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> Pedro Cantos-Sánchez
Universitat de València and ERI-CES, Spain

> Rafael Moner-Colonques
Universitat de València and ERI-CES, Spain

> Alba Ruiz-Buforn
Universitat de València, Spain

> Jose J. Sempere-Monerris
Universitat de València and ERI-CES, Spain

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Vniversitat de València

Sequential entry in Spanish HSR markets and its effect on prices*

Pedro Cantos-Sánchez[a], Rafael Moner-Colonques[a], Alba Ruiz-Buforn[b] and Jose J. Sempere-Monerris[c]

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[a] Department of Economic Analysis and ERI-CES, University of Valencia

[b] Department of Economic Analysis, University of Valencia

[c] Department of Economic Analysis and ERI-CES, University of Valencia, and Center for Operations Research & Econometrics, LIDAM/UCLouvain

Abstract

This paper evaluates the effects of open access competition in two of the most important High-Speed-Rail (HSR) routes in Spain, Madrid-Valencia and Madrid-Barcelona. In the Spanish market, the rail incumbent Renfe's Ave brand is competing with two rail entrants (Ouigo and Iryo). Additionally, Renfe introduced its own low-cost brand Avlo. Employing data on ticket prices between November 2020 and April 2024, we measure the effect of entry of each new operator in both markets and evaluate operator's individual responses. Results for both routes are qualitatively similar. A new entry produces price decreases in the range of eight to almost fifteen euros. The entry of Ouigo and Iryo reduced Ave basic fares by 11.17 and 17.80 euros in Madrid-Valencia, and by 8.27 and 17.18 euros in Madrid-Barcelona. However, the entry of Renfe's low-cost brand Avlo increased Ave basic fares by 10.50 and 21.03 euros in Madrid-Valencia and Madrid-Barcelona, respectively.

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Contact author: Pedro Cantos-Sanchez (Pedro.Cantos@uv.es)

1 Introduction

The liberalization of high-speed rail markets that has happened in several European countries (Austria, the Czech Republic, Italy, the UK, France and Spain) has had a notable effect on the competitive environment and hence on the market share of incumbent operators of passenger rail services. Scholars have devoted attention to studying the effects on prices that follow from the introduction of intramodal competition. Spain offers an exemplary context in which to analyze this matter before exogenous changes in the number of operators that have entered in sequence. The use of a rich dataset allows us to quantify the effects of the successive entries on industry prices; the price responses of the incumbent operator and newcomers are also determined. Spain is the unique country that offers four service brands, which belong to three different operators. This paper assesses the price effects of successive entry and the individual responses of operators in Spanish high-speed rail markets.

Spain has the largest high-speed network in Europe and one of the largest in the world totaling almost 4,000 Km. The infrastructure manager designed a tender process to allocate track capacity regarding the three busiest corridors in the country: northeast (Madrid–Barcelona), east (Madrid–Valencia and Alicante), and south (Madrid–Seville and Malaga). This was an element of competition for the market resulting in several operators competing in the aforementioned corridors. To be specific, until May 2021 high-speed services were exclusively offered by Renfe under the brand name of Ave. On May 10th 2021, Ouigo entered the Madrid-Barcelona (MAD-BCN) route to compete with Renfe. One month later on June 23rd, Avlo, the low-cost brand of Renfe started operations on that route and Iryo entered in November 25th 2022. In the Madrid-Valencia (MAD-VLC) route, Renfe has also witnessed the introduction of Avlo (February 21th 2022), followed by the competition of Ouigo (October 7th 2022) and then by Iryo (December 16th 2022). This paper examines the price effects of sequential entry in Spanish long-distance passenger rail markets. Our sample period covers November 2021 to April 2024 and because entry was sequential, we have windows with one operator (referred to as Period I), two (Period II), three (Period III) and four operators (Period IV). This allows for the analysis of the price effects following the introduction of competition.

A Generalized Linear Model with Heteroskedasticity and Autocorrelation Consistent (HAC) robust errors is used to evaluate the changes in prices when market structure switches from one to two, from two to three and from three to four operators. For the ease of exposition, we identify every brand (Ave, Avlo, Ouigo and Iryo) to an operator. The results obtained for both routes are qualitatively similar, noting that the entry pattern has been different. Thus, when the second operator is independent from the incumbent – as happens in Madrid-Barcelona – competition brings average prices down by 8.28 euros. Instead, in Madrid-Valencia, the additional service is Avlo, which belongs to Renfe, and this structural change meant an increase of 9.42 euros on average prices. However, Avlo prices were 15.81 euros lower than Ave prices, which signals a pricing behavior by the multibrand operator to segment the market. Further moves to structures with independent operators imply average price decreases in the range of 11 to almost 15 euros.

Our analysis also evaluates the individual price responses to entry. Ave prices decrease by more after Iryo's entry compared to Ouigo's entry; this result suggests that Renfe's Ave service quality is closer to that of Iryo. Besides, Ouigo reduced its price by 1.05 euros in Madrid-Valencia and by 7.68 in Madrid-Barcelona following Iryo's entry. However, Avlo reduced its price to a greater extent, by 6.84 euros in Madrid-Valencia and by 10.92 in Madrid-Barcelona after the entry of Iryo. All in all, the competition with four operators has definitely led to lower prices.

2 Literature review

More than twelve years ago, the European Commission set out the basis regarding the opening of the market for domestic passenger transport services by rail (see European Commission, 2013), which was developed and confirmed in the 4th Railway Package EU 2014. Thus, open access in passenger rail services has been implemented in a few European countries. The UK, Germany and Sweden opted for allowing entry in niche markets thus avoiding the direct competition with the incumbent; this type of competition involved low-scale entries with low prices and low quality of service (see Nash et al., 2013, for further details). A second more recent type of competition entails head-on competition as new private operators compete with the incumbent on the main railway routes. This is observed in Austria (2011), the Czech Republic (2011), Italy (2012), Slovakia (2014), Sweden (2015) and Spain (2021). These experiences have drawn the attention of scholars who have looked into the effect that open access competition has had on average high-speed rail prices; our study adds to the literature that examines the effects of direct competition in high-speed rail markets that focuses on the Spanish case.

Cascetta and Coppola (2015) provide a detailed description of the Italian case, in which the competition between the incumbent and a new private operator was first introduced on the same line. They report that the competition increased frequencies, brought fares down (around 30%) and a notable passenger traffic increase happened. Bergantino et al. (2015) and Beria et al. (2016) find that entry has resulted in significant price reductions, although incumbent's, Trenitalia, fares are higher than entrant's. Shtele and Beria (2025) consider a time period in which the competition has stabilized; they conclude that price decreases were stronger for the cheapest non-flexible tickets (in the range of 12-24%) than for flexible tickets (1-3-2%). The case of Sweden has been studied by Vigren (2017) finding that competition in the Stockholm-Gothenburg line led to an average price decrease of 12.6 percent. Other cases in Central Europe - Austria, the Czech Republic and Slovakia – are examined in detail by Tomeš and Jandová (2018). Entries have concentrated on important city pairs, where lower prices and service innovations have attracted demand. Despite the growth in ridership, operators are facing profitability problems. Beria et al. (2025) deliver an informed up-to-date description of the benefits that European experiences of on-track competition have meant. More importantly, the authors note that access charges might pose obstacles, thus making competition unstable.[1]

Finally, with regard to Spain, the relevance of network capacity and how it is allocated is discussed in Montero and Ramos Melero (2022). The recent paper by Brenna (2024) investigates the price effects of competition in Spanish less congested routes; his differences-in-differences model shows a price decrease around thirty percent after nine months of competition. To the best of our knowledge, ours is the first quantitative analysis that consistently evaluates how the successive competition in Spanish high-speed rail markets has shaped average prices, as well as studying the price responses of individual operator brands. As shall be seen, our results complement earlier findings in the literature and add some novel features that influence the changes in high-speed rail prices.

The effects of entry have been widely studied in the airline industry. Among other issues, the literature has studied the relationship between product quality and entry (Dunn, 2008; Gil and Kim, 2021), the pricing response of full service airlines before entry of low-cost carriers (Alderighi et al., 2012), and the impact that low-cost carriers have had on international pas-

[1]Ex-ante analyses have also advised about the potential difficulties that may appear with the introduction of competition. Thus, the papers by Johnson and Nash (2012), Álvarez-SanJaime et al. (2015, 2016) and Cherbonnier et al. (2017) remark elements like entrant's costs regarding profitability, the level of access charges and the necessary increase in passenger traffic, and the way by which competition is implemented, respectively.

senger movements (Bilotkach et al., 2019) – see Sun et al. (2024) for a comprehensive review of recent research covering a number of factors that shape the competition in the airline industry.

The paper is organized as follows. Section 3 provides some background on the introduction of HSR competition in Spain. Then, the data and summary statistics are given in Section 4. Results are presented and discussed in Section 5, where subsection 5.1 looks at the Madrid-Valencia market and subsection 5.2 at the Madrid-Barcelona market. Conclusions in Section 6 summarize the main results.

3 Background on the introduction of HSR competition

Following the implementation of European directives on railways into the Spanish legislation, infrastructure operations by ADIF (Administrador de Infraestructuras Ferroviarias) were separated from the provision of services by Renfe. Later, in 2013, ADIF was divided into ADIF and ADIF Alta Velocidad, the latter in charge of developing the high-speed network in Spain. Although in 2014 the government devised a tender to concede a second license to introduce competition with Renfe in the east corridor (Madrid-Barcelona), it was finally discarded. The development of the Spanish high-speed network was very costly leaving ADIF highly indebted. This, coupled with the fact that the network was underutilized and the fear that potential entrants would cherry-pick the Madrid-Barcelona route, the one generating the highest revenues, pushed ADIF to implement a tender process for track capacity that comprised the northeast corridor (Madrid–Barcelona), the east (Madrid–Valencia and Alicante), and the south corridor (Madrid–Seville and Malaga). Montero and Ramos Melero (2022) describe in detail how the rail capacity was allocated between the different rail operators in the liberalization process. First, infrastructure capacity was designed from the optimal definition of the timetable of services. Second, 30% of the optimized capacity was left for the annual allocation of capacity, and the remaining 70% of the optimized capacity would be allocated in three framework agreements: Package A with 60% of the capacity, Package B with 30%, and Package C with 10%. Finally, the criterion for granting the packages was the intensity of use of capacity; applicants were requesting a specific number of paths. The result of this process was that Package A was allocated to the incumbent (Renfe), Package B for an entrant with the objective to compete head-to-head with Renfe (Iryo), while Package C was achieved by Ouigo, the low cost brand of SNCF. In May 2020, the framework agreements were signed, and Spain was ready for the introduction of competition in high-speed rail markets – commercial passenger transport services. Entry of new operators was gradual and happened in the main routes Madrid-Barcelona, Madrid-Valencia/Alicante and Madrid-Toledo/Seville/Malaga through the above mentioned packages, which imply a certain number of services per day and direction.

Thus, there was successive entry in the Madrid-Barcelona route with first Ouigo, followed by Avlo and then by Iryo. Ouigo operates with Alstom Euroduplex double-decker trains with 500 seats; as it was awarded package C this meant five trains per day and direction. Avlo employed Talgo Serie 112 trains with a passenger capacity of 438 seats starting with four trains per day and direction. Finally, Iryo is a consortium in which Trenitalia is the main partner (51%). It uses Frecciarossa 1000 trains offering 457 seats, and its service quality is comparable to that of the incumbent Ave, which now has twenty-one trains per day and direction. Iryo was awarded package B, offering up to sixteen trains per day and direction. Entry also took place sequentially in the Madrid-Valencia route, yet Avlo entered before Ouigo. In this line, newcomers Avlo and Ouigo started with three and five trains per day and direction, respectively, whereas Iryo currently offers seven trains per day and direction; Ave has twelve services per day and direction.

Besides, there are four operators in Madrid-Seville and Madrid-Málaga since January 16th 2025. Ouigo entered in Madrid-Valladolid on April 19th 2024 and in Madrid-Murcia Ouigo on September 5th 2024. The infrastructure manager ADIF announced in May 2025 a plan to design framework agreements comprising the liberalization of high-speed services in the north corridor (Madrid-Galicia and Madrid-Asturias) and in the south-west corridor reaching the provinces of Cádiz and Huelva. The Spanish regulator Comisión Nacional de Mercados y Competencia (CNMC) has positively assessed liberalisation of high-speed rail transport in Spain (see CNMC, 2024), highlighting significant benefits for consumers and a notable increase in global demand. However, it underlines the importance of addressing structural and operational challenges to ensure the long-term financial sustainability of rail entrants.

Altogether we see that the business practices of operators are varied. They introduce features that make operator brands appear differentiated in the eyes of passengers. Ave and Iryo offer three different types of fares – depending on the flexibility and purchase conditions–, whereas Avlo and Ouigo have one. A given package awarded to an operator supposes different frequency of service; Ave has more services thus offering trains during the whole day and many seats whereas Ouigo offers substantially fewer trains and are equally spread throughout the day. Ave can programme more departures in peak time. On-board facilities imply different service quality. Finally, note that a distinctive element of the Spanish case is that the incumbent Renfe is a multi-service operator that offers both Ave and Avlo brands. This strategy can be understood in the context of the fighting brands literature.[2] As it will be shown below our results indicate that Ave prices respond by more when Iryo enters and Avlo do it before Ouigo's entry. The gap between Ave and Avlo prices changes when entry occurs showing a kind of price discrimination behavior. As already noted, we wish to study how the sequential entry of differentiated operators has impacted industry prices while learning about their business practices through their price responses.

4 Data and summary statistics

A web crawler programme was employed to collect data on ticket prices for the Madrid-Barcelona and Madrid-Valencia route between November 2020 to April 2024, developed by staff at CNMC.[3] The raw data, which have been supplied for exclusive use, required an exhaustive cleaning process on our side. The web crawler took information about prices (several types of fares) on a specific train departure from the online booking sites of Renfe, Ouigo and Iryo. In fact, for Ave it took data on prices corresponding to three types of fares: *básico*, *elige*, *premium*, which we will refer to as fare P1, P2 and P3, respectively. Both fares P2 and P3 accept reimbursement, and only the latter changes without a cost and choice of seat. Ouigo and Avlo fares are basic P1 fares. Iryo information on fares comprise fares *inicial*, *singular only you* and *infinita bistro*, identified as fares P1, P2 and P3, respectively. Each departure time several times in a week is considered a separate train. The information taken for each departure every day started forty days ahead of departure, which allows us to consider advance purchase effects. The way of collecting the data is similar to that employed in some of the above noted references, ending up with a rich dataset. It contains information about the operators, train number, departure and arrival station, and time. Given the successive entry dates mentioned above, the study may cleanly distinguish time windows with just the incumbent, others with two, then with three and finally with four operators.

Note that Madrid-Barcelona and Madrid-Valencia are the two most important HSR routes

[2] Johnson and Myatt (2003) has shown that an incumbent can find it strategically profitable to use a low-quality fighting brand and accommodate entry – see Bourreau et al. (2021) for a recent empirical contribution. Alternatively, another justification of a multi-service incumbent is the exploitation of scope economies in the joint provision of services, see Cantos-Sánchez et al. (2025).

[3] In particular, for the Madrid-Barcelona route the first date collected for a purchase day data is Nov, 16, 2020; while for the Madrid-Valencia corridor is Dec, 13, 2021.

in Spain. Madrid-Barcelona, 506 km in length, was in 2019, before the liberalization and the pandemic, the route with the highest number of passengers, around 8 million. Total travel time by HSR is around five hours including one hour access/egress time plus one hour twenty minutes of average schedule delay, see Cantos-Sánchez et al. (2023). The modal split in 2018 was 46% HSR, 27% air and 24% private car. This is a route with a notable movement of business passengers between the two most important Spanish cities. On the other hand, in the same date, Madrid-Valencia is a route with a slightly lower number of passengers (2 million and a half), but with a different modal distribution, being a route dominated by the private car (66.2%), followed by the HSR (26.2%) and by air travel (3.9%). This is explained by the fact that it is a shorter route (303 km) with a high number of tourist travelers, where a significant part of the competition from the HSR comes from the car. Total travel time by HSR is around four hours twenty minutes including one hour access time plus one hour thirty minutes of average schedule delay, see Cantos-Sánchez et al. (2023). These facts, together with the different entry pattern justify the analysis of these two routes to check for regular (or not) pricing behavior following the introduction of competition.

Table 1 shows data on passenger traffic and market shares per operator and route for 2019-2024, except for 2020. By looking at the data in 2024 we observe that Renfe is the dominant operator in terms of market share. It is also worth noting the notable growth in traffic in such a short period of time. Markets with several operators can be viable with sufficient traffic and it has almost doubled in both these routes. Table 2 reports the descriptive statistics of the basic fare per period and route of the industry. The mean fares decrease with more competitors, however, it is remarkable that Avlo's entry supposes an increase in mean prices both in Madrid-Valencia in Period I to II and, in Madrid-Barcelona in Period II to III. Figures 1b and 1a illustrate the evolution of average daily fares over time.[4] To compute these averages, we first calculate the median fare for each train i based on prices observed during the ten days prior to its departure on day t, denoted by $\tilde{P}_{i,t}$. Next, the average fare for each operator j on day t, with $n_{j,t}$ trains operating that day, is computed as the mean of the corresponding train-level medians ($\overline{P}_{j,t} = \frac{1}{n_{j,t}} \sum_{i=1}^{n_{j,t}} \tilde{P}_{i,t}$). The market average fare for each day is calculated following the same process, but without distinguishing among operators. It is remarkable to observe the parallel trends of average prices followed by operators along time. Ave average prices appear above the average industry prices whereas those of Avlo, Ouigo and Iryo lie below the average industry prices. Note also the strong reduction of average prices that occurs in moving from

[4]The curves shown in the figures are smoothed using a LOESS method with a smoothing parameter (span) set to 0.2.

three to four operators. Finally, an ordering can be established so that Ave has the highest average prices, followed by Iryo, then by Avlo and the lowest average prices correspond to Ouigo.

Finally, Tables 3 and 4 display information about the number of services in each route per period and operator. As noted above, each newcomer was awarded a different package, which implies different number of services per day. This is reflected in Period IV data, where we see that Ave plus Avlo offer more trains than Iryo, which in turn offers more trains than Ouigo. Note the significant increase in the supply of train services following the introduction of competition, especially in Madrid-Barcelona which jumps from 14 services per day and direction on average to 40.

Table 1: Passengers in MAD-BCN and MAD-VLC markets (2019-2024)

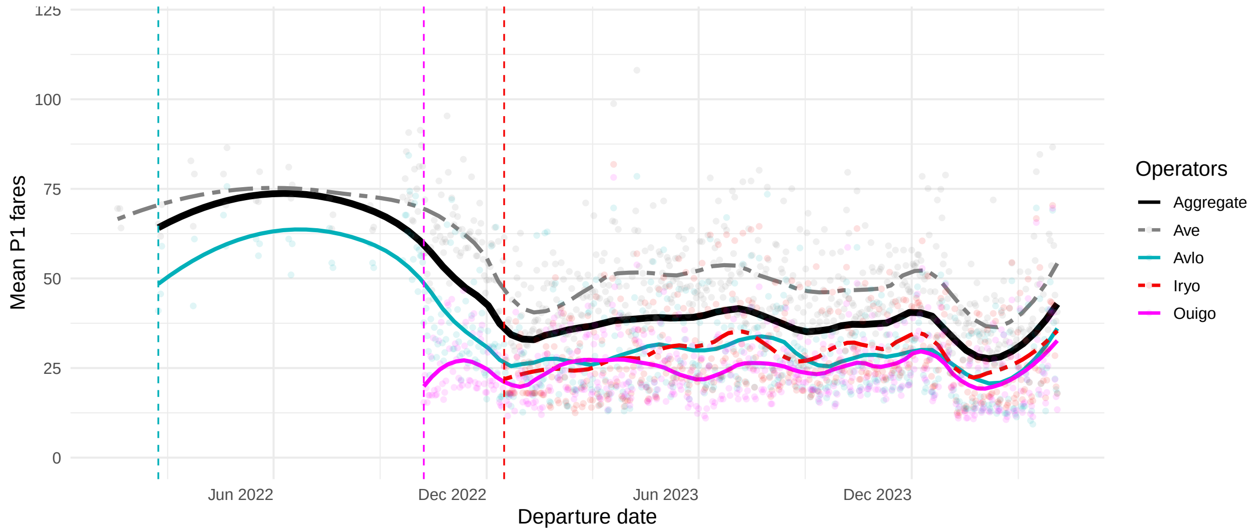
MAD-VLC	2019	2021	2022	2023	2024
Renfe (Ave+Avlo)	2,671,392	1,411,964	2,571,585	2,680,240	2,841,697
Renfe mkt. share	100	100	87.24	52.41	50.68
Ouigo	-	-	368.629	1,206,554	1,402,595
Ouigo mkt. share	-	-	12.51	23.59	25.02
Iryo	-	-	7,602	1,227,410	1,362,308
Iryo mkt. share	-	-	0.26	24.00	24.30
Total	2,671,392	1,411,964	2,947,816	5,114,204	5,606,600
MAD-BCN	2019	2021	2022	2023	2024
Renfe (Ave+Avlo)	8,154,440	4,438,101	7,416,868	7,993,436	8,784,255
Renfe mkt. share	100	79.08	72.39	57.95	60.37
Ouigo	-	1,173,870	2,708,842	2,776,474	2,310,294
Ouigo mkt. share	-	20.92	26.44	20.13	15.88
Iryo	-	-	119,667	3,024,762	3,457,129
Iryo mkt. share	-	-	1.17	21.93	23.76
Total	8,154,440	5,611,971	10,245,377	13,794,672	14,551,678

Source: CNMC

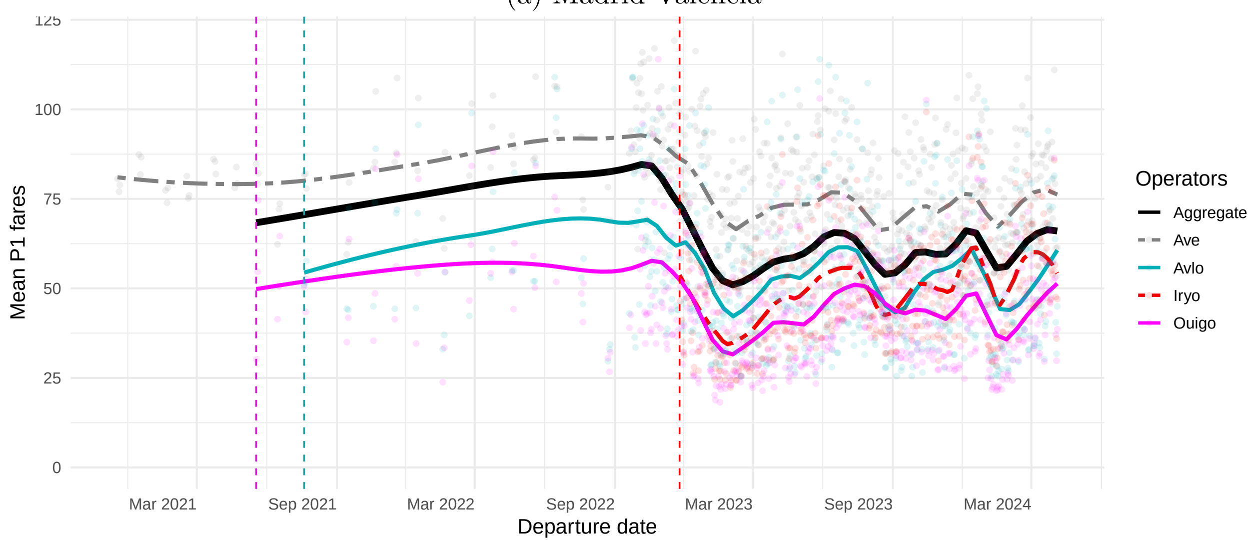
Table 2: P1 fares descriptive statistics per period and route

MAD-VLC	Min.	Median	Mean	Max.	SD
Full sample	7.00	25.00	30.80	268.00	17.82
Period I	22.15	61.75	53.83	77.20	17.13
Period II	15.00	61.75	63.27	115.80	18.14
Period III	7.00	46.30	43.19	139.00	20.78
Period IV	7.00	25.00	29.66	268.00	17.05
MAD-BCN	**Min.**	**Median**	**Mean**	**Max.**	**SD**
Full sample	6.70	46.95	52.09	170.20	27.31
Period I	38.10	72.95	72.42	128.50	18.08
Period II	9.00	64.25	60.09	107.98	23.25
Period III	9.00	68.20	70.92	161.05	30.68
Period IV	6.70	45.50	51.20	170.20	26.82

Source: Own elaboration



(a) Madrid-Valencia



(b) Madrid-Barcelona

Figure 1: Daily P1 fare averaged by operator over time for both routes. Each colored line represents an operator - Ave (grey), Avlo (blue), Iryo (red), and Ouigo (pink). Colored dots indicate the raw daily average P1 fare for each operator. The black, thicker line represents the aggregate market average P1 fare per day. Vertical dashed lines mark the market entry dates of each competitor.

Table 3: Number of train services per direction in the MAD-VLC route

Period	Operator	Median	Mean	SD
I	Ave	13	12.00	1.73
	Aggregate	13	12.00	1.73
II	Ave	9	9.41	1.98
	Avlo	3	2.98	0.15
	Aggregate	12	12.39	1.97
III	Ave	11	10.25	1.97
	Avlo	3	3.00	0.00
	Ouigo	5	5.00	0.00
	Aggregate	19	18.25	1.97
IV	Ave	12	10.80	1.56
	Avlo	3	2.99	0.09
	Iryo	7	6.43	1.97
	Ouigo	3	3.65	0.93
	Aggregate	24	23.87	2.97

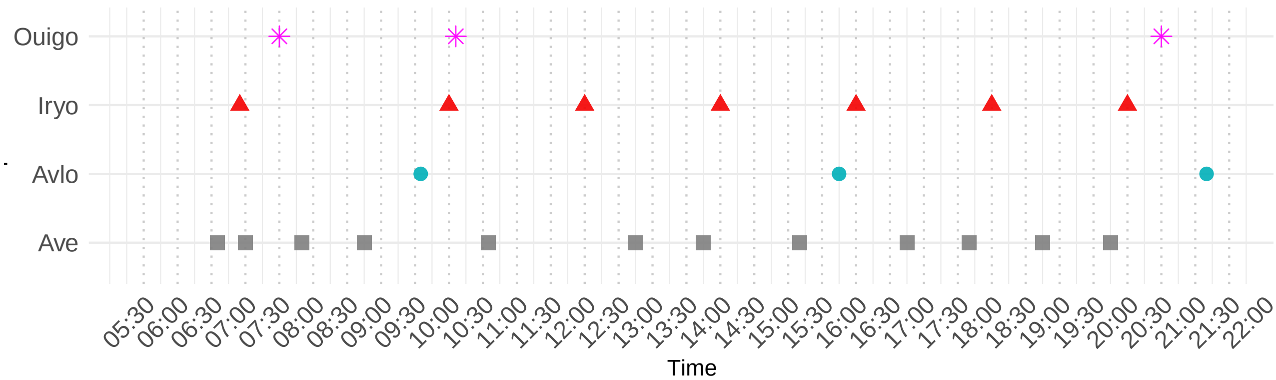
Source: Own elaboration

Table 4: Number of train services per direction in the MAD-BCN route

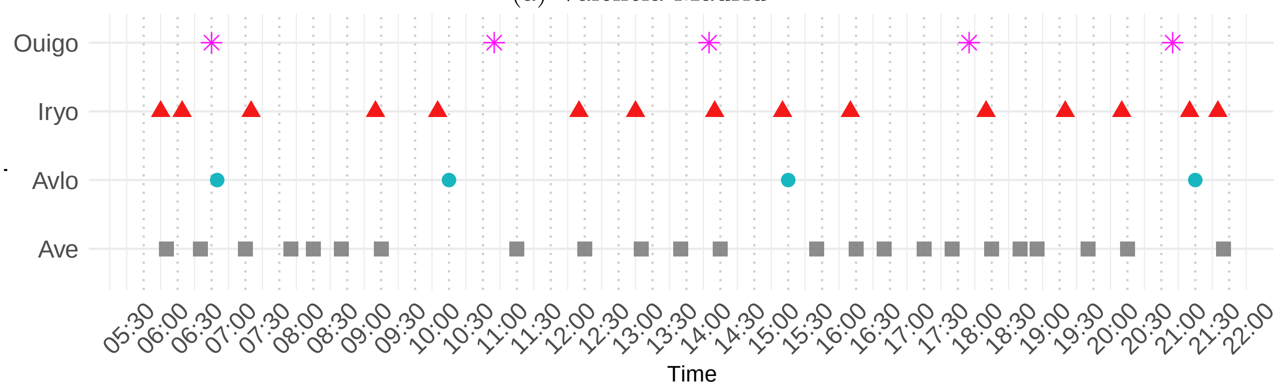
Period	Operator	Median	Mean	SD
I	Ave	14	14	0.49
	Aggregate	14	14	0.49
II	Ave	15	15	1.72
	Ouigo	5	5	0.00
	Aggregate	20	20	1.72
III	Ave	18	17	3.58
	Avlo	4	4	0.56
	Ouigo	5	5	0.31
	Aggregate	27	26	4.40
IV	Ave	21	19	3.57
	Avlo	4	4	0.18
	Iryo	12	12	2.84
	Ouigo	5	5	0.24
	Aggregate	42	40	5.94

Source: Own elaboration

Finally, Figure 2 displays the departure schedules for a representative/typical weekday in Period IV arranged by operator (brand) for each route. Thus, Ave, which provides the highest number of trains per day can schedule services throughout the day, especially at peak times in the morning and the evening. Iryo can also distribute its offer in a rather balanced manner, whereas Ouigo has fewer rolling stock and so is bound to organize its services once a train reaches destination and then returns to origin.



(a) Valencia-Madrid



(b) Barcelona-Madrid

Figure 2: Departure times for a representative day (08-05-2023, Monday)

5 Empirical strategies and discussion of results

As already mentioned, our purpose is to offer evidence about the impact that the introduction of competition in a sequential manner has had on HSR prices and how individual operator's prices change. Our empirical strategy consists of defining a chronological treatment in order to carefully assess the effect on prices of an additional operator at a time. For the Madrid-Valencia route, we have split the sample period into four time windows as follows:

Period I: sample prices for Ave from December 13th 2021 up to February 20th 2022, which is the date when Avlo started operations. This is the time frame with just the incumbent Ave services.

Period II: sample prices for Ave and Avlo running from February 21st 2022 until October 6th 2022. Therefore, it identifies the time frame with two operators.

Period III: sample prices for Ave, Avlo and Ouigo. There are three operators between October 7th 2022 and December 15th 2022.

Period IV: sample prices from December 16th 2022 to April 4th 2024. This is the time frame with all four operators in competition, Ave, Avlo, Ouigo and Iryo.

For the Madrid-Barcelona route the time windows are as follows:

Period I: sample prices for Ave from the beginning of data collection, November 16th 2020, until May 9th 2021.

Period II: sample prices when there were two operators, Ave and Ouigo, between May 10th 2021 and June 22nd 2021.

Period III: sample prices for Ave, Ouigo and Avlo running from June 23rd 2021 and November 24th 2022. This is the time frame with three operators.

Period IV: sample prices from November 25th 2022 until April 4th 2024, the time frame with all four operators.

To evaluate the impact of the introduction of competition and the main determinants of high-speed rail prices, we estimate a generalized linear model with HAC robust errors (using the Newey-West estimator) that allows for the presence of heteroskedasticity and autocorrelation. The dependent variable is the fare P1 of train i departing at time t, the cheapest fare as it is subject to no changes and reimbursement and seat choice is not allowed.[5] The general empirical model, which we adapt for the specific purposes of the analysis throughout this study, is specified as the following equation to be estimated:

[5]As mentioned in the text, there are two more fare types, P2 and P3, that are more flexible and will be considered in some of the regressions to enrich the analysis. It should be noted that Ouigo and Avlo only offer fare P1.

$$
\begin{aligned}
P_{it} = \beta_0 &+ \sum_{j=1}^{3} \beta_j \cdot \text{Entry}_{j,it} + \sum_{j=1}^{J-1} \alpha_j \cdot \text{Operator}_{j,it} + \theta \cdot \text{VLC/BCN}_{it} \\
&+ \gamma_1 \cdot \text{Peak1}_{it} + \gamma_2 \cdot \text{Peak2}_{it} + \gamma_3 \cdot \text{First}_{it} + \gamma_4 \cdot \text{Last}_{it} + \tau_1 \cdot \text{Advance}_{it} + \tau_2 \cdot \text{Advance}^2_{it} \\
&+ \sum_{d=1}^{6} \delta_d \cdot \text{Day}_{d,it} + \sum_{m=1}^{11} \mu_m \cdot \text{Month}_{m,it} + \sum_{m=12}^{22} \mu_m \cdot (\text{Month}_{m,it} \times \text{Weekend}_{it}) + \varepsilon_{it} \qquad (1)
\end{aligned}
$$

Among the key independent variables, the model includes entry dummies that take the value 1 after the day that each operator $j \in \{Avlo, Ouigo, Iryo\}$ enters the market. Entry dates differ by operator and route:

EntryAvlo: is a dummy variable taking the value 1 for observations after February 20th 2022 in Madrid-Valencia, and after June 22nd 2021 in Madrid-Barcelona.

EntryOuigo: is a dummy variable taking the value 1 for observations after October 6th 2022 in Madrid-Valencia, and after May 9th 2021 in Madrid-Barcelona.

EntryIryo: is a dummy variable taking the value 1 for observations after December 15th 2022 Madrid-Valencia, and after November 24th 2022 in Madrid-Barcelona.

The equation also includes dummies that identify each operator observation j, noting that Ave is the reference category, which is omitted from the regression. Specifically, **Avlo** equals 1 for observations associated with Avlo prices, likewise for **Ouigo** and **Iryo**, noting that J denotes the total number of operators in the corresponding period. An origin route dummy takes value 1 indicating whether services run from Valencia (**VLC**) or Barcelona (**BCN**) to Madrid is also included.

To account for systematic price variations in daily schedules, we define time of the day dummies grouping trains in separated periods. We define two peak periods, the remainder of the day is considered off-peak, which is the omitted dummy. We also identify the first and the last train in a day.

Peak1 equals 1 for departures in the morning peak hours. For Madrid-Valencia, morning peak is 7:00-9:30 on weekdays (Saturday and Sunday observations are excluded). For Madrid-Barcelona, the morning peak is 6:15-7:30 on weekdays.

Peak2 equals 1 for departures in the evening peak. For Madrid-Valencia, evening peak is 16:00-19:30 on weekdays. Saturday observations are not considered and the time frame for Sunday observations spans from 16:30-19:30. For Madrid-Barcelona, the evening peak is 17:30-20:00 on weekdays and Sunday.

Last is a dummy variable taking the value 1 for observations of the latest train departure in a day.

First is a dummy variable taking the value 1 for observations of the earliest train departure in a day.

The number of days until departure (**Advance**) and its square (**Advance**^{2}) are considered to capture the well-established fact that buying in advance gives a lower price than buying closer to the departure date. Finally, we include different time effects. In particular, day-of-week effects capturing differences in prices per day of the week, month effects and interaction terms between monthly effects and a weekend indicator (covering Friday to Sunday). Weekend equals 1 when the dependent variable falls on a weekend.

5.1 Results for Madrid-Valencia

In explaining the effects on prices that sequential entry has had, we will run estimates following a Generalized Linear Model with HAC robust errors. Thus, Table 5 shows in column 1 the results corresponding to periods I-II for the Madrid-Valencia route. The estimates are to be interpreted as to what are the effects on prices P1 following the entry of Avlo. That is, we assess the effects in moving from a setting with one operator to a competitive setting with two operators, noting here that the two operators belong to the same railway company Renfe. We find that all coefficients are significant at the one percent level across all estimates provided. Specifically,

- Entry of Avlo has meant an increase in average industry prices of 9.42 euros.
- The average price of Avlo is 15.81 euros lower than that of Ave.
- The average price in the morning peak time is 4.20 euros higher and the one in the evening peak is 8.44 euros higher.

- Buying a ticket in advance results in a reduction of prices until the 35th day before the departure, and from this date prices would increase. The sign of the coefficients of Advance and Advance square suggest a non-linear pattern.

- The earliest train is priced 7.12 euros cheaper on average and the latest train in a day is 2.69 euros cheaper.

For the sake of the presentation, dummies for time effects are not reported in tables although they are typically significant. We would nevertheless like to note that prices are the highest on Friday and Sunday whereas Tuesday is the cheapest day to travel.

Column two in Table 5 shows the results corresponding to periods II and III and so it captures the effects on average prices that arise from the entry of Ouigo. Thus, we have an estimate of what happened in the move from two to three operators, where now we have a third operator different from the existing two operators. Entry of Ouigo pushed prices down by 13.67 euros. It is worth noting that, compared to Ave, average Avlo prices are almost 24 euros cheaper, and average Ouigo prices 32.67 euros cheaper. These results are compatible with the trends displayed in Figure 1a. The other coefficients have the same interpretation as above.

Finally, column three refers to periods III-IV and indicates the effects when moving from three to four operators. Entry of Iryo produced a decrease in average prices of almost 11.50 euros. Compared to Ave, we see that Avlo and Iryo have average fares around 15 euros cheaper, whereas Ouigo average fares are 19.28 euros cheaper. This finding confirms our intuitions and conversations with industry agents that Ouigo is a sort of a low-cost operator that has entered the markets with a strong price strategy. It is worth noting the consistency in the changes in mean prices reported in Table 2 with the estimated price changes show in Table 5. Furthermore, as noted above, Friday and Sunday are the most expensive days to travel and Tuesday is the cheapest. Likewise, December is the most expensive month while September is the cheapest month. Finally, weekends in January and August are cheaper, in contrast to weekends in the rest of the moths where tickets are more expensive.[6]

Once we have established the effects in industry prices with the introduction of competition in the MAD-VLC route, we next explore the price response of individual operators in every

[6]Considering average fares for each operator per day as defined above to draw Figure 1, we have re-run colunms 2 an 3 of Table 5 obtaining similar results regarding the entry effects induced by Ouigo and Iryo operators, respectively (see Table 19 in the Appendix).

Table 5: MAD-VLC route. Effect of successive entry on P1 fares

	Period I-II	Period II-III	Period III-IV
Constant	67.77^{***}	71.83^{***}	60.18^{***}
	(0.92)	(0.73)	(0.14)
EntryAvlo	9.42^{***}		
	(1.14)		
EntryOuigo		-13.67^{***}	
		(0.67)	
EntryIryo			-11.44^{***}
			(0.10)
Avlo	-15.81^{***}	-23.95^{***}	-15.40^{***}
	(0.80)	(0.22)	(0.07)
Ouigo		-32.67^{***}	-19.28^{***}
		(0.14)	(0.06)
Iryo			-15.17^{***}
			(0.05)
VLC	-0.77	0.15	0.65^{***}
	(0.71)	(0.14)	(0.04)
Peak1	4.20^{***}	2.22^{***}	2.22^{***}
	(0.87)	(0.21)	(0.08)
Peak2	8.44^{***}	10.06^{***}	7.96^{***}
	(0.88)	(0.17)	(0.05)
First	-7.12^{***}	-6.23^{***}	-7.09^{***}
	(1.22)	(0.40)	(0.14)
Last	-2.69^{*}	-4.63^{***}	-5.73^{***}
	(1.34)	(0.34)	(0.10)
Advance	-1.39^{***}	-0.56^{***}	-0.81^{***}
	(0.17)	(0.03)	(0.01)
Advance^2	0.02^{***}	0.01^{***}	0.01^{***}
	(0.01)	(0.00)	(0.00)
Num. obs.	2,129	79,507	975,661
Log Likelihood	$-8,264.86$	$-315,287.29$	$-3,873,936.63$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

route and time window. Table 6 considers Ave fare types P1, P2 and P3 as the dependent variable. Estimation results refer to periods I and II. As expected, the results displayed in column one for P1 fares are similar to those reported in column one of Table 5. Note that the entry of Avlo implied stronger increases in P2 and P3 average prices – twelve and seventeen euros, respectively. Differently, there is a gap in average prices of Ave and Avlo reflecting the difference in service quality as well as the pricing behavior of a multi-brand monopolist. Ave offers far more train services per day than Avlo, which reduces schedule delay and positions Ave brand as of a higher quality than the Avlo brand. The effect of advance purchase is larger for fare P3. Coefficients for First and Last are non-significant for fares P2. Note that periods I and II have a low number of observations where Renfe operates these train schedules. Column four, and as an estimate check, takes Avlo prices as the dependent variable. It can be seen that the constant is 56.81 euros, below any of Ave constants, and the earliest train prices are fairly cheaper by some twelve euros.

Table 6: MAD-VLC route. Effect on prices of Avlo's entry

	P1 Ave	P2 Ave	P3 Ave	P1 Avlo
Constant	68.06^{***}	76.50^{***}	112.67^{***}	56.81^{***}
	(0.96)	(1.11)	(1.79)	(2.72)
EntryAvlo	10.50^{***}	11.91^{***}	17.26^{***}	
	(1.20)	(1.28)	(1.93)	
VLC	-0.09	-0.48	-1.43	-7.13^{***}
	(0.77)	(0.85)	(1.25)	(1.70)
Peak1	2.30^{*}	2.62^{*}	3.23^{*}	14.93^{***}
	(0.94)	(1.04)	(1.56)	(2.10)
Peak2	6.73^{***}	6.73^{***}	9.66^{***}	14.96^{***}
	(0.93)	(1.01)	(1.55)	(1.83)
First	-3.39^{*}	-2.84	-7.26^{***}	-11.93^{***}
	(1.42)	(1.66)	(2.08)	(1.47)
Last	-0.14	-0.58	-5.15^{*}	-0.31
	(1.66)	(1.69)	(2.37)	(2.03)
Advance	-1.30^{***}	-1.44^{***}	-1.84^{***}	-1.85^{***}
	(0.18)	(0.19)	(0.28)	(0.34)
Advance^2	0.01^{**}	0.02^{**}	0.02^{*}	0.03^{**}
	(0.01)	(0.01)	(0.01)	(0.01)
Num. obs.	$1,674$	$1,705$	$1,666$	455
Log Likelihood	$-6,448.41$	$-6,783.81$	$-7,265.47$	$-1,725.94$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Considering the price effects in moving from two to three operators, Table 7 shows estimates on prices of Ave as per fare type following Ouigo's entry. The fact that the third operator is now different from Renfe supposes lower average prices, 11.17 euros for P1 fares, 10.96 euros for fare P2 and 11.07 euros for fare P3. The rest of the coefficients keep the same sign as before, where the morning peak effect is smaller for fares P1 and P2. The effect of competition is also reflected in the size of the linear term of the advance purchase effect, which also diminishes, it ranges from seventy cents of euro to one euro twenty-two cents per day. However, and relative to Table 6, we can see that average fare types of Ave happen to be around four to six euros higher following Ouigo's entry. This is indirect evidence of the asymmetry in service quality provided by Ave and Ouigo.

Table 7: MAD-VLC route. Effect on Ave prices of Ouigo's entry

	P1 Ave	P2 Ave	P3 Ave
Constant	72.34^{***}	82.05^{***}	118.51^{***}
	(0.85)	(0.91)	(1.21)
EntryOuigo	-11.17^{***}	-10.96^{***}	-11.07^{***}
	(0.74)	(0.81)	(1.11)
VLC	-0.34	-0.15	0.92^{***}
	(0.20)	(0.20)	(0.23)
Peak1	1.26^{***}	1.59^{***}	3.92^{***}
	(0.28)	(0.28)	(0.28)
Peak2	10.72^{***}	10.77^{***}	12.69^{***}
	(0.23)	(0.24)	(0.28)
First	1.49^{**}	1.69^{***}	-0.40
	(0.47)	(0.48)	(0.50)
Last	-3.29^{***}	-2.98^{***}	-4.42^{***}
	(0.60)	(0.58)	(0.62)
Advance	-0.71^{***}	-0.89^{***}	-1.22^{***}
	(0.04)	(0.04)	(0.04)
Advance^2	0.01^{***}	0.01^{***}	0.02^{***}
	(0.00)	(0.00)	(0.00)
Num. obs.	$45,098$	$45,527$	$45,323$
Log Likelihood	$-181,864.23$	$-184,727.44$	$-188,757.77$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

The analysis of the consequences on prices in the move from two to three operators is completed in Table 8 by having Avlo and Ouigo prices as dependent variables. Thus, column one reports the estimates to capture the price response of Avlo to Ouigo's entry; Avlo prices went down by 15.76 euros. This effect is stronger than the one on Ave prices shown in column one of Table 7. These results suggest that the effect of Ouigo competition mainly affects Avlo, which offer similar services, e.g. low frequencies, they do not carry a cafeteria car and so on. The constant in column two of Table 8 (20.62), is an indication of the aggressive price strategy of Ouigo against competitors. The sign of the rest of the coefficients are similar to those in previous tables.

Table 8: MAD-VLC route. Effect on prices of Ouigo's Entry

	P1 Avlo	P1 Ouigo
Constant	50.60^{***}	20.62^{***}
	(1.41)	(0.35)
EntryOuigo	-15.76^{***}	
	(1.30)	
VLC	-6.12^{***}	-0.40^{*}
	(0.43)	(0.17)
Peak1	13.73^{***}	0.29
	(0.66)	(0.22)
Peak2	13.24^{***}	7.97^{***}
	(0.41)	(0.24)
First	-16.56^{***}	-0.00
	(0.44)	(0.99)
Last	-2.80^{***}	3.13^{***}
	(0.54)	(0.49)
Advance	-0.74^{***}	-0.13^{***}
	(0.06)	(0.03)
Advance^2	0.01^{***}	-0.00
	(0.00)	(0.00)
Num. obs.	13,104.00	21,305.00
Log Likelihood	$-51,424.05$	$-76,488.49$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

The sequential entry analysis finalizes with the estimates corresponding to periods III and IV. Therefore, Tables 9 and 10 are analogous to Tables 7 and 8 above, and are meant to capture the price effects of Iryo's entry. Table 9 looks at the effects on average prices of Ave per fare type. The competition of one more operator implies price reductions of 17.80 euros on P1 fares, of 19.23 euros on P2 fares, and of 25.13 euros on P3 fares. The magnitude of such price responses allows us to conclude that Renfe considers Iryo a fairly direct competitor in terms of service quality compared to Ouigo, and hence, price reductions are more important with Iryo's entry. Another result that merits attention is that now the change from three to four operators implies price decreases in both the earliest and the latest trains. We conjecture that this may obey to more intense competition in this period of the day which leads operators to fight for more price sensitive customers. The comparison of the values of constants in Tables 7 and 9 once again confirms that there is a price decrease in all fare types as the number of competitors increases. Friday and Sunday are the most expensive days and June the most expensive month, while Tuesday and September are the cheapest for P1 fares.

Table 9: MAD-VLC route. Effect on Ave prices of Iryo's Entry

	P1 Ave	P2 Ave	P3 Ave
Constant	69.24^{***}	79.20^{***}	116.37^{***}
	(0.21)	(0.23)	(0.25)
EntryIryo	-17.80^{***}	-19.23^{***}	-25.13^{***}
	(0.13)	(0.13)	(0.16)
VLC	-0.03	0.28^{***}	0.63^{***}
	(0.08)	(0.08)	(0.09)
Peak1	2.69^{***}	3.08^{***}	3.25^{***}
	(0.12)	(0.12)	(0.14)
Peak2	9.85^{***}	10.05^{***}	10.63^{***}
	(0.09)	(0.09)	(0.11)
First	-3.25^{***}	-3.76^{***}	-3.66^{***}
	(0.27)	(0.28)	(0.29)
Last	-6.09^{***}	-6.79^{***}	-8.86^{***}
	(0.17)	(0.19)	(0.20)
Advance	-1.04^{***}	-1.16^{***}	-1.50^{***}
	(0.01)	(0.02)	(0.02)
Advance^2	0.01^{***}	0.02^{***}	0.02^{***}
	(0.00)	(0.00)	(0.00)
Num. obs.	$446,948$	$450,034$	$446,559$
Log Likelihood	$-1,844,034.09$	$-1,892,964.67$	$-1,926,788.08$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Finally, Table 10 takes P1 fares of Avlo (column one), Ouigo (column two) and Iryo (column three) as the dependent variable. We may therefore see the effect of entry on each operator prices. It is worth noting that Ouigo – whose service is differentiated from that of the last entrant – just decreases its average price by 1.05 euros. Iryo earned a package with more train services than Ouigo, which together with other features (cafeteria, number of suitcases allowed and so on) positions Iryo as of a higher service quality. The size of price reductions discloses that Iryo's entry affects Ave prices by more than Avlo and Ouigo prices. We would like to draw attention to the significant price reductions in the first and last Avlo trains. Iryo also lowers the prices of the earliest and the latest trains, whereas this behavior is not followed by Ouigo as it increases the average price of its latest train service.

Table 10: MAD-VLC route. Effect on prices of Iryo's Entry

	P1 Avlo	P1 Ouigo	P1 Iryo
Constant	39.45^{***}	24.48^{***}	33.44^{***}
	(0.29)	(0.18)	(0.17)
EntryIryo	-6.84^{***}	-1.05^{***}	
	(0.20)	(0.12)	
VLC	-0.95^{***}	1.53^{***}	0.58^{***}
	(0.11)	(0.08)	(0.07)
Peak1	8.39^{***}	0.83^{***}	3.38^{***}
	(0.45)	(0.08)	(0.14)
Peak2	9.59^{***}	7.42^{***}	5.00^{***}
	(0.13)	(0.11)	(0.08)
First	-10.66^{***}	-0.80	-6.61^{***}
	(0.14)	(0.87)	(0.30)
Last	-5.34^{***}	3.27^{***}	-4.76^{***}
	(0.23)	(0.56)	(0.12)
Advance	-0.75^{***}	-0.38^{***}	-0.74^{***}
	(0.02)	(0.01)	(0.01)
Advance^2	0.01^{***}	0.00^{***}	0.01^{***}
	(0.00)	(0.00)	(0.00)
Num. obs.	124,969	160,146	243,598
Log Likelihood	$-470,214.37$	$-584,487.16$	$-905,224.34$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

5.2 Results for Madrid-Barcelona

We follow a similar approach to that used in Madrid-Valencia route. In order to characterize this sequential process, the periods in Madrid-Barcelona are the ones described in Section 4 above.

We start by looking at the effects of sequential entry on prices in Table 11, where the dependent variable (as in Table 5 for Madrid-Valencia) is the basic fare P1. As earlier explained, the identity of entrants in the sequential process is different. Now in Madrid-Barcelona, we find that Ouigo is the first entrant in the market on May 10th 2021, although Avlo quickly entered in the next month. Regarding the analysis for periods I and II, where the effects of Ouigo's entry are analyzed, these are the most relevant comments:

- Entry of Ouigo reduced the average price in the industry by 8.28 euros. However, Ouigo prices are 29.28 euros smaller than prices set by Ave.
- The variables Advance and Advance square suggest that there is a non-linear pattern. In fact, prices would decrease until the 27th day before departure, and from this date on prices would increase.
- The prices for the first train are smaller by 8.22 euros, while the effect for the last train is non-significant.
- Unlike the route Madrid-Valencia, Peak1 has a non-significant effect, while the effect of Peak2 is to increase prices by 13.05 euros.

In column 2 corresponding to Period II-III we assess the effects produced by the entry of Avlo. We must remark that Avlo's entry increases the industry price by 20.04 euros. At the same time, Ouigo prices and Avlo prices are, respectively, 36.15 and 26.37 euros cheaper than Ave prices in this period. Advance and Advance square coefficients are similar to those obtained in period I-II, but the minimum price is obtained 61 days ahead of the train departure, suggesting that, within the full 40-day range, prices tend to increase when the departure day is closer. And now prices for Peak1 and Peak2 are larger by 7.81 and 10.23 euros, respectively. Note as well that trains with origin in Barcelona are 1.20 euros cheaper. Most of these results, especially those indicating the effect of Ouigo's entry, are similar to those obtained in Madrid-Valencia. Further note that prices are more expensive on Friday and Sunday in both routes; May and October appear as the most expensive months to travel. Weekend prices are

Table 11: MAD-BCN route. Effect of successive entry on P1 fares

	Period I-II	Period II-III	Period III-IV
Constant	80.08^{***}	65.43^{***}	96.38^{***}
	(1.91)	(2.00)	(0.19)
EntryOuigo	-8.28^{***}		
	(2.43)		
EntryAvlo		20.04^{***}	
		(1.31)	
EntryIryo			-14.87^{***}
			(0.14)
Ouigo	-29.28^{***}	-36.15^{***}	-26.58^{***}
	(2.15)	(0.28)	(0.07)
Avlo		-26.37^{***}	-21.01^{***}
		(0.35)	(0.09)
Iryo			-23.29^{***}
			(0.06)
BCN	3.34^{***}	-1.20^{***}	0.32^{***}
	(1.01)	(0.23)	(0.05)
Peak1	-0.40	7.81^{***}	9.13^{***}
	(1.35)	(0.37)	(0.09)
Peak2	13.05^{***}	10.23^{***}	9.93^{***}
	(1.19)	(0.29)	(0.07)
First	-8.22^{***}	-13.24^{***}	-9.30^{***}
	(2.21)	(0.83)	(0.14)
Last	-0.04	-7.88^{***}	-16.47^{***}
	(1.78)	(0.59)	(0.17)
Advance	-1.10^{***}	-1.23^{***}	-0.90^{***}
	(0.28)	(0.04)	(0.01)
Advance^2	0.02^{*}	0.01^{***}	0.01^{***}
	(0.01)	(0.00)	(0.00)
Num. obs.	$1,327$	$71,124$	$1,594,546$
Log Likelihood	$-5,429.14$	$-318,932.12$	$-7,072,572.48$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

typically smaller.

The results for period III-IV in Table 11 show that Iryo's entry reduced the average prices by 14.87 euros. Ouigo, Avlo and Iryo prices are smaller than Ave prices by 26.58, 21.01 and 23.29 euros, respectively.[7]

Table 12 indicates how Ave prices react to Ouigo's entry in periods I-II. In this period there are not enough data for fare P3, the most expensive but more flexible fare. Note that P1 fares of Ave decreased by 8.27 euros, but P2 fares increased by 4.77 euros. It is obvious that Renfe competes with Ouigo using P1 fares while widening the difference with P2 fares. Although with a reduced number of observations, we estimate the determinants of Ouigo's price. In this case trains with origin Barcelona are more expensive, and the coefficient for Advance is not statistically significant.

[7] Similarly to the Madrid-Valencia route, Table 20 in the Appendix shows the entry effects induced by Avlo and Iryo operators, respectively, for the average prices per operator and day.

Table 12: MAD-BCN route. Effect on prices of Ouigo's entry

	P1 Ave	P2 Ave	P1 Ouigo
Constant	79.59^{***}	101.12^{***}	42.31^{***}
	(1.95)	(2.24)	(3.31)
EntryOuigo	-8.27^{**}	4.77^{*}	
	(2.63)	(2.32)	
BCN	2.84^{**}	2.11	7.01^{***}
	(1.05)	(1.24)	(1.61)
Peak1	0.02	4.12^{*}	-6.30
	(1.44)	(1.64)	(3.47)
Peak2	13.43^{***}	16.13^{***}	9.45^{***}
	(1.29)	(1.38)	(1.84)
First	-8.03^{***}	-10.01^{***}	
	(2.25)	(2.08)	
Last	-1.09	-4.81^{*}	2.53
	(2.11)	(2.43)	(2.39)
Advance	-1.08^{***}	-2.83^{***}	0.99
	(0.30)	(0.32)	(0.72)
Advance^2	0.02^{*}	0.06^{***}	-0.05^{*}
	(0.01)	(0.01)	(0.02)
Num. obs.	1207	$1,191$	120
Log Likelihood	$-4,953.20$	$-5,009.52$	-423.49

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 13 shows the analysis of period II-III considering the effects of Avlo's entry on P1 and P2 fares of Ave. In particular, the entry of Avlo increases P1 Ave by 21.06 euros and P2 Ave by 12.84 euros. The rest of the estimated coefficients have the same signs, indicating similar conclusions to the comments of previous tables. Positive coefficients for Peak1 and Peak2 are obtained. Also coefficients for Advance and Advance square indicate that the minimum price is found for a day before the data collection of forty days in advance was started.

Table 14 reports the effects of Avlo's entry on Ouigo prices in period II-III. Note in column one that Avlo's entry increased Ouigo prices by 15.52 euros. This result may seem surprising but note that Avlo's entry provoked an increase of Ave prices (P1 fare) by 21.06 euros, and this rise allowed Ouigo to increase its prices too but to a lower extent. Comparing results of both columns, note that the constant for Avlo is almost twice that of Ouigo. This indicates that, on average, Avlo prices are significantly higher than Ouigo prices, which are below Ave; this is consistent with the trends of average fares displayed in Figure 1b. In these estimates, note that Peak2 is positive, indicating that Ouigo and Avlo increase the prices in this time of the day. The first and last train are cheaper, but especially in the case of Avlo trains. The first and last train is 19.90 and 12.84 euros cheaper, respectively.

Table 13: MAD-BCN route. Effect on Ave prices of Avlo's Entry

	P1 Ave	P2 Ave
Constant	60.42^{***}	85.73^{***}
	(2.56)	(2.87)
EntryAvlo	21.06^{***}	12.84^{***}
	(1.57)	(1.52)
BCN	-1.15^{***}	-1.03^{**}
	(0.30)	(0.33)
Peak1	8.14^{***}	7.59^{***}
	(0.41)	(0.44)
Peak2	10.33^{***}	8.22^{***}
	(0.36)	(0.38)
First	-6.58^{***}	-2.82
	(1.72)	(1.47)
Last	-26.87^{***}	-27.19^{***}
	(1.66)	(2.11)
Advance	-0.94^{***}	-1.12^{***}
	(0.05)	(0.06)
Advance^2	0.01^{***}	0.01^{***}
	(0.00)	(0.00)
Num. obs.	46,978	49,335
Log Likelihood	$-211,937.57$	$-226,928.62$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 14: MAD-BCN route. Effect on prices of Avlo's Entry

	P1 Ouigo	P1 Avlo
Constant	38.77^{***}	74.18^{***}
	(2.58)	(2.76)
EntryAvlo	15.52^{***}	
	(1.78)	
BCN	-0.21	-4.65^{***}
	(0.38)	(0.56)
Peak1	1.79^{**}	
	(0.69)	
Peak2	6.90^{***}	11.07^{***}
	(0.52)	(0.59)
First	-5.69	-19.90^{***}
	(6.04)	(0.85)
Last	-2.76^{***}	-12.84^{***}
	(0.62)	(1.02)
Advance	-1.52^{***}	-2.21^{***}
	(0.07)	(0.10)
Advance^2	0.02^{***}	0.03^{***}
	(0.00)	(0.00)
Num. obs.	13,948	10,198
Log Likelihood	$-59,511.55$	$-45,528.75$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 15 reports the effects in period III-IV of Iryo's entry on Ave prices. Now we have information for the three fare types of Ave prices. Firstly, note that entry of Iryo reduced fare P1 even a little bit more than fare P2. Prices with origin Barcelona are slightly more expensive. Peak1 and Peak2 all have positive signs, indicating that Renfe increases prices at these times of the day. We must stress that prices for the last Ave train notably decrease by around 25 euros. The daily dummies indicate that Ave prices are more expensive on Friday and Sunday. December is the most expensive month while August is the cheapest.

Table 16 shows the results of Iryo's entry on Ouigo and Avlo prices in period III-IV (also the determinants for Iryo price are estimated). Entry of Iryo reduced Ouigo price by 7.68 euros and Avlo price by 10.92 euros. The coefficients for Peak1 and Peak2 are different from the estimates for Ave prices in Table 15. Now the effects are smaller, Peak2 always has positive effect, while Peak1 shows a negative effect for Ouigo. The coefficients for Advance and Advance square are qualitatively similar, however, Iryo price is the fare that allows customers to obtain the lowest price the further in advance of purchase.

As a robustness exercise, we transformed prices in logarithms in order to check our results. For the sake of presentation, only equations corresponding to Tables 5 and 11 are displayed in the Appendix (see Tables 17 and 18) although all estimates have been re-run. Note that in this case, the dependent variable denotes the operators' prices and coefficients must be interpreted as percentage variations. As commented before, entry of newcomers (Ouigo and Iryo) reduced prices to a higher extent in Madrid-Valencia than in Madrid-Barcelona. In particular, the entry of Ouigo and then Iryo decreased industry prices by 24.5% and 29.7%, respectively, in Madrid-Valencia, while they decreased by 9.2% and 24.3% in Madrid-Barcelona. However, Avlo's entry had a different impact, because it increased industry prices by 15.3% in Madrid-Valencia, and by 29.4% in Madrid-Barcelona. All these results reinforce the conclusion that the entry of Renfe's low-cost operator notably reduced the final decrease of prices in the industry provoked by the entry of the newcomers.

Table 15: MAD-BCN route. Effect on Ave prices of Iryo's Entry

	P1 Ave	P2 Ave	P3 Ave
Constant	98.78^{***}	119.35^{***}	170.52^{***}
	(0.30)	(0.32)	(0.41)
EntryIryo	-17.18^{***}	-16.54^{***}	-25.05^{***}
	(0.19)	(0.20)	(0.30)
BCN	0.55^{***}	0.43^{***}	0.32^{**}
	(0.10)	(0.10)	(0.12)
Peak1	12.17^{***}	10.60^{***}	14.58^{***}
	(0.14)	(0.14)	(0.18)
Peak2	12.02^{***}	9.52^{***}	9.86^{***}
	(0.11)	(0.11)	(0.14)
First	-5.45^{***}	0.69	-3.19^{***}
	(0.59)	(0.58)	(0.57)
Last	-22.89^{***}	-24.80^{***}	-27.64^{***}
	(0.22)	(0.24)	(0.29)
Advance	-0.88^{***}	-1.27^{***}	-1.31^{***}
	(0.02)	(0.02)	(0.02)
Advance^2	0.01^{***}	0.01^{***}	0.01^{***}
	(0.00)	(0.00)	(0.00)
Num. obs.	$751,775$	$796,331$	$781,969$
Log Likelihood	$-3,474,558.58$	$-3,746,934.47$	$-3,768,454.86$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 16: MAD-BCN route. Effect on prices of Iryo's Entry

	P1 Avlo	P1 Ouigo	P1 Iryo
Constant	78.39^{***}	59.34^{***}	57.20^{***}
	(0.50)	(0.33)	(0.18)
EntryIryo	-10.92^{***}	-7.68^{***}	
	(0.32)	(0.23)	
BCN	-0.45^{**}	-0.80^{***}	0.49^{***}
	(0.16)	(0.10)	(0.07)
Peak1		-2.12^{***}	5.52^{***}
		(0.16)	(0.10)
Peak2	11.77^{***}	4.93^{***}	6.85^{***}
	(0.18)	(0.12)	(0.08)
First	-12.39^{***}	-17.62^{***}	-7.46^{***}
	(0.26)	(0.27)	(0.14)
Last	-16.86^{***}	-1.70^{***}	-5.05^{***}
	(0.43)	(0.32)	(0.19)
Advance	-1.43^{***}	-0.72^{***}	-0.83^{***}
	(0.03)	(0.02)	(0.01)
Advance^2	0.02^{***}	0.01^{***}	0.01^{***}
	(0.00)	(0.00)	(0.00)
Num. obs.	158,251	209,721	474,799
Log Likelihood	−678,607.54	−849,300.64	−1,935,633.59

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

6 Conclusions and policy implications

The paper has estimated the effects on prices of the successive entry of different rail operators in the HSR routes Madrid-Valencia and Madrid-Barcelona, as well as the price responses of each operator individually. We have used a very large data set of prices obtained by a web crawler programme, where prices of the different trains and operators were collected and registered daily with a maximum advance purchase of forty days. Results for both routes are qualitatively similar, although the price decreases provoked by the entry of Ouigo and then Iryo were smaller in relative terms in Madrid-Barcelona. Entry was much more aggressive with stronger reductions in prices in the Madrid-Valencia route. In particular, the entry of Ouigo and subsequently Iryo reduced rail prices by 13.67 and 11.44 euros in Madrid-Valencia, and 8.28 and 14.87 euros in Madrid-Barcelona. However, Avlo's entry increased rail prices by 9.42 and 20.04 euros in Madrid-Valencia and Madrid-Barcelona, respectively. Also price reactions of incumbent Ave to entry have been identified. So, Ave reduces its prices by more with the entry of Iryo (17.80 euros in Madrid-Valencia and 17.18 euros in Madrid-Barcelona for P1 fare) than with the entry of Ouigo (11.17 euros in Madrid-Valencia and 8.17 euros in Madrid-Barcelona for P1 fare). In fact, Ave increases its P2 fare following Ouigo's entry by 4.77 euros in Madrid-Barcelona. These results suggest that Ave considers competition from Iryo more important than competition from Ouigo. This is why Ave reduces its prices by more after Iryo's entry.At the same time Ouigo reduced its price by 1.05 euros in Madrid-Valencia and 7.68 in Madrid-Barcelona after the entry of Iryo. However, Avlo reduced its price by 6.84 euros in Madrid-Valencia and 10.92 in Madrid-Barcelona when there are four operators. Other interesting results suggest a non-linear pattern in the pricing system depending on the purchase date. Prices increase when the departure date of the train is close, but the minimum price is never obtained with a shorter lead time of at least 30 days. It is interesting to stress that travelling is more expensive on Sunday and Friday. Therefore, our analysis unveils part of operators' business practices in facing an increase in the number of competitors.

Some policy implications and interesting lessons can be reached from our paper. It is important to stress that open access in HSR Spanish markets has been beneficial for consumers in terms of lower prices and more trains. However, these impacts on prices and train numbers are short-term effects where price falls might not be sustained in the medium to long term. The entry of operators offering different service qualities has clearly segmented the market into two types: a higher quality segment characterized by a higher number of trains and better service quality, and a lower quality segment with a reduced number of trains and lower service quality. This segmentation could be particularly beneficial in very elastic markets, especially in routes with a high number of tourist or leisure travellers, as the MAD-VLC market.

In fact, our paper shows evidence that entry by a low-cost operator, belonging to the rail incumbent, is an instrument to discriminate prices between the high quality services offered (Ave) and the additional low quality service brand(Avlo). This effect is independent of the sequence of entry, i.e. whether it happens before or after the entry of other entrants.

There are some caveats and limitations in our paper. The first limitation is the impact on the stability of the industry of the falls in prices. These provoke higher increases in rail demand especially in the more elastic markets, like in Madrid-Valencia where the entry of new operators has doubled the rail traffic since 2019. However, we do not have the appropriate information to evaluate the profitability, especially in the long run, of the different operators. In this matter, how the access fees are set by the infrastructure manager becomes crucial, as they can be an element affecting the economic sustainability of the different operators in a relevant way.

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A Appendix: Robustness

A.1 Estimation using log of prices

Table 17: MAD-VLC route. Effect of successive entry on log(P1) fares.

	Period I-II	Period II-III	Period III-IV
Constant	4.203^{***}	4.279^{***}	4.276^{***}
	(0.018)	(0.014)	(0.004)
EntryAvlo	0.153^{***}		
	(0.018)		
EntryOuigo		-0.245^{***}	
		(0.012)	
EntryIryo			-0.297^{***}
			(0.002)
Avlo	-0.287^{***}	-0.602^{***}	-0.534^{***}
	(0.016)	(0.006)	(0.002)
Ouigo		-0.887^{***}	-0.644^{***}
		(0.004)	(0.002)
Iryo			-0.518^{***}
			(0.002)
VLC	-0.010	0.012^{***}	0.023^{***}
	(0.013)	(0.004)	(0.001)
Peak1	0.078^{***}	0.070^{***}	0.095^{***}
	(0.015)	(0.005)	(0.002)
Peak2	0.132^{***}	0.232^{***}	0.239^{***}
	(0.015)	(0.004)	(0.002)
First	-0.156^{***}	-0.213^{***}	-0.310^{***}
	(0.026)	(0.014)	(0.005)
Last	-0.065^{*}	-0.144^{***}	-0.216^{***}
	(0.026)	(0.009)	(0.004)
Advance	-0.021^{***}	-0.011^{***}	-0.024^{***}
	(0.003)	(0.001)	(0.000)
Advance^2	0.000^{*}	0.000^{***}	0.000^{***}
	(0.000)	(0.000)	(0.000)
Num. obs.	$2,129$	$79,507$	$975,661$
Log Likelihood	$-8,252.42$	$-316,041.47$	$-3,721,384.04$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 18: MAD-BCN route. Effect of successive entry on log(P1) fares.

	Period I-II	Period II-III	Period III-IV
Constant.	4.394^{***}	4.190^{***}	4.760^{***}
	(0.034)	(0.033)	(0.003)
EntryOuigo	-0.092^{*}		
	(0.039)		
EntryAvlo		0.294^{***}	
		(0.023)	
EntryIryo			-0.243^{***}
			(0.002)
Ouigo	-0.630^{***}	-0.632^{***}	-0.541^{***}
	(0.059)	(0.005)	(0.002)
Avlo		-0.442^{***}	-0.425^{***}
		(0.006)	(0.002)
Iryo			-0.478^{***}
			(0.001)
BCN	0.061^{***}	-0.017^{***}	0.005^{***}
	(0.018)	(0.004)	(0.001)
Peak1	-0.001	0.123^{***}	0.192^{***}
	(0.023)	(0.005)	(0.002)
Peak2	0.195^{***}	0.144^{***}	0.184^{***}
	(0.020)	(0.004)	(0.001)
First	-0.129^{**}	-0.257^{***}	-0.251^{***}
	(0.041)	(0.017)	(0.003)
Last	0.009	-0.163^{***}	-0.365^{***}
	(0.037)	(0.013)	(0.004)
Advance	-0.023^{***}	-0.018^{***}	-0.017^{***}
	(0.005)	(0.001)	(0.000)
Advance^2	0.000^{**}	0.000^{***}	0.000^{***}
	(0.000)	(0.000)	(0.000)
Num. obs.	$1,327$	$71,124$	$1,594,546$
Log Likelihood	$-5,610.48$	$-320,733.51$	$-6,932,933.44$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

A.2 Estimation using mean per day prices

Table 19: MAD-VLC route. Effect of successive entry on mean P1 fares.

	Period II-III	Period III-IV
Constant	68.034^{***}	57.846^{***}
	(2.737)	(1.408)
EntryOuigo	-16.602^{***}	
	(2.241)	
EntryIryo		-13.136^{***}
		(1.143)
Avlo	-22.147^{***}	-18.720^{***}
	(1.062)	(0.604)
Ouigo	-32.856^{***}	-23.380^{***}
	(1.057)	(0.598)
Iryo		-18.145^{***}
		(0.549)
VLC	0.194	0.493
	(0.882)	(0.415)
Num. obs.	565	4,373
Log Likelihood	$-1,963.634$	$-15,835.117$

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 20: MAD-BCN route. Effect of successive entry on mean P1 fares.

	Period II-III	Period III-IV
Constant	59.561^{***}	94.776^{***}
	(4.449)	(1.483)
EntryAvlo	23.779^{***}	
	(3.937)	
EntryIryo		-14.598^{***}
		(0.959)
Ouigo	-35.734^{***}	-30.605^{***}
	(1.454)	(0.689)
Avlo	-22.097^{***}	-19.263^{***}
	(1.891)	(0.764)
Iryo		-24.003^{***}
		(0.730)
BCN	-1.052	-0.477
	(1.414)	(0.529)
Num. obs.	627	4579
Log Likelihood	-2530.199	-18364.616

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$