)	91.40	286.9	64.31	192
BW Bias (b)	284.6	541.4	256	377.4
Non-treated obs.	455	1430	320	955
Treated obs.	460	1435	325	960

Note: The units of observation for all specifications are 5 corridors during the period January 2016 to December 2024 (16,044 observations) covering the relations Madrid - Alicante, Madrid - Barcelona, Madrid - Málaga, Madrid - Sevilla and Madrid - Valencia. The dependent variable is the average number of seats per flight (in logs) offered by airlines in each corridor each day. Panel A reports estimates from FE regressions fitting Eq. 1, sequentially including different sets of covariates. Panel B reports estimates from RDiT global depicted in Eq. 2 for the linear ($p = 1$) to quintic ($p = 5$) polynomial time trend, with AIC suggesting better fit for even higher polynomial orders. Panel C reports estimates from RDiT global depicted in Eq. 2, including time-specific bins common to all corridors, for specifications linear (p = 1) to quintic (p = 5) polynomial time trend. All specifications include 20 bin dummies pre-intervention and 21 bins post-intervention (132 and 63 days each, respectively), following the data-driven procedure of Calonico et al. (2015). Panel D reports estimates from a non-parametric RDiT local regression for a combination of zero and linear degree polynomials with triangular and homogeneous kernel weights. Estimates in panel D are computed using the data-driven MSE optimal bandwidth choice and robust bias-corrected statistics proposed in Calonico et al. (2018, 2022). Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6 shows the results for the impact of HSR liberalisation on the daily average number of seats per flight. Panel A (FE models) suggests a reduction in the number of seats per flight (−5.5%). Panel B (RDiT global) tends to confirm this, even its shows point estimates that fluctuate across polynomial specifications due to overfitting to noisy data. Panel C (RDiT global + bins) counters this and suggests long-run reductions slightly above the ones detected in Panel A, hovering around 6%. Panel D (RDiT local) point estimates confirm that the effect of liberalisation on the total number of seats supplied is a reduction of around 6%, equivalent to the one found for the total number of seats (even not all estimates are statistically significant due to the reduced sample size).

These results show that HSR liberalisation has impacted the airline industry in the corridors affected by reducing total supply. This reduction seems to be achieved by shifting to smaller aircraft rather than by reducing frequencies.

6. Discussion

Our empirical analysis reveals a nuanced airline response to HSR liberalisation. While the treatment effect is consistently negative and statistically significant for the number of seats per flight across all specifications, the impact on flight frequencies is smaller or nonexistent and most (if not all) of the change in supply is achieved through aircraft down-gauging.

The intense point-to-point (P2P) competition drove the LCA response based on a down-gauging mechanism. Vueling was highly exposed to HSR, which is a direct substitute for its core point-to-point traffic. As a defensive move, Vueling engaged in down-gauging (i.e., swapping larger aircraft for smaller ones) to maintain service levels while reducing capacity. This is evident in Table 7, which shows the evolution of the frequency share by aircraft type in the largest corridor (i.e., Barcelona-Madrid). Vueling employed aircraft downgauging within the constraints of a rigid fleet, as is typical for low-cost carriers. They reduced the number of A320s (180 seats) and increased the number of A319s (144 seats) frequencies.

This finding refines the conclusions of Albalate et al. (2015), who found that airlines might not reduce frequencies as much to compete with HSR. The main difference is that Albalate et al. (2015) focused on a previous period, 2002 to 2009, when the number of HSR operators was limited; we looked at a more recent period, dominated by various HSR operators, in other words, with higher competitive pressure from HSR operators towards airline operators.

Secondly, the strategic need to protect hub connectivity drove the network carrier response. Network carriers use these routes to feed their hubs. Their demand comes from connecting passengers who are less likely to switch to HSR. These airlines have a strong strategic incentive to maintain frequencies to protect their hub's connectivity and schedule integrity. As HSR enters, the proportion of point-to-point passengers in the cabin will decrease, while the share of hub-feeding passengers will remain unchanged. Consequently, the network carrier has an incentive to reduce the average number of seats per flight on the route through down-gauging. This frequency resilience is also consistent with the findings of Bernardo and Fageda (2020), who show that competition from HSR on short segments does not harm airlines' connecting travellers.

Indeed, in the Madrid-Barcelona corridor, Iberia reduced the number of A321 flights, which have 200 seats, and significantly increased the A320 (between 180 and 186 seats) and, to a lesser extent, the A319 (141 seats). The goal isn't just capacity reduction, but frequency preservation, as it is essential for maintaining the schedule integrity and network connectivity. The value of a flight frequency lies not just in the point-to-point revenue it generates, but also in the downstream revenue it generates for connecting passengers and feeds into the rest of the network. The simultaneous exit of point-to-point-focused LCAs and the resilience of hub-fed network traffic constitute a significant market-share shift on these routes, favouring the network carriers. This outcome aligns with Dobruszkes's (2011) findings, which also showed a reduction in airline seat supply but a stable evolution in frequencies in response to HSR entry.

Our findings move beyond a simple view of intermodal competition, revealing a resilient market that reconfigures itself around two service models: hub-feeding network service and P2P service. However, despite its observed resilience, the substitution of flights dominated by P2P traffic appears more vulnerable, particularly when the HSR network's star-like pattern replicates the airline network configuration without intermodal integration (Levinson, 2012). This provides a more granular understanding for policymakers, suggesting that while overall seat capacity may fall, the essential connectivity provided by network carrier hubs is likely to remain very resilient.

From an economic perspective, our findings suggest that HSR liberalisation primarily operates through strategic supply adjustments rather than through uniform market contraction. Airlines appear to respond not only to changes in demand, but also to shifts in competitive pressure and network incentives, leading to differentiated responses across business models. This interpretation is consistent with evidence showing that airlines adjust both frequency and aircraft size as strategic margins in response to changing market conditions and competition (Pitfield, Caves, & Quddus, 2010), and with work highlighting that aircraft size choices are closely linked to the value of preserving frequency under competitive pressure (Givoni & Rietveld, 2009). In network markets, such adjustments may also reflect the value of maintaining hub connectivity and schedule integrity. In this context, aircraft down-gauging emerges as a key adjustment margin that allows airlines to remain present in contested corridors while mitigating revenue risk.

These results are broadly consistent with earlier evidence on HSR competition showing reductions in airline seat supply with more limited changes in flight frequencies (Albalate et al., 2015; Dobruszkes, 2011; Dobruszkes, Dehon, & Givoni, 2014). However, our findings extend this literature in two important ways. First, unlike much of the previous research, which focuses on infrastructure expansion or descriptive evidence, we provide quasi-experimental estimates of the causal effects of large-scale HSR liberalisation. Second, our results reveal heterogeneous strategic responses across airline business models, offering a more granular understanding of how intermodal competition reshapes market

Table 7
Evolution of the share of frequencies by aircraft type of the leading airline operators in the Barcelona-Madrid corridor. Source: Based on OAG Schedules.

	2016	2017	2018	2019	2020	2021	2022	2023	2024
Iberia									
Airbus A319	1%	1%	7%	9%	12%	3%	5%	7%	4%
Airbus A320	27%	21%	43%	46%	49%	62%	60%	77%	73%
Airbus A321	71%	78%	50%	45%	40%	36%	34%	16%	23%
Other	1%	0%	0%	0%	0%	0%	0%	0%	0%
Vueling									
Airbus A319	1%	0%	0%	0%	2%	9%	2%	7%	14%
Airbus A320	99%	99%	100%	100%	97%	90%	98%	90%	83%
Airbus A321	0%	1%	0%	0%	1%	1%	0%	3%	3%

structure.

The observed shifts in aircraft gauge and frequency also have implications for aviation emissions. For climate change, absolute emissions are the primary concern: while smaller regional aircraft exhibit worse fuel efficiency per Available Seat Kilometre (ASK) than larger narrow-bodies such as the A320 or A321, they emit fewer absolute emissions, so this disadvantage only translates into greater climate harm if the number of aircraft movements increases (Dobruszkes, Mattioli, & Gozzoli, 2024; Suau-Sanchez, Dobruszkes, & Mattioli, 2025). When down-gauging is accompanied by frequency preservation or growth, as observed in the hub-feeding strategy of network carriers, more individual rotations are required to deliver equivalent seat capacity, potentially raising total fuel burn and CO_2 emissions relative to a consolidated high-capacity service. In corridors such as Madrid-Sevilla and Madrid-Malaga, where both frequencies and aircraft size increased, the absolute impact on emissions is unambiguously greater. Conversely, in routes where HSR effectively absorbed point-to-point demand, most notably Madrid-Barcelona following Vueling's exit, the net emissions outcome depends critically on the carbon intensity of the rail alternative (Reiter, Voltes-Dorta, & Suau-Sanchez, 2022). Given that Spanish HSR is powered predominantly by green-certified energy, modal substitution from air to rail in high-density corridors represents a meaningful reduction in emissions.

7. Conclusions

High-speed rail is increasingly seen as an efficient alternative to air transport in long-distance travel. Many governments and international institutions, especially in Europe, are actively committed to expanding HSR infrastructure and favour policies and regulations that promote its development and utilisation, particularly amid growing concerns about climate change and the goal of consolidating a more sustainable mobility transportation network. Among them, the liberalisation of the rail market, particularly for high-speed rail, is considered a potential catalyst for mode substitution, thereby improving the relative attractiveness of HSR compared with environmentally inefficient domestic air transportation. Yet, few countries experimented with HSR liberalisation, and the scientific literature on intermodal impacts is still in its infancy. Only scarce and methodologically limited studies are available today. Previous research on intermodal competition had mainly focused on new HSR deployments or on pre-post comparisons.

This paper contributes to the literature by using a quasi-experimental approach to evaluate a large-scale HSR liberalisation involving several new entrants. Spain provides the ideal setting for this analysis because its large HSR and air transport markets compete directly over distances well suited to mode substitution, with significant overlap between their networks.

Our causal results confirm that HSR liberalisations can produce significant long-term impacts on air transport in competing routes – a reduction of between 10% and 16% in airline seats supplied - not only in new HSR deployments. We show that liberalisation may act as a second catalyst for mode substitution and as a strategy to increase the utilisation – and therefore the socioeconomic return – of the expensive HSR infrastructure. The supply of airlines in the evaluated treated corridors decreased in response to the increased competition in the HSR market. More interestingly, we provide insights into the strategic mechanisms employed by the airline industry, uncovering two strategic responses. The first is a defensive capacity reduction by LCCs, who react to intense point-to-point competition with aircraft downgauging (within the limits of their rigid fleet). The second is a resilient hub-protection strategy by network carriers, who preserve frequencies for connecting traffic by also down-gauging, resulting in a market-share shift in their favour. The latter should be understood in the context of Spain's distinctive centralised configuration of the radial HSR network, which could resemble other centralised networks with the same nodes sharing airport and HSR hubs, such as France.

Our findings also carry relevant implications for countries that have not yet liberalised their HSR markets. First, they suggest that opening HSR services to competition can alter airline supply even without additional infrastructure investment, indicating that service liberalisation may be an important policy lever once a viable HSR network is already in place. Second, the results show that airline adjustment may occur mainly through capacity reconfiguration—particularly aircraft down-gauging—rather than through large cuts in flight frequencies, which suggests that intermodal rebalancing need not imply a full withdrawal of air services from affected corridors. Third, our evidence points to a more intensive use of existing HSR infrastructure when competition in rail services is introduced, reinforcing the role of liberalisation as a tool to increase the utilisation of sunk transport assets. More broadly, these findings may help policymakers anticipate how market opening can reshape intermodal competition, although the magnitude and form of these effects will depend on corridor density, market structure, and the role of hub-feeding traffic in domestic air services. Together, these findings offer practical guidance for policymakers designing liberalisation processes in other national contexts, particularly those with an existing HSR network.

These findings also suggest that liberalisation can influence airline supply making it a potentially cost-effective complement to infrastructure expansion. At the same time, the differentiated responses across airline business models imply that liberalisation may have uneven effects across corridors, requiring careful sequencing and monitoring of market adjustments. For regulators, the results highlight the importance of considering network effects and connectivity objectives when designing liberalisation processes, particularly in hub-based systems. More broadly, the findings contribute to ongoing policy debates on sustainable mobility by showing that the intermodal effects of liberalisation depend not only on modal substitution but also on how firms strategically adapt to competitive pressures.

Beyond capacity adjustments, our findings on these heterogeneous strategic responses of airlines to HSR liberalisation suggest that liberalisation reshapes intermodal competition by reconfiguring airline business models rather than uniformly reducing service levels. They also carry broader implications for aviation emissions. Where down-gauging is accompanied by frequency preservation, total fuel burn and emissions may increase despite lower seat capacity, whereas in dense corridors where HSR absorbs point-to-point demand, modal substitution is likely to reduce emissions, particularly in systems such as Spain where HSR relies heavily on low-carbon electricity.

Ultimately, our findings provide valuable insights not only for promoting sustainable transport but also for airline executives navigating these markets, highlighting the vulnerability of pure point-to-point models and the enduring strategic value of hub connectivity. Because these results and their generalisation are essential to understanding the common implications of liberalisation, they must be confirmed in other experiences and contexts. Future research could examine the second-order impacts on airfares and consumer welfare. An analysis of how these supply shifts affect the network structures of smaller, regional airports would also be a valuable contribution. Furthermore, investigating the potential for air-rail intermodal cooperation in liberalised markets rather than pure competition remains an important question.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

The authors used ChatGPT 5.3–5.5 (OpenAI, San Francisco, CA) to assist in refining the structure, language, and style of the manuscript, ensuring stylistic consistency across authors, and verifying terminology consistency. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Daniel Albalate: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Albert Gragera:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Pere Suau-Sanchez:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation, Conceptualization.

Declaration of competing interest

None.

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Data availability

Data will be made available on request.

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Fewer seats, resilient frequencies: Impacts of large-scale high-speed rail liberalisation on air transport supply

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