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Keywords: HSR; Intermodal competition; Multiproduct firms' strategies; Low-cost transportation; France



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Abstract

This paper provides an empirical analysis of the determinants of service prices and frequencies of conventional high-speed rail (HSR) in France. We use original data for the period 09/2019-03/2020 and consider the intensity of intermodal competition and the diversification strategy of the incumbent rail operator. The main econometric results show that the determinants of the price per kilometer of conventional HSR services (1st and 2nd class) are partly common (especially for the variables explaining the technical characteristics of the routes and the alternative offer) and partly specific (competitive environment, economic and demographic environment). Frequencies depend mainly on travel time. On the routes for which the conventional HSR does not provide a quality service (frequency and/or price), a complementary alternative offer compensates the low frequency of conventional HSR services.

Keywords: HSR; Intermodal competition; Multiproduct firms' strategies; Low-cost transportation; France.

1. Introduction

Over the past few decades, long-distance transport has undergone a strong diversification in terms of services, particularly on the European continent. This has been driven by two underlying trends: the development of low-cost offers, which have helped segment markets, and the emergence of digital platforms that have enabled the development of new offers such as carpooling. The consequence is a diversification of transport services for journeys of more than 100km with options such as conventional air, low-cost air, high-speed train, conventional train, low-cost train, bus, and carpooling. In addition, the development of intramodal competition increases the diversity. While many studies have looked at the effect of one mode on another, few have looked at intramodal and intermodal competition.

Our paper investigates the effect of intramodal and intermodal competition on the structuring of fares and frequencies of high-speed rail services in France. France is an interesting case study for several reasons. First, it offers great diversity in intermodal competition with the European leader in carpooling (*BlaBlaCar*), free bus services, and even air travel over longer distances. Second, its historical rail operator was the first in Europe to develop an original form of competition that could be described as "in-house competition" with the development of a low-cost high-speed rail service (*Ouigo*) in parallel with its traditional service (*Inoui*). The management of this new service is an interesting point to study, particularly to identify the potential for substitution between offers. Finally, the French case offers origins-destinations with very different characteristics in terms of distance, which increases the diversity in the analysis.

The scope is therefore limited to five routes (origin-destination), four of which are in France only (Paris-Lyon, Paris-Bordeaux, Paris-Toulouse and Paris-Nice) and one international (Paris-Brussels). They all include a high-speed rail service and several competing intermodal or intramodal offers of varying intensity. Buses are more present on Paris-Brussels, while air travel is more pronounced on Paris-Nice because of the distance. The data consider all the transport offers present on these routes in terms of price, capacity, and frequency over a period from September 2019 to March 2020 (n=929). This is before the Covid 19 pandemic and before the opening of the French rail sector to

competition. The data treatment is based on an econometric analysis using the estimation of apparently unrelated regression equations (Zellner, 1962).

The main results show that the determinants of the price per kilometer of conventional HSR services (1st and 2nd class) are partly common (especially for the variables explaining the technical characteristics of the DO and the alternative offer) and partly specific (competitive environment, economic and demographic environment). Frequency depends mainly on travel time. In more detail, we observe that on the routes for which the conventional HSR does not provide a quality service, in terms of frequency and/or price, a complementary alternative offer would compensate for the low frequency of conventional HSR services. This complementary alternative offer would be provided by low-cost HSR buses and carpooling. On the routes for which the HSR does not allow for a round trip in the day, an alternative substitute offer would develop and would be mainly provided by low-cost flights.

This paper adds to the literature with a comprehensive analysis of the long-distance transport supply and the main interactions between the different modes. It also characterizes the French system prior to the opening of the rail sector to competition, thus serving as a basis for comparison for subsequent studies.

Section 2 summarizes the economic literature on the subject and recalls the French context in terms of transport supply and price regulation. Section 3 presents the data used and the methodology employed. Section 4 describes the empirical strategy and the variables used. Section 5 presents and discusses the econometric results. Section 6 concludes.

2. Literature Review

This section presents the study's background and the lessons learned from the literature. Section 2.1 provides an overview of the diversification strategy of long-distance transport services in France. Section 2.2 presents the main results of the literature and their limitations. Finally, Section 2.3 focuses on the specific case of price regulation of HSR in France and sets out the main hypotheses to be tested.

2.1. Diversification strategy of long-distance transport services

The long-distance market in Europe, and even more so in France, has been characterized in recent decades by a significant diversification of transport services. This has been driven by low-cost offers and the development of digital platforms. The entire transport offer has been affected by these developments, which have taken different forms depending on the mode.

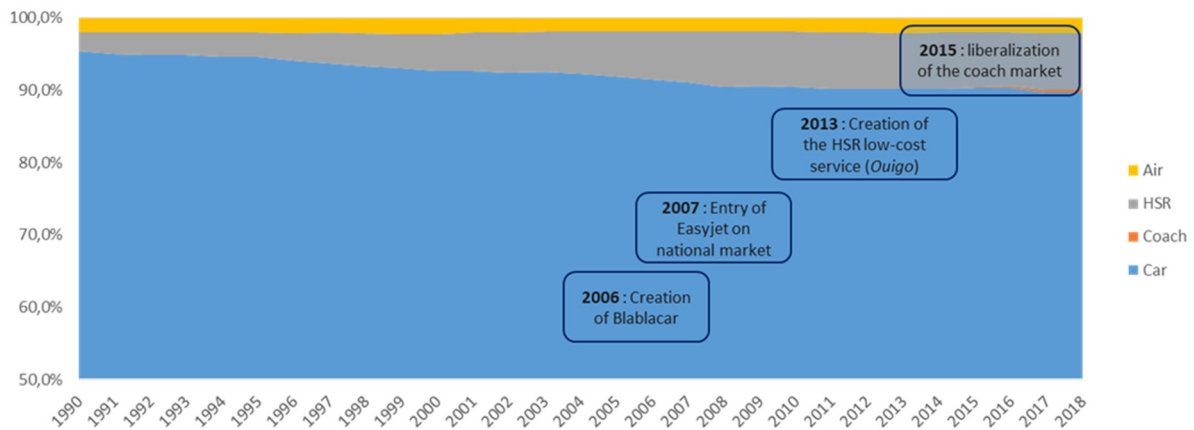


Fig. 1. Modal distribution of the main long-distance transport modes in France between 1990 and 2018 (excluding carpooling)
Source: Compte national de transports (2022)

Fig. 1 shows the modal distribution of long-distance transport in France between 1990 and 2018. The triptych is composed of the private car, which remains unchallenged, HSR, which is increasing its share as the network expands, and air, which has grown over the last few decades under the influence of low-cost air transport, although it is not very visible in Fig. 1 (+40%).

The end of the 2000s marked a profound shift in the composition of long-distance services. First, the personal car opened up to other passengers with the development of digital platforms of trust and contact, of which the French leader BlaBlaCar holds a virtual monopoly in Europe in 2022. The effect on the modal split is marginal, but several studies have shown that this service can complement the dominant rail offer for public transport (Givoni and Dobruszkes, 2013; Beria et al., 2018; Bergantino and Madio, 2020; Laroche and Lamatkhanova, 2022).

The rail sector has also undergone a transformation by applying part of the low-cost airline strategy to its services to create in 2013 the low-cost high-speed operator Ouigo, a subsidiary of the SNCF. It complements, or even replaces on certain routes, the more conventional high-speed offer (Inoui). Chiambaretto and Fernandez (2014) show that the transfer of the low-cost model from air to rail has not been total due to the technical and regulatory specificities of the rail sector. It has considerably broadened the user base, with fares dropping from about €25 in the old system to €10 for the low-cost offer.

The road sector saw a last evolution starting in 2015 with the authorization to operate and the liberalization of the coach market in France. This marks the return of collective road transport services in France with competition that was very strong in the first years before a consolidation of the sector around two main players in 2022, FlixBus and BlaBlaBus (subsidiary of BlaBlaCar). Blayac & Bougette (2022) have shown that the reduction in the number of competitors may have had a negative effect on prices and capacities. Nevertheless, these services seem to have found their place alongside carpooling and low-cost HSR.

Lastly, this study does not deal with the opening of the French rail network to competition from 2021. The scope of our analysis is situated before the arrival of this new intramodal competition, which limits the analysis of the effect of low-cost rail services on the conventional offer (Inoui) to a more or less substitutable multi-product service offer.

2.2. Diversification challenges in the academic literature

The diversification of supply since the 2010s raises several questions on both the demand and supply sides. In this study, the effects on demand will not be addressed. We are only interested in the supply side, and more specifically in the interactions between the offers in terms of price and frequency. This choice is mainly motivated by the data set available. Consequently, we retain two questions to be addressed. Taking the high-speed rail service as our starting point, (1) what effect on prices and frequencies has the development of an internal low-cost service had? (2) What is the effect on prices and frequencies of the development of modal alternatives, including low-cost air travel, carpooling and bus travel?

Question (1) has been relatively little addressed compared to question (2). From a theoretical point of view, Ivaldi and Vibes (2008) showed that the introduction of an LC rail offer could have a significant impact on the fares charged by the incumbent operator (-30%) but little impact on air travel. Nevertheless, they did not consider that competition could be home-grown as happened in 2013 with the creation of Ouigo. The company can more easily distinguish its offer to segment demand as much as possible and maximize its profits by minimizing the risk of cannibalization (Chiambaretto and Fernandez, 2014).

However, Beria et al (2018) show that even in a single operator system, supply segmentation can influence prices. They observe lower prices in Italy where the incumbent competes with its public service obligation (PSO) services compared to other lines. They also suggest that there may be an indirect effect of carpooling or busing on HSR fares. This observation refers to the question (2) which has been more widely discussed in the literature, especially on the competitive or non-competitive relationship between HSR and air.

In broad terms, the authors agree that there is a relationship between the evolution of HSR and air travel. Ivaldi and Pouyet (2018) suggest that rail is a highly constrained mode compared to other modes and is therefore relatively insensitive to intermodal competition. However, its intensity is highly debated. Givoni and Dobruszkes (2013) show a stronger substitution between HSR and modes such as car, conventional rail, or air than with carpooling or bus. Casetta and Coppola (2014) state that competition between HSR and car is stronger than with air, the latter being less

substitutable because of its time savings. Bergantino and Madio (2020) explain these observations by a greater proximity of customers between HSR, air and car, sensitive to time savings and less to price, unlike alternative modes such as carpooling or bus. Their users generally have a high price elasticity and are more likely to choose longer and less expensive modes.

Concerning air travel, many studies have been produced, notably in Spain and China, to evaluate the effect of the deployment of the high-speed network on air services. Overall, they confirm the effect of HSR on air services for distances less than 900km or 3h travel time (Gonzales-Savignat, 2004; Rothengatter, 2011; Yang and Zhang, 2012; Gundelfinger-Casar and Coto-Millan, 2017; Xia and Zhang, 2016; Zhang et al., 2018; Chen et al., 2019; Wang et al., 2021).

On short-haul routes, Zhang et al. (2019) estimate a price reduction for air of 34% and 60% for frequency. In the Spanish case, Jimenez and Betancor (2012) observe a 17% reduction in air frequency and an increase in overall demand. Conversely, for connections longer than 3 hours by high-speed train, several authors point to a marked effect on the number of seats but relatively weak on frequency (Albalade et al., 2014; Dobruszkes, 2011, Dobruszkes et al., 2014). Gundelfinger-Casar and Coto-Millan (2017) show that pro travelers accustomed to these routes have low price elasticity favoring schedule and travel time for their modal choice.

This result questions the often taken-for-granted substitutability of the two modes. Castillo-Manzano et al (2015) showed that in the Spanish case, only 14% of air demand shifted to HSR between 1999 and 2012, demonstrating a lower-than-expected substitutability between the two modes and the ability of HSR to create its own demand. Finally, Mizutani and Sakai (2021) investigate the comparative effect of HSR on a conventional air offer versus a new low-cost air offer. They find that the effect of HSR is greater than that of the low-cost airline, especially because of its effect on volumes.

Nevertheless, most of the studies cited focus on the effects of HSR on air travel and not the other way around. Only a few studies explore the effects of a new air service on HSR. For example, Friebel and Niffka (2009) analyze the effect of a new low-cost airline (German wings) in Germany on the incumbent airline (Lufthansa) and the incumbent rail operator (Deutsche Bahn). They show a very strong reaction on the part of Lufthansa, particularly on fares, unlike DB, which has reacted little to the new entrant. They suggest that DB may be less flexible than Lufthansa, particularly because of the technical constraints inherent in rail travel and a more rigid fare policy. For the other modes (carpooling, bus), there is less work. One reason is the risk of substitution between modes, which seems less obvious insofar as the speed and price differentials are high. However, several authors show that the markets are not completely independent (Fageda and Sansano, 2018; Gremm, 2018; Laroche and Lamatkhanova, 2022). Gremm (2018) shows that rail prices are lower on routes exposed to intermodal competition (mainly bus) than those where rail is a monopoly. Laroche and Lamatkhanova (2022) find that the probability of finding a carpool or bus route increases with the price of rail tickets.

Finally, analyzing the bus market, Fageda and Sansano (2018) find that intramodal competition is primarily expressed through frequencies while intermodal competition is expressed through prices. Again, however, the literature is primarily concerned with the effect of rail on other modes, not the effect of other modes on it.

This literature review suggests several avenues of exploration for our study. First, the scope of analysis should be extended to all modes. Most studies are limited to one or two modes in competition with rail and do not cover the whole market and its interactions. Second, the effects of intermodal competition and of the segmentation of rail services on HSR prices have yet to be analyzed. Most studies focus on the effect of HSR on alternative modes and not the other way around, assuming that HSR would be a price maker and insensitive to the evolution of alternative services. In a context where the long-distance market is evolving very rapidly with new services, this assumption deserves to be reconsidered. Finally, the effect of a highly segmented multi-product offer for a single producer on a single route remains to be tested empirically. Our study proposes a textbook case by considering the Inoui offer in relation to Ouigo.

2.3. Pricing policy of the high-speed train in the French experience

This last point focuses on the pricing structure for high-speed rail in France. Several key elements are to be considered in setting prices, including public regulation, the internal strategy of maximizing revenues through joint price-capacity management (yield management), and the effect of infrastructure costs (access charges).

Train fares in France are set according to a simple formula that considers the number of kilometers multiplied by a degressive fare to which is added a constant that reflects the fixed costs inherent in rail travel. The price of tickets increases with distance but less than proportionally so as not to penalize long distance travel.

The price of HSR train ticket prices is thus capped by the government, and the national operator SNCF is free to adjust its fares within this range. Under this constraint, the solution found in the 1990s to maximize revenues and increase the attractiveness of the HSR was to implement yield management techniques to the HSR product (Finez, 2014). The objective is to maximize the company's revenues by varying the sales price of a single seat according to various criteria (age, reason, reservation date, etc.) on the model of the airline industry.

Perennes and Finez (2015) show that this technique is particularly suited to economic activities with regulatory price caps and high fixed costs in addition to producing non-stockable goods. Thus, the SNCF relies on various tools to set its prices, including sales histories, train occupancy rates, and computer algorithms that analyze the dynamics of reservations in real time. The objective is to capture the surplus of users while reducing the social loss thanks to the possibility of proposing low prices.

However, Perennes and Finez (2015) point out that users rarely actually pay the capped price because of the discounts offered, except on the busiest routes such as Paris-Lyon. This structuring of fares should be considered to understand the fare differences observed in the rest of the study between the different routes. Fares should vary according to distance, but also according to the level of wealth of the territories (ability to pay) and demography (age structure). These determinants will be controlled for by socio-demographic controls.

Finally, the analysis of prices and frequencies cannot avoid the debate on the cost of access to infrastructure. The railway industry is highly vertically integrated, with the need for railroads in good condition to run trains (Bougette et al., 2021). Following the EEC/440/91 directive, the infrastructure manager was separated from the railway operators. In France, *SNCF Réseau* is the infrastructure manager in charge of the network while *SNCF Voyage* is in charge of the operation of rail services.

The use of the network by a train is conditional on the payment of a right of way charged per kilometer for any type of track. There is a debate among economists about the effect of these access charges on price and frequency. France stands out from the rest of Europe for having adopted pricing that tends toward full cost (Sanchez-Borras and Lopez-Pita, 2011; Nash, 2018). In this case, the user is considered to bear all the costs incurred by the infrastructure, unlike most other European networks that price their access at marginal cost, with the taxpayer taking all or part of the fixed costs of the network (Sanchez-Borras and Lopez-Pita, 2011).

The effect of a high access cost is debated. It may reduce traffic (Sanchez-Borras et al., 2010), and its effect seems to be stronger on frequencies than on prices (Börjesson et al., 2021). Operators have an incentive to use infrastructure more efficiently by reducing the number of trains and increasing their capacity. Crozet and Chassagne (2013) show that despite the high level of access charges in France, they do not constitute a barrier to entry or a handicap for the rail system because of the fine modulation implemented by the infrastructure manager to capture the operator's surplus and send the right price signals regarding the availability of the infrastructure (time modulation).

The effect of access charges should therefore be marginal in our study, but nevertheless perceptible in the evolution of prices or capacities according to time periods. For this reason, it will be necessary to distinguish between several time periods. Prices are expected to be higher during peak hours, while trains are expected to have more capacity.

3. Data Collection

This section specifies the scope of the study, the collection method, the sources used, and the nature of the data collected.

3.1. Scope of study

Fig. 2 shows the five routes on which the study is based. They are oriented in the province-Paris direction, with four solely national routes (Bordeaux-Paris, Toulouse-Paris, Lyon-Paris, Nice-Paris) and one international (Brussels-Paris). Their purpose is to connect major urban centers in France and Europe with varying characteristics in terms of distance, population, type of transport infrastructure, and diversity of supply. More specifically, the Brussels-Paris link is a special case in that it is international. It is mainly subject to technical and organizational constraints for rail (rolling stock, staff qualifications), which contributes to its higher operating cost (Laroche and Guihéry, 2013). It is also the shortest of the panel.

The Lyon-Paris and Bordeaux-Paris links differ from the rest of the panel in that they are of similar distance, with Lyon's advantage (466 km versus 585 km for Bordeaux). Lyon has more inhabitants than Bordeaux (1.3 million and 749,595 respectively), but both cities are very attractive, and both are linked to Paris by a high-speed line and an efficient highway network. Finally, Toulouse-Paris and especially Nice-Paris are characterized by a greater distance from Paris (677km and 933km respectively) and the absence of a high-speed line to serve them. This variety in line profiles directly impacts the diversity of transportation services, which reinforces the interest of the data panel.

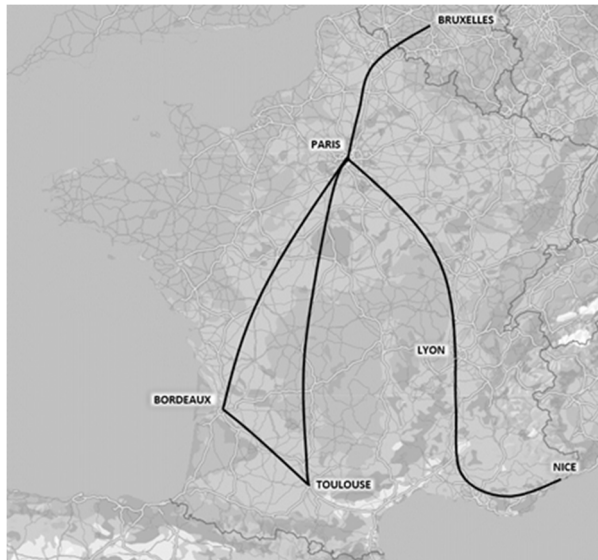


Fig. 2. The five routes under study

Fig. 2 illustrates the multimodal diversity of the sample by considering the modal share of the different modes available. The modal share is defined in terms of the seating capacity of each mode, as demand data were not available for the study. In addition, the private car is excluded from the evaluation, again because of lack of data. The shortest routes (Brussels, Bordeaux, and Lyon) are dominated by rail, while the longest routes (Nice and Toulouse) are more evenly balanced between air and rail. In all cases, road solutions (bus and carpooling) are marginal, although they are more prevalent on short routes than on long routes.

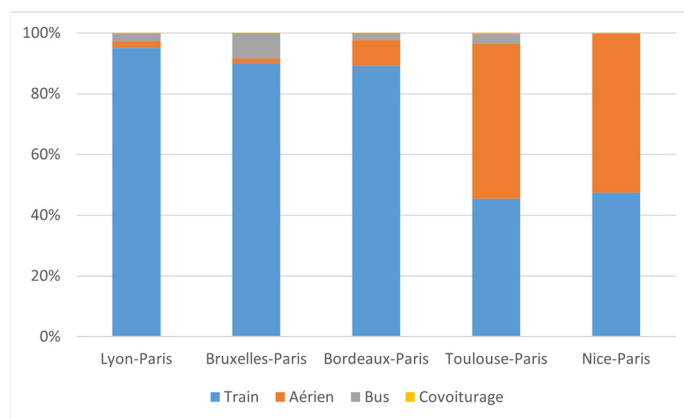


Fig. 3. Distribution of modal shares (by estimated number of seats) by route

3.2. Collection method and sources

Data collection was conducted from September 24, 2019, to March 10, 2020, which marked the beginning of lockdown in France following the COVID 19 pandemic. In total, 13 days were analyzed. They are all positioned on Tuesdays as a reference day with a collection at D-7. Each day was a working day, with public holidays, school vacations and strikes excluded from the analysis.

The webscraping technique was used to collect the data. However, it was decided not to use automatic data collection, but to use manual data collection. This choice is more costly in terms of time and limits the volume of data, but it allows us to avoid a certain number of errors that are very common and often result from poorly configured merchant sites. The most common errors are the duplication of schedules, which consists in offering two apparently different services with different prices for a service that is identical. This error is very common in the rail industry and can lead to an artificial overestimation of the number of services or prices. A very common error is also found in bus services that have several departure or arrival stops in the same city. They may be presented as several different services by websites even though they are identical. Again, automatic data collection could lead to an overestimation of the number of services. In the end, manual data collection saves time in cleaning up the data and making the panel more reliable.

The data comes from the commercial sites of the different operators identified on the market. The www.omio.fr comparator is used to identify the available offers. We then switch to the operators' own sites to obtain the most complete and reliable information possible. In the case of railways, the monopoly situation of the national operator requires consultation of its reference site www.sncf-connect.com. However, it is necessary to complete the search with its site dedicated to low-cost services to be exhaustive (<https://www.ouigo.com>). The bus offer requires the use of two websites linked to the two operators who share the French market in 2019, namely Flixbus (www.flixbus.com) and BlaBlaBus (www.blablacar.fr). The latter is also used for carpooling. No other site is used for carpooling as BlaBlaCar has a virtual monopoly in France. Finally, the data for air travel is collected from the Google flight database which lists the different flights.

3.3. Descriptive data

The data collected are diverse and depend heavily on the level of information available on the operators' websites. The data used for the study are common to all operators, including the departure/arrival time, the departure/arrival location, and the price. This information makes it possible to reconstitute the schedule, travel time, distance, frequency, and to estimate the capacity offered in terms of seats.

Table 1 describes the raw data obtained for each of the identified transport services. The data are detailed for the rail mode, which is the main object of study, between conventional high-speed (Inoui, TGV, and Thalys), low-cost

high-speed (Ouigo) and non-high-speed rail services (Intercités, night Intercités, Izy, and TER). They are reported in aggregate for the other modes. Overall, the raw sample is based on 3,901 observations. They are presented for all routes and for the whole period studied, except for frequency, which is given per day.

Table 1. Raw descriptive statistics.

		Obs.	Mean	Min.	Max.
Rail (conventional HSR: Inoui, Thalys, TGV)	2nd class price	946	83.5	31	132
	1st class price	916	115.5	37	189
	Frequency (per day)	946	72.7	70	75
	Number of seats	946	887.9	510	1020
	Distance	946	492.7	322	940
	Travel time	946	2:13:42	1:22:00	6:15:00
Rail (low-cost HSR: Ouigo)	2nd class price	220	23.7	10	79
	1st class price	220	16.9	16	20
	Frequency (per day)	220	1170	634	1268
	Number of seats	220	568.9	466	940
	Distance	220	2:34:07	1:43:00	5:57:00
Rail (HSR excluded: Intercités, Intercités Nuit, TER)	2nd class price	110	43.9	15	86
	1st class price	77	67.4	23	130
	Frequency (per day)	110	8.4	6	10
	Number of seats	110	558.8	393	720
	Distance	110	543	322	683
	Travel time	110	5:47:35	2:23:00	8:13:00
Bus (all operators)	2nd class price	955	16.4	5	79
	Frequency (per day)	955	73.5	70	79
	Number of seats	955	50	50	50
	Distance	955	457	322	940
	Frequency (per day)	955	6:21:20	3:45:00	13:50:00
Air (all operators)	2nd class price	1156	244.2	40	555
	Frequency (per day)	1156	87.6	85	91
	Number of seats	1156	150	150	150
	Distance	1156	718.4	240	940
	Frequency (per day)	1156	1:23:36	00:55:00	1:45:00
Carpooling	2nd class price	514	40.7	13	88.5
	Frequency (per day)	514	39.5	28	72
	Number of seats	514	3	3	3
	Distance	514	525	265	933
	Frequency (per day)	514	5:26:53	1:51:00	11:10:00

The comparison between modes ranks air as the fastest and most frequent mode with an average of 87.6 services across all routes. They are highly concentrated on the longest distances and have less capacity than rail. The latter is abundant, but above all has a high capacity over all distances, although the average is much lower than that of air. Buses are also very frequent, especially on the shortest routes. It seems to be penalized by a relatively low average speed in relation to the average travel time compared to other modes. Carpooling is faster and surprisingly positioned on an average distance closer to rail than to bus. The higher average speed of cars compared to buses could explain this ability of carpooling to cover longer distances for equivalent travel times. As far as price is concerned, it is not surprising that air travel comes out on top, while low-cost high-speed rail and especially bus are the most attractive services. Carpooling appears to be less attractive with a higher average price. Finally, it can be noted in general that transport offers seem to be relatively stable with little variation in terms of frequency, except for carpooling where the offer in normal periods can vary by up to 2.5.

4. Empirical Strategy

The empirical strategy is based on econometric modeling of the Seemingly Unrelated Regression Equations Models (SURE models). In this perspective, the raw data collected are reworked to: (i) take into account the context of intermodal and intramodal (or intra-firm in our case) competition, (ii) identify the determinants of prices (1st and 2nd class) and frequencies of TGV services.

4.1. Consideration of the competitive environment

For each of the thirteen days analyzed in this study, we have chosen to group the observations concerning the supply of transport services for the different routes (Brussels-Paris, Bordeaux-Paris, Toulouse-Paris, Nice-Paris, and Lyon-Paris) into three main daily periods: Morning for rail services departing before 9:00 a.m., Afternoon for those departing between 9:00 a.m. and 5:00 p.m., and Evening for those departing after 5:00 p.m. This segmentation is justified by the different types of customers depending on the time of day considered, as well as by intramodal and intermodal competition, the intensity of which also varies with the period.

From the data collected (see Section 3.3), this methodology makes it possible to build indicators measuring the intensity of competition: the HHI_PASS variable measures the intensity of intermodal competition for the time of day and the DO under consideration. To do so, the Herfindhal-Hirschman index (HHI) is used in its standard approach, using the market shares of each of the modes in terms of passengers carried. It comes to:

$$HHI_PASS = \sum_{m=1}^4 s_m^2$$

expression where m denotes the mode of transport (train, air, bus, and carpool), and s_m is the market share of the mode for the period, DO and date considered.

The degree of intramodal diversification for the rail mode is also measured by the Herfindhal-Hirschman index, this time in terms of frequency, and for the different rail products (TGV Inoui, TGV Ouigo, Intercity, TER). It comes:

$$HHI_TRAIN = \sum_{g=1}^4 s_g^2$$

expression where g is the rail product, and s_g is the frequency market share of the rail product g for the period, route, and date considered. Both indices take values between 0 and 10000, reflecting low/high concentration for HHI_PASS and high/low diversification for HHI_TRAIN respectively.

4.2. Econometric modeling

The purpose of our research is to better understand the determinants of HSR prices and the extent to which they are influenced by the competitive positioning of the HSR vis-à-vis other modes and/or by intra-rail mode range diversification. The HSR Inoui services provided by SNCF use railcars with two physically distinct comfort classes. From the operator's point of view, this requires management of the available capacity of each comfort class. Many factors are likely to affect the prices of HSR services in 1st and 2nd class (see 2.3), and it is reasonable to assume that the two comfort classes are not perfectly sealed.

From an econometric point of view, if one wishes to estimate the determinants of the prices of 1st and 2nd class HSR services, it is legitimate to consider some degree of dependence between the error terms of the two equations defining them. It is precisely for this reason that Fageda and Sansano (2018) use a SURE model on the long-distance bus service market. Beyond the prices of 1st and 2nd class HSR services, we also want to study the determinants of HSR frequencies. In the following paragraphs, we describe the dependent variables used (4.2.1) as well as the explanatory variables (4.2.2) before briefly presenting the SURE model used (4.2.3).

4.2.1. Description of dependent variables

Three variables are of interest. These are the prices of HSR services in first and second class and the frequencies of the incumbent operator's flagship product (Inoui in the case of SNCF). The elements discussed regarding the pricing of HSR services in the French case (see 2.3) lead us to use not gross prices but prices per kilometer or kilometer prices for each of the routes considered in this article. Descriptive statistics are provided in Table 1 below and in Fig. 1 (Price per kilometer, 1st class), and 2 (Price per kilometer, 2nd class) and 3 (Frequency).

Table 1. Descriptive statistics.

Variable	N	Mean	Standard deviation	Minimum	Maximum
Frequency	929	6.85	2.22	1.00	10.00
PK_TGV_1	894	0.26	0.10	0.05	0.45
PK_TGV_2	905	0.19	0.08	0.02	0.32

There are strong disparities in the price per kilometer. Thus, in 1st class, the average price per kilometer is 0.26€/km with a minimum of 0.05€/km and a maximum of 0.45€/km, revealing the existence of a factor of 9. The analysis by route is revealing of the phenomena described above (see Fig. 1). Of the 5 routes, 3 correspond to routes for which the comparative advantage is in favor of HSR (Brussels, Bordeaux, and Lyon). Nevertheless, in terms of pricing strategies (*PK_TGV*, 1st class), the relationships differ: very little fare variability for Brussels and Lyon (mainly business customers), much more for Bordeaux. For the Nice and Toulouse routes, for which the HSR rail mode is not well-positioned (price-time-frequency), the picture is mixed: little variability for Nice, much more for Toulouse (in connection with access via Bordeaux or Montpellier).

The observation is identical regarding 2nd class. The average price per kilometer is €0.19/km with a minimum of €0.02/km and a maximum of €0.32/km, revealing the existence of a factor of 16. This high variability in prices is most likely due to the period under consideration, the use of Yield Management to optimize train loadings, different competitive positioning among the routes, and regulatory factors. Among the latter, it is worth mentioning the adoption of an article in the framework of the Climate and Resilience Law (August 22, 2021), stemming from the Citizens' Climate Convention, relating to the prohibition of domestic flights for which a rail alternative of less than 2.5 hours exists. For the routes in our sample, only the Nice-Paris and Toulouse-Paris routes could legitimately use domestic flights. In fact, Fig. 4 and 5 show that the price per kilometer for these routes is lower than for the other routes for which HSR has a very different competitive position. This prompts us to use as dependent variables the prices per kilometer, while introducing as control variable the distance. We expect the estimated coefficient of the distance variable to be negative in the econometric estimation phase, in both 1st and 2nd class.

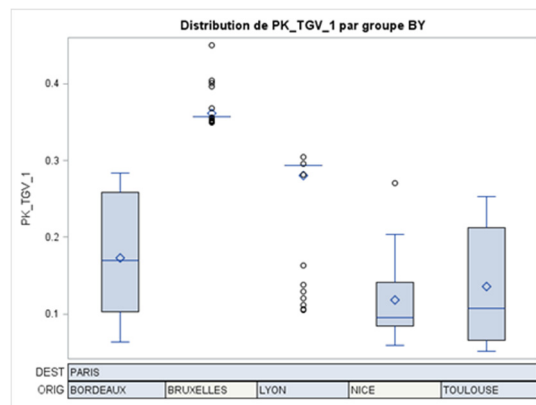


Fig. 4. Price per kilometre of HSR - 1st class by route

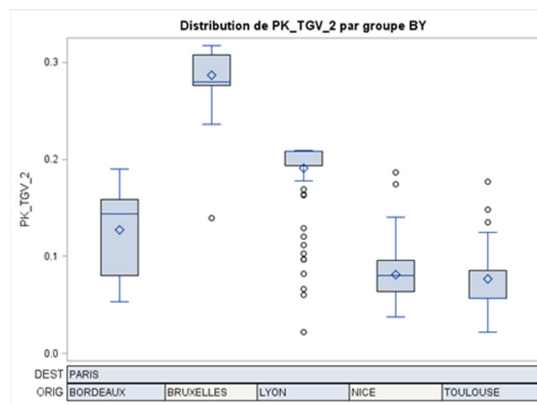


Fig. 5. Price per kilometre of HSR – 2nd class by route

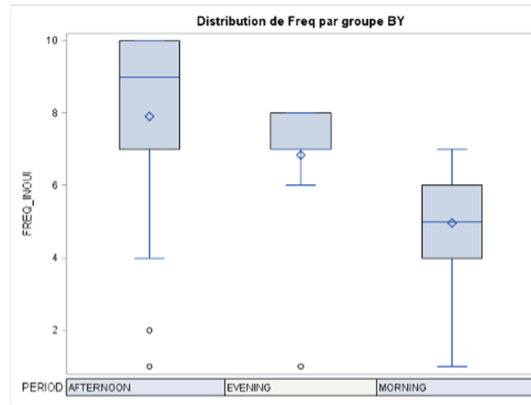


Fig. 6. Frequency of HSR services by time of day

The frequency of HSR services varies from 1 to 10 depending on the period considered (Morning, Afternoon, and Evening) and on the route, with an average for all periods combined of 6.85. Fig. 6 shows the dispersion of HSR frequencies by time of day for all routes analyzed in this study.

4.2.2. Description of explanatory variables

The variables used as explanatory variables in the different regressions are presented briefly and their descriptive statistics are provided in Table 3. They can be grouped into three main categories. The first category includes the technical characteristics of the routes and the transport offer: the distance in kilometers, the travel time (expressed in minutes), the capacities and frequencies offered by the other types of train (Low Cost, Intercity, TER), or the other modes (Bus, Low-Cost Flight, Carpooling). These variables reveal extremely contrasting situations depending on the DO and the time of day. The average distance between origin and destination cities is 490 km (from 312 to 940 km) for an average travel time of 2h14 (from 1h22 to 7h48). The capacities and frequencies offered naturally consider these differences in observable situations.

Table 3: Descriptive Statistics - Explanatory Variables

Variable	N	Mean	Standard deviation	Minimum	Maximum
DISTANCE	929	490.33	157.84	312.00	940.00
TT_TGV (min)	929	134.50	72.11	82.00	448.00
CAPA_LC_TRAIN	929	1956.04	2290.97	0.00	6340.00
CAPA_INTERCITES	929	30.65	156.63	0.00	1203.00
CAPA_BUS	929	332.02	199.57	0.00	900.00
FREQ_LC_TRAIN	929	1.66	1.75	0.00	5.00
FREQ_TER	929	0.48	1.02	0.00	3.00
FREQ_BUS	929	6.64	3.99	0.00	18.00
FREQ_LC_AIR	929	0.28	0.80	0.00	4.00
FREQ_CARPOOL	929	10.89	12.94	0.00	81.82
QLT_TGV	929	3.88	0.58	1.36	4.88
HHI_PASS_CTRD	929	-0.00	1143.07	-3802.08	1368.68
HHI_TRAIN_CTRD	929	-0.00	2028.24	-3820.66	3565.11
YOUNG_MEAN	929	24.28	2.90	20.54	27.50
SENIOR_MEAN	929	12.26	1.31	10.63	15.77
POP_MEAN	929	829948.87	185197.59	624528.00	1062234.83
UNEMP_MEAN	929	12.39	0.54	11.89	13.56

The second major category of variables groups together variables that characterize the competitive environment of routes. It is based on three variables developed for this purpose:

- The *HHI_PASS_CTRD* variable is built from the *HHI_PASS* variable, which captures the degree/intensity of intermodal competition by using the standard definition of the HHI index (0 to 10,000). For the *HHI_PASS_CTRD* variable, we have chosen to use a centering with respect to the average *HHI_PASS* for the period of the day under consideration. Therefore, if for an observation in our database, this variable takes a positive (resp. negative) value, it means that the degree of concentration is higher (resp. lower) than that observed on all the observations of the period considered.
- The *HHI_TRAIN_CTRD* variable is intended to capture the degree or intensity of intramodal competition. In the absence of intramodal competitors, this variable can be an indicator of the range diversification implemented by the incumbent operator (e.g. SNCF and the OUIGO, OUIGO Train classique, TER, Intercités offers, etc.) which then clearly behaves like a multi-product firm. The *HHI_TRAIN_CTRD* variable is derived from the *HHI_TRAIN* variable (calculated based on the frequencies offered and not the passengers carried) using the same centering process. In fact, for an observation in our database, any positive (respectively negative) value for the *HHI_TRAIN_CTRD* variable reflects less (respectively more) range diversification.
- The variable *QLT_TGV* can be considered as an indicator of the quality of the HSR service. In France, HSR services are often criticized for making too frequent stops or for using for a large part conventional (non-HSR) infrastructure (cf. *Cour des Comptes*, 2014). The variable *QLT_TGV* is defined as the ratio between distance and travel time by TGV (expressed in minutes). It is therefore expressed in km per minute of travel time. The minimum and maximum values of *QLT_TGV* are respectively 1.36 and 4.88 with an average of 3.88, which corresponds respectively to “travel speeds integrating stops” of 82 km/h, 293 km/h and 233 km/h.

The third and final category of explanatory variables used includes variables relating to the economic and demographic environment of the relationships concerned. These are the proportion of young people aged 15-29, the share of people aged 60-74, the unemployment rate of 15–64-year-olds, and the population of the origin and destination

cities (Source: INSEE,¹ year 2018 for the French data, and IBSA,² year 2017 for the Belgian data). For each route and each variable, we use the geometric mean of the values for the origin and destination city. The use of the geometric mean allows us to simultaneously consider the emission factors and/or attraction factors of the origin and destination cities (as in a gravity model), but also to keep the original unit of measurement. Thus, on average, the share of 15–29-year-olds for the routes in our sample is 24.3%, the share of 60–74-year-old is 12.3%, the unemployment rate is 12.4%.

The explanatory variables presented above are used to explain the determinants of the price per kilometer of HSR 1st and 2nd class services and the frequency of HSR services. The econometric modeling used is presented in the following section.

4.2.3. The SURE model

The interest of the SURE models lies in the possibility of estimating the various equations translating the functioning of a system in its entirety. Thus, these models make it possible to exploit the information provided by the covariance matrix of the error terms associated with each of the equations, provided, however, that the variables dependent on certain equations do not become explanatory variables for the other equations of the system.

More specifically, we have:

$$\begin{cases} \log(PK1)_k = X_{1k}\beta_1 + \varepsilon_{1k} \\ \log(PK2)_k = X_{2k}\beta_2 + \varepsilon_{2k} \\ \log(FREQ)_k = X_{3k}\beta_3 + \varepsilon_{3k} \end{cases} \quad (1)$$

where k denotes the routes considered for each period of the day (Morning, Afternoon, and Evening), X_{ik} represents the vector of explanatory variables for the three system equations, and ε_{ik} are the error terms.

The model is estimated using the FGLS (*Feasible Generalized Least Square*) method, which operates in two stages. First, each of the equations is estimated equation by equation via the OLS and the error terms obtained allow us to determine the covariance matrix of the error terms. This covariance matrix is then used to estimate the system (1) via generalized least squares (GLS).

The estimators obtained in the SURE models are equivalent to those that would be obtained by an equation-by-equation OLS estimation if the covariance matrix is diagonal or if, for each equation, the explanatory variables are identical.

In our case, the model chosen is a semi-log model.

5. Results

5.1. Econometric estimation

The model described by the system of equations (1) is estimated according to the procedure described (see 4.2.3). At the end of the first step (OLS), the covariance matrix of the error terms is estimated and reveals significant correlations, in particular for the error terms of the equations explaining the price per kilometer of TGV 1st and 2nd class services (see Table 4).

¹ Institut National de la Statistique et des Études Économiques, <https://www.insee.fr/fr/accueil>

² Institut Bruxellois de Statistique et d'Analyse, <https://ibsa.brussels>

Table 4: Seemingly Unrelated Regression Estimation

Cross Model Covariance			
	LPK1	LPK2	LFREQ
LPK1	0.089296	0.064942	0.001250
LPK2	0.064942	0.071913	0.000647
LFREQ	0.001250	0.000647	0.020999

Cross Model Correlation			
	LPK1	LPK2	LFREQ
LPK1	1.00000	0.81041	0.02887
LPK2	0.81041	1.00000	0.01664
LFREQ	0.02887	0.01664	1.00000

System Weighted MSE	0.9959
Degrees of freedom	2650
System Weighted R-Square	0.8029

In a second step, generalized least squares are applied. The results obtained are presented in Table 5.

Table 5: SURE model – Estimation results

Variables	<i>Log(PK1)</i>	<i>Log(PK2)</i>	<i>Log(FREQ)</i>
	Coef. (SE)	Coef. (SE)	Coef. (SE)
Intercept	-0.00768 (0.1094)	5.4314 (0.4761)***	0.19195 (0.1143)*
Distance	-0.0018 (0.0001)***	-0.00133 (0.0001)***	
TT TGV (min)			-0.00263 (0.0004)***
CAPA LC TRAIN	-0.00005 (7.2E-6)***	-0.00004 (5.0E-6)***	
CAPA INTERCITES		-0.00022 (4.5E-5)***	
CAPA BUS	-0.00025 (0.0001)***	-0.00017 (8.0E-5)**	
FREQ LC TRAIN			0.14047 (0.0064)***
FREQ TER			0.11031 (0.0117)***
FREQ BUS			0.02626 (0.0024)***
FREQ LC AIR			-0.11049 (0.0121)***
FREQ CARPOOL			0.00191 (0.0006)***
QLT TGV	0.135492 (0.0304)***		0.08363 (0.0362)**
HHI PASS CTRD	0.000104 (1.7E-5)***		
HHI TRAIN CTRD			0.00012 (5.6E-6)***
YOUNG MEAN	-0.08206 (0.0076)***		-0.01842 (0.0053)***
SENIOR MEAN			0.17625 (0.0141)***
POP MOYENNE	1.296E-6 (1.3E-7)***		-5.83E-7 (9.9E-8)***
UNEMP MEAN		-0.51827 (0.04)***	
# of Observations ³	892	892	892

*** Statistical significance at 1% level, ** Statistical significance at 5% level, * Statistical significance at 10% level.

From a statistical point of view, the results presented support the choice of estimating a SURE model since the covariance matrix is not diagonal, but also insofar as the explanatory variables used to explain the mileage prices in 1st and 2nd class or the frequencies of HSR services are not identical. The explanatory power of the model (i.e., the system of equations) appears to be quite satisfactory since the weighted R² is 0.8029. Furthermore, the analyses of the residuals from the SURE model do not reveal any significant elements (see Appendices).

³ The estimation of the equations of system (1) must be performed on the same number of observations to adequately estimate the covariance matrix of the error terms.

5.2. Economic analysis and discussion

5.2.1. Determinants of the price per kilometre of HSR 1st class services

For the variables belonging to the first category (technical characteristics of the routes and transport offer, cf. 4.2.2) three variables are significant with a negative coefficient. These are the variables *DISTANCE*, *CAPA_LC_TRAIN* and *CAPA_BUS*. Thus, all other things being equal, the price per kilometre in 1st class decreases with distance, reflecting the reduced competitiveness of this mode as distance increases. This effect was expected. The same is true for the variables *CAPA_LC_TRAIN* and *CAPA_BUS*, which reflect the impact of the supply of alternative modes (Bus and Low-Cost Train) on the price per kilometer. An effective and consistent supply of these alternative modes is likely to moderate the price per kilometer of HSR services in 1st class. Surprising at first sight, this explanation should not make us lose sight of the fact that this moderation effect will probably occur more markedly outside the peak periods of the day (*AFTERNOON*). It could also reflect the efficient use of SNCF's yield management system to ensure optimal use of HSR capacity; in this respect, SNCF would still be obliged to consider the effective low-cost offer (Bus and Train).

For the variables belonging to the 2nd category (Competitive environment of the routes, see 4.2.2), the positive signs of the coefficients associated with the variables *QLT_TGV* and *HHI_PASS_CTRD* were expected.

The variable *QLT_TGV*, which can be seen as a proxy for the greater or lesser fraction of use of HSR infrastructure for a given route, has a positive and significant impact on the price per kilometer of 1st class HSR services. Fig. 1 and A1 illustrate this graphically: Brussels-Paris and Lyon-Paris are routes for which the average price per kilometer is the highest (respectively 0.36 €/km and 0.28 €/km) and for which the *QLT_TGV* variable takes some of the highest values in our sample (respectively 3.88 and 3.89 on average). These routes symbolize, in a way, what a high-speed train service should be: use of dedicated infrastructure with few stops. Nice-Paris and Toulouse-Paris are routes with diametrically opposed characteristics. They offer HSR services that combine a low price per kilometer (respectively 0.12 €/km and 0.14 €/km on average) with low values of the variable *QLT_TGV* (respectively 2.50 and 2.58 on average). Bordeaux-Paris presents a strong singularity compared to the other routes: while this route has the highest average value of the *HSLQ* variable (4.48) in our sample, the average price per kilometer is at an intermediate level (0.17 €/km). This would tend to confirm the existence of a multiplicity of factors influencing the price-km of HSR services, both on the supply side (e.g., infrastructure tolls) and on the demand side (e.g., catchment area and type of customer).

The variable *HHI_PASS_CTRD* has a positive and significant effect on the price per kilometer of HSR services. This was expected. A positive value of this variable for an observation reflects a higher degree of concentration than the other observations in the period of the day considered. Without strong organized competition, the incumbent rail operator can fully exploit its competitive advantage over other modes. On the other hand, when there is less competitive advantage and/or when the incumbent rail operator faces more competition (especially intermodal competition), the variable *HHI_PASS_CTRD* has a negative value: this contributes to a downward pressure on the price per kilometer of the HSR - 1st class services concerned.⁴

Two variables belonging to the third category (economic and demographic environment, see 4.2.2) are significant. These are the variables *YOUNG_MEAN* (negative sign) and *POP_MEAN* (positive sign). Thus, the high proportion of people aged 15 to 29 years for the connected cities (geometric mean) contributes *ceteris paribus* to decrease the price per kilometer of 1st class HSR services. The size of the potential market, captured in our study by the geometric mean of the population of the connected cities (*POP_MEAN*) has a positive effect on the price per kilometer of 1st class HSR services. This effect was expected and consistent with the findings of the gravity modeling of spatial interactions.

The mileage prices of HSR 1st class services are influenced by multiple factors. Some of them refer to technical characteristics or alternative offers (*DISTANCE*, *CAPA_LC_TRAIN*, *CAPA_BUS*), others to the competitive positioning (*QLT_TGV* and *HHI_PASS_CTRD*), and still others to the economic and demographic context of the connected cities (*YOUNG_MEAN* and *POP_MEAN*).

The determinants of mileage prices for 1st class HSR services appear to be consistent and compatible with most

⁴ A graphical representation of the *HHI_PASS_CTRD* variable for the different routes and time periods is provided in the Appendix (see Fig. A2).

of the work done in this area (Bergantino and Madio, 2020; Borjesson et al., 2021). Nevertheless, we legitimately wonder whether the same determinants are involved in explaining the mileage prices of second-class HSR services.

5.2.2. Determinants of the price per kilometre of HSR 2nd class services

The existence of two comfort classes (1st and 2nd class), physically distinct as in conventional TGVs, is a source of additional difficulties. Indeed, the rail operator must implement more elaborate capacity management pricing strategies to ensure the right trade-off between waste risk and waste risk (Finez, 2014; Perennes and Finez, 2015).

The results (see Table 4) confirm some of the factors already identified as having an impact on mileage prices for 1st class HSR services. These include the variables belonging to the 1st category (route technical characteristics and transport offer, see 4.2.2): distance (*DISTANCE*) as well as capacities offered by alternative modes (*CAPA_BUS*) and/or by other rail "products" or "ranges" (*CAPA_LC_TRAIN* and *CAPA_INTERCITES*). For these variables, the negative and significant signs of the estimated coefficients reflect the impact on the moderation of the price per kilometer of HSR services for long trips (for which the comparative advantage of HSR is less) and/or for which the financially "accessible" alternative offer is more developed. It should be noted that none of the variables in the second category (competitive environment of HSR, see 4.2.2) is significant in explaining the mileage prices of second-class HSR services.

Finally, among the variables of the 3rd category (economic and demographic environment, cf. 4.2.2), only the geometric mean of the unemployment rate of the origin and destination cities is a determinant of the price per kilometer of HSR 2nd class services. The associated negative coefficient reflects a *ceteris paribus* reduction in the price per kilometer of routes with high average unemployment rates.

The determinants of the price per kilometer of HSR services (1st and 2nd class) are partly common (notably for the variables explaining the technical characteristics of the DO and the alternative offer) and partly specific (competitive environment, economic and demographic environment). They illustrate the complexity of the fare strategy to be implemented by the incumbent rail operator to ensure optimal management of the available capacity in 1st and 2nd class, while meeting the mobility needs of individuals.

5.2.3. Determinants of HSR service frequency

The results of the econometric estimation (Table 6) highlight many explanatory factors for the frequency of HSR services. Among these, we find factors belonging to the first category of variables (technical characteristics of the routes and transport offer, see 4.2.2). These are the travel time (*TT_TGV_MIN*) and the frequency offered by the alternative modes of transport (*FREQ_LC_TRAIN*, *FREQ_TER*, *FREQ_BUS*, *FREQ_CARPOOL*, and *FREQ_LC_AIR*).

Logically, the travel time (*TT_TGV_MIN*) negatively affects the frequency of HSR services, proposed on a given route. To some extent this observation reflects the competitive advantage of HSR on relatively short trips (less than 2-3h) over other modes. Beyond this travel time, the frequency of conventional HSR services decreases and an alternative offer is developing.⁵ This alternative offer may result from a diversification of services (intra-modal) or, on the contrary, from an intermodal competition. In our study, this alternative offer would be the result of range diversification, low-cost TGVs (*FREQ_LC_TRAIN*) and TERs (*FREQ_TER*), whereas intermodal competition would be the result of freely organized bus services (*FREQ_BUS*), low-cost flights (*FREQ_LC_AIR*), and carpooling (*FREQ_CARPOOL*). The signs of the coefficients associated with the frequencies of the different modes in the estimation phase are positive except for the low-cost air mode. This is an extremely revealing element to which we could give the following interpretation: on the routes for which the conventional HSR does not provide a quality service, in terms of frequency and/or price, a complementary alternative offer would compensate for the low frequency of conventional HSR services. This complementary alternative offer would be provided by low-cost HSR, regional express trains, buses, and carpooling (positive coefficients associated with the corresponding *FREQ_* variable). On the routes for which the HSR does not allow a round trip in the day, an alternative substitutable offer would develop

⁵ This link between frequency and travel time (or distance) has been demonstrated for other transport modes. This is the case for freely organized bus services in France (Blayac and Bougette, 2017, 2022).

and would be mainly provided by low-cost flights (negative coefficient associated to the variable *FREQ_LC-AIR*).

The frequency of HSR services is also positively related to two variables belonging to the 2nd category (competitive environment of routes, see 4.2.2). These are the variables *QLT_TGV* and *HHI_TRAIN_CTRD*. Regarding the *QLT_TGV* variable, we find here the main complaints and recommendations made in the Court of Auditors report (2014): a HSR service should be designed on a dedicated infrastructure with a minimum of stops. The positive sign associated with the variable *HHI_TRAIN_CTRD* means that for those relations on which a diversification of rail range or products has been implemented, more intensively than on other relations, the frequency of conventional HSR services will be, *ceteris paribus*, lower. We find here the explanation in terms of alternative substitutable offer in the intramodal case.

Finally, the explanatory factors for the frequency of HSR services belonging to the 3rd category (economic and demographic environment, cf. 4.2) are the size of the origin and destination cities (*POP_MEAN*), the share of young people from 15 to 29 years old (*YOUNG_MEAN*), and the share of people from 60 to 74 years old (*SENIOR_MEAN*). Here again, the results appear quite logical. The negative sign associated with the variables *YOUNG_MEAN* and *POP_MEAN* reflects not a reduced need for mobility, but rather a shift to alternative, more flexible and, above all, more affordable modes. The positive coefficient associated with the *SENIOR_MEAN* variable reflects the attachment of this category of population to conventional HSR services.

The study of the determinants of the price per kilometer of the conventional HSR services 1st and 2nd class as well as of the frequencies is rich in information and highlights the role played by the three main categories of variables. It also suggests the importance of intermodal competition and the role of range diversification strategies implemented by the incumbent rail operator.

6. Conclusion

In a pre-COVID19 period and before the opening of the French rail market to competition, this study analyzes the main determinants of prices and frequencies of French conventional HSR services (1st and 2nd class) using an original database. The main results show that the determinants of the price per kilometer of conventional HSR services are partly common between 1st and 2nd class (especially for the variables explaining the technical characteristics of the DO and the alternative offer) but also specific (competitive environment, economic and demographic environment). Frequency depends mainly on travel time. It can be observed that on the routes for which the conventional HSR does not provide a quality service, an alternative complementary offer compensates for the low frequency of conventional HSR services. This offer is mainly provided by low-cost HSR, buses and carpooling. On the routes for which the HSR does not allow for a round trip in the day, a substitute offer is developing and would essentially consist of low-cost flights. The study thus highlights the multi-product strategy adopted by the historical rail operator and its subsidiaries (SNCF Group) in reaction to the low-cost positioning of certain alternative modes, also anticipating the imminent entry of competitors on the domestic rail market.

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Appendices

Fig. A0: Graphical analysis of residuals (SURE model)

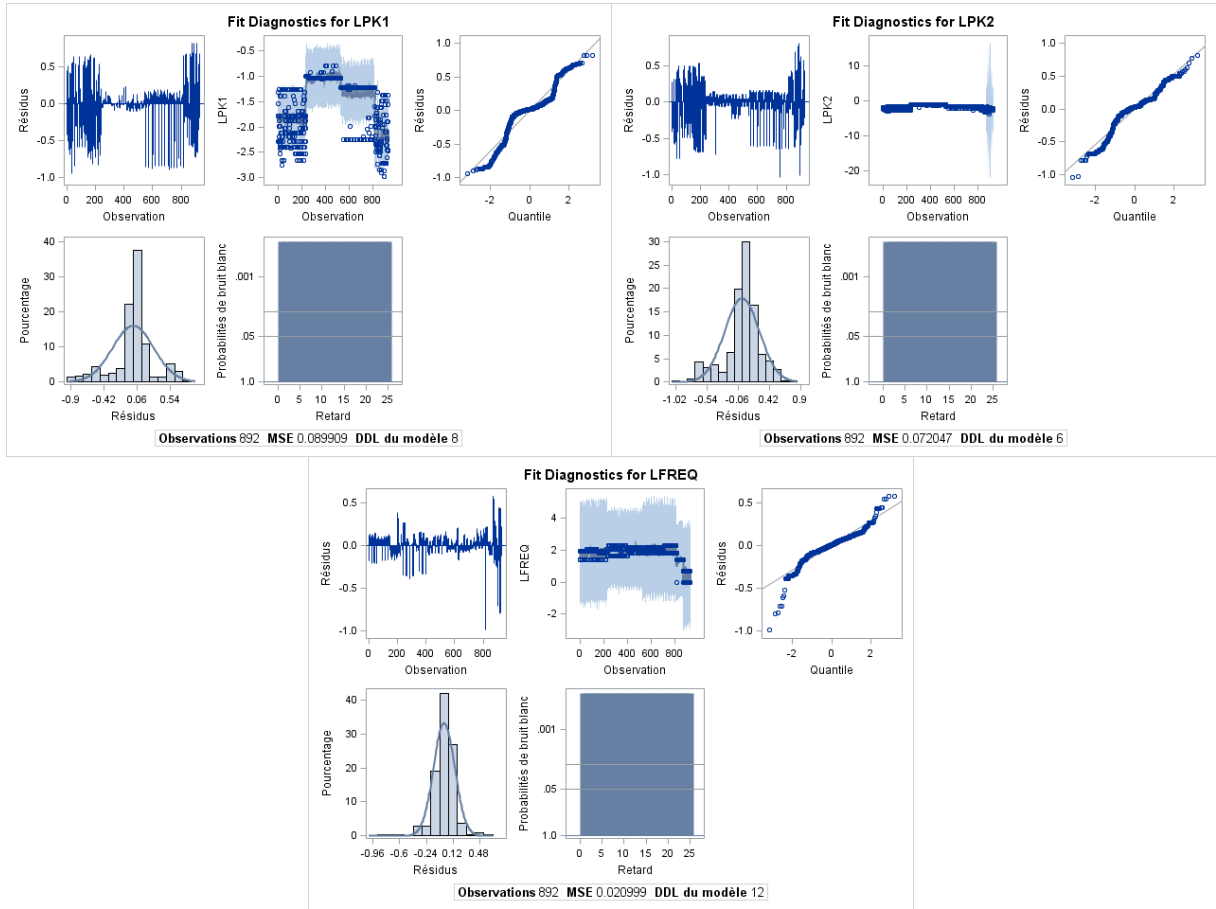


Fig. A1: Descriptive statistics - *QLT_TGV*

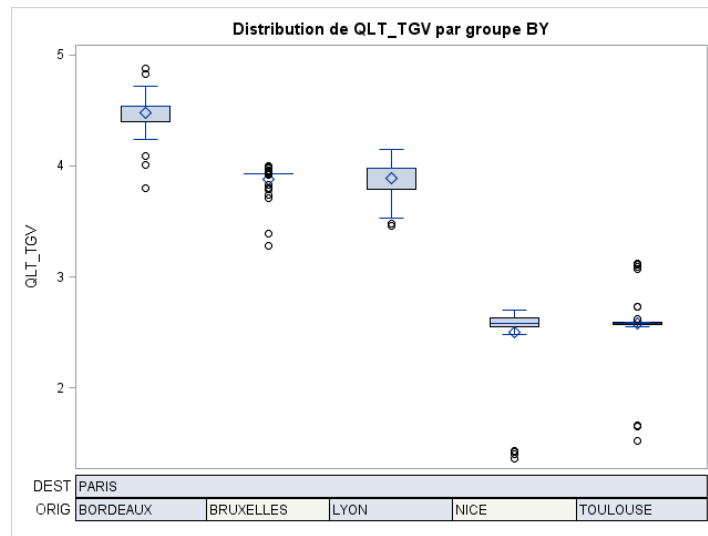


Fig. A2: Descriptive statistics - *HHL_PASS_CTRD*

