

Dynamic Structure of Fares for High Speed Rail Services

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Abstract. The entering of High Speed Rail (HSR) passenger services caused competition in the market with other conventional rail services, and other transport modes. The dynamic structure of fares in the HSR services assume a crucial role in the supply of scheduled transport services and influence travelers' choice behavior. The HSR fare structures, similarly to the air services, is characterized by evolutions and changes over time due to several factors, such as travelers' behavior; strategies of the companies supplying the HSR services. The results reported in the paper contain a framework for analysis of the evolution of fares over time in relation to the day of ticket purchase and of the day of trip. A sample representation of a pilot case study implemented on the existing HSR line between Rome and Milan (Italy), where two HSR companies operate and compete each other, is presented.

The aim of the study is to identify the characteristics fares evolution over time in the HSR market. This work is useful for support transport planners and decision-makers for the ex-ante evaluation of fare structure in terms of users' behavior.

Keywords: High Speed Rail · method for dynamic fares analysis · fares structure

1 Introduction

Worldwide extension of High-Speed Rail (HSR) lines, according to last report of Union International des Chemins de Fer [1], is about 129,850 km in the world: 59,498 km in operation, 19,927 km under construction, 16,850 km planned, and 33,575 km planned over longer term. The largest network today is in China (40,493 km), followed by Spain (3,917 km), which has overtaken Japan (3,146 km) and then France (2,735 km). The HSR network in Italy includes 921 km in operation and about 327 km under construction [2].

According to the European Union [3] the rate of CO2 emissions in the transport sector is about 20% of the global emissions. In order to pursue sustainable development as a priority, it is necessary to refer to the Sustainable Development Goals of Agenda 2030 [4–6], in particular focusing on the Goals 9, 11 and 13.

According to the SDGs annual Report of United Nation [7] the global CO2 emissions from energy combustion and industrial processes resulted in strong growth in the last two decades, reaching the record of 36,8 billion metric tons in the year 2022. It is

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necessary to recall that in terms of CO2 emissions [8], HSR is more sustainable than other transport modes, impacting about, respectively, 75% and 70% less than air and car modes. Therefore, the HSR mode-service goes in the direction of reaching the targets identified in the above mentioned goals.

The opening of HSR lines caused an increment of transport demand namely on its the three components [9, 10]:

- diverted, from other modes or other rail services;
- induced, in terms of trip frequency and destination generated by increment of level of service (e.g. reduction of travel time) due to HSR;
- economy-based, in terms of trip frequency and destination generated by increment of economy in the cities, or areas, served by HSR.

The entering of HSR in the market caused competition in the intermodal level (e.g., mode choice level) and intramodal levels (e.g., service and company choice level). The fare structures of HSR services play a key role in both levels of competition [11] in the intercity context. According to [12], HSR mode-service is mainly chosen in context of short-medium travel times and distances, in particular at the national scale. Hence, with a travel time about 2 h, HSR is completely chosen rather than air, within a travel time between 2 and 3 h and half HSR is the dominant mode, and with more than 3 h and half of travel time the air mode is the principal alternative for travellers. The positive effects of HSR on travel demand may be amplified when the HSR stations are located not far to residential and work areas [13–16], and to ports and related areas [14, 17, 19].

In the context of demand analysis, it is important to investigate the characteristics of fare structures in the HSR market. The analysis of dynamic structure of fare is an important issue for the company's perspective, for the maximization of revenues and seat allocation; but also, for the travellers' perspective, for the minimization of travel cost (in this case the monetary cost of trip). The analysis and the determination of the patterns of dynamic fares in the HSR market has relevant impacts on the transport services scheduling and on travellers' choices of competing modes and services.

The contribution of this paper is to provide a framework which is characterized by a dynamic approach based on the evolution of tickets, according two time variables: the *day of ticket purchasing* and the *day of trip*. The paper is developed in relation to the gaps in the current literature about fare structures in the HSR mode-services. The gaps regard the insufficient level of analysis in the context of dynamic fare structures of HSR services.

The following part of the paper is organized as follows. Section 2 analyzes the state-of-the-art concerning the dynamic fare structures, mainly in the air transport markets. Section 3 contains the description of the experimental framework for the analysis of dynamic structure of fares and a pilot survey on the Rome-Milan relationship. Some preliminary remarks and the issues for future research are reported in the last section.

2 Literature Review

The existing literature shows that the fare structure analysis and its determination in the transportation market is mainly oriented for two research objectives: revenue management and seats allocation optimization [18–21].

The fare structures may be classified in two main classes: static and dynamic [22]. Static fare structures are mainly used in the conventional passenger rail and bus services, whereas dynamic fare structures historically characterized air services. In the last decades, the dynamic fare structure in the context of air transport market has been adopted in the High Speed Rail (HSR) market. The dynamic approach implies fares changes over time, that are regulated and are dependent from several factors. For instance, the Italian HSR companies declare that the determination of fare values mainly depends on the following elements: the runs, the days of the week, the class and the time between the day of ticket purchase and the day of the trip, according to NTV [23]; the market conditions, the occupancy level of the train during the period, the day or the hour of travel, "regardless of the distances travelled by the passenger", according to Trenitalia [24].

The literature is wide about the Air mode insights; hence the paper regards the analysis of the HSR case, however, are analyzed papers about Air considered relevant because of the method applied. The Table 1 contains the selected papers, classified by the Author(s), the year of publication, the mode analyzed (HSR or Air), the country of the case study, the type of analysis (user behavior or fare estimation) and the objective of the analysis (revenue management or seat allocation). The Table 1 shows that the papers mainly focus on the objective of the analysis, and few papers deepened the type of analysis, thus the fare estimation or the user behavior.

Table 1. Literature review on dynamic fare structure in rail and air markets.

Paper	Year	HSR	Air	Country	User behaviour	Fare estimation	RM/SA
Zheng J., Liu J. [11]	2016	x		China			x
Koenigsberg O., et al. [18]	2008		x	UK		x	x
Malighetti P., et al. [21]	2015		x	EU		x	x
Zheng J., et al. [22]	2017	x		China			x
Hetrakul P., Cirillo C. [25]	2014		x	n.a	x	x	x
Selcuk A., Avsar Z. [26]	2019	x		EU	x		x
Yao E., et al. [27]	2013	x		China	x		x
Xiao YB., et al. [28]	2008		x	China	x	x	x

With: RM = Revenue Management; SA = Seat Allocation; n.a. = not available.

Zheng J. and Liu L. (2016) [11] handle the fare structures in order to optimize fares with the aim of maximize revenues of companies, including the effects on demand. The case study analyses the time-series of ticket-sale data in the Chinese HSR market context. The authors stated that the travellers' tickets purchasing is conditioned by various factors,

such as fare purchasing behaviour of travellers, travel distance, number of runs that serve the same origin-destination relationship, trip purpose.

Zheng J. et al. (2017) [22] analyse the fare structures and optimal timing of pricing, considering the role of transport demand. The paper shows that company pricing strategy, in terms of number of seats that is predetermined and changeless, and number of fare classes, have impacts on the travellers' fare choice behaviour. The Chinese case study contains two experiments based on historical ticket data analysis of HSR lines, that consider a ticket-selling period and the demand density, defined as the number of tickets sold divided by ticket selling hours in a day. The authors propose a fare structure determination based on a clustering approach in which every class of fares is characterized by a given prize.

Koenigsberg et al. (2008) [18] deal with low-cost fare strategies in airline transportation by analysing the scenario of a last-minute and low-fare pricing policy in the context of short-haul flights. The structure of fares is analysed in a European case study, and it is based on the EasyJet pricing policy in contrast to traditional airline pricing strategies that offer last-minute tickets. The analysis of ticket fares over a period of observation shows the variation of the fares comparing to the seat occupation, thus the tickets sold of each flight. The fares' observation shows that the relevant variation about the seats evolution (tickets sold) occurs during the most distant period to the travel day characterized by lower average fares (behaviour of the non-business users), whereas the highest fares variation is observed approaching the flight day. The empirical results of the analysis show that the fares value, organized in several segments, depends on the remaining capacity at a given time over the selling period, introducing the phenomenon of last-minute discounting, hence an additional selling period in which the airline has unsold seats.

Malighetti et al. (2015) [21] studied the EasyJet pricing policy throughout methods for fare structures estimation considering the effects of the demand. The objective of the paper concerns the identification of elements of competition based on the surveyed average fares and the role of demand in the pricing strategy. The paper shows that the competition reduces average fares, (e.g., in the analysis period between 2008 and 2009 of almost 10%). The fares offered, for different routes and departure days, were daily surveyed on the company website. The results show that the ticket fares are higher and less discounted when there is a direct competition among airlines companies on a specific origin-destination relationship. The parameters of the calibrated model show the increasing of the slope of the fare curve with the decreasing of the distance between the day of trip and day of ticket purchasing.

Hetrakul and Cirillo (2014) [25] analyse the travellers' behaviour about ticket purchasing with the aim of the identification of the optimal Revenue Management (RM) strategy. The results of fare analysis show that, on average, the fare variations over time are related to the distance between the day of trip and the day of ticket purchasing, to the departure time during the day, to the day of the week. The authors assume that users' behaviour about ticket purchasing is based on the fare variations over time and on personal attitudes towards the trip, such as departure time of day, day of week, and trip distance.

Selcuk and Avsar (2019) [26] deal with the analysis of dynamic pricing in the context of air transportation with the aim of revenue management. They investigate the relationship between the aggregate demand and the fares evolution over time. The implementation of a procedure for real-time dynamic pricing in a Turkish case study shows the influence on the pricing policy, in terms of price variation, on the number of the remaining seats.

Yao E. et al. (2013) [27] analyse the High Speed Rail (HSR) pricing strategies at the mode competition level with the aim of revenue maximizing throughout seat allocation strategies. A discrete choice model (Nested Logit) was calibrated in order to identify the relationship between ticket fare and HSR market share, based on the stated preferences data. The results shows that the probability of the users' choice behaviour to choose the HSR depends on the travel time and travel cost of each available alternative (HSR, conventional rail, air, and road), the profession and age of travellers and the trip purpose. The authors performed a sensitivity analysis on the marker share depending on the fare variations.

Xiao Y.B. et al. (2008) [28] investigate travellers' behaviour about ticket purchasing by means of a classification based on two main criteria, which are: price-based choice, where the travellers choose a flight with the lowest fare available, independently of the departure time; and time-based choice, where the travellers choose the flight on the basis of their desired departure time, regardless to the amount of the fare. The case study concerns the definition of the pricing strategy of an airline company by optimizing the revenue management on multiple flights.

It is evident that several examined papers use the fare structure analysis in order to optimize fares in the context of the revenue management or seat allocation optimization, thus in the perspective of the company supplying the transport services. The analysis of dynamic fare structures with regards to the travellers' perspective, analysing the travellers' behaviour about ticket purchasing is weakly studied in literature. Therefore, the contribution of this paper is oriented to provide a framework useful for the identification of fares of HSR services variation criteria according to the users' perspective.

3 Framework for Analysis of Dynamic Fares

The section presents a framework characterized by a dynamic approach of the analysis of tickets, c, along two time variables defined as follows:

- *p, day of ticket purchase*, day when a traveller chooses to purchase a ticket of a trip on a HSR run (e.g. a traveller chooses to purchase at day $p^* = 16^{th}$ of August, 2022 an "economy" ticket on an HSR run travelling from Rome to Milan);
- *t, day of trip*, day when a traveller chooses to make a trip (e.g. a traveller chooses to make a trip at day $t^* = 3^{rd}$ of September 2022 on a HSR run travelling from Rome to Milan).

It is easy to derive a new variable defined as the time interval, k, between the day of the trip, t, and the day of ticket purchase, p:

$$k = t - p \left[\text{days}\right] \tag{1}$$

that synthetizes the two time variables (e.g., the time interval between the day of ticket purchase $p^* = 16^{th}$ of August, 2022 and the day of trip: $t^* = 3^{rd}$ of September, 2022 is $k^* = 21$ days).

According to the above definitions, the value of the purchased ticket depends on a function of the two time variables:

$$c = c(p,\ t) \tag{2}$$

Case 1: intersection between $c = c(p, t)$ and the plane parallel to the (c, p) plane. In this case the day of trip is fixed, and the resulting intersection is a curve providing the evolution of ticket depending on p.

$$c = c(p) \text{ for } t = t^* \tag{3}$$

Case 2: intersection between $c = c(p, t)$ and the parallel to the (c, t) plane. In this case the day of ticket purchase is fixed, and the resulting intersection is a curve providing the evolution of ticket depending on t.

$$c = c(t) \text{ for } p = p^* \tag{4}$$

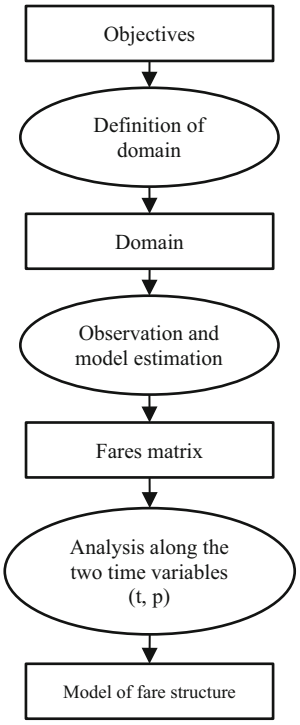


Fig. 1. Framework for analysis of dynamic fares

The proposed framework is composed by three steps (Fig. 1):

- definition of domain,
- observation and model estimation,
- analysis along the two time variables t, p.

Step 1: Definition of Domain. It is the first step after the definition of the objective(s), which may concern, for instance, the observation and the estimation of the patterns that determine the changes of fares with some characteristics associated to a given set of HSR services offered along a given origin-destination relationship.

According to the objectives, the definition of domain of analysis regards the following elements.

- *Number and type of HSR fares.* It is selected a reference fare to be analysed based on several criteria, for instance the cheapest fare of the economy class.
- *Day(s) of trip.* The day(s) of trip may be part of a set of days and may cover several days of the week, thus working days and/or holydays.
- *Day of ticket purchasing*. The day of ticket purchasing may also be part of a set of days and it allows to determine the distance between the day of ticket purchase and the day of trip. It is clear that the size of the set of days of ticket purchasing, p for a given t, should be enough extended to allow an accurate analysis of the dynamic structure of HSR fares.
- *Number of HSR runs.* A census analysis allows to analyse all the runs operating inside the day of trip, but this analysis could be too expensive in terms of resources. In order to conduct a sample analysis that considers the more representative runs of the day, the procedure may include several time windows, subdivided according to the objective of the analysis. The procedure applies a filter for the runs, belonging to the time window(s), in order to analyse the reference run assumed in relation to some criteria (e.g., minimum travel time, minimum number of intermediate stops).

Step 2: Observation and Model Estimation. The second step contains the observation of fares and a first elaboration of the observed data. The input of this step is the domain of analysis and the output obtained is an elaboration of observed fares.

The observation of fares, organized in a survey, may be conducted in several ways, by directly extracting the information from the companies' websites or by means of the support of automatic procedures (e.g. web scraping software). The data obtained are structured inside an observed fare matrix related to each HSR run, where the dimensions of row and columns are respectively the number of days of trip and the number of days of ticket purchasing. Therefore, the number of observed fare matrices obtained is equal to the number of monitored HSR runs.

The transition towards the model estimation involves the elaboration of the observed fare matrix, which concerns the alignment of the fares observed in different days of trip along each column associated to the day of ticket purchasing. Consequently, a new fare matrix is achieved. This new matrix shall be performed for each HSR run, monitored with its own characteristics (e.g. departure time, arrival time, number of intermediate stops).

The resulting elaborated matrix is the input of the successive steps of analysis, thus the analysis along the time dimension of the day of ticket purchasing (p) and along the time dimension of the day of trip (t) in order to estimate a model of fare structure.

Step 3: Analysis Along t and k. The fare structure analysis with the approach along p (day of ticket purchasing) is composed by several parts. The first part regards the calculation of the matrix containing the day-to-day variations of fares. The second part includes an additional filtering operation, by using a threshold which allows the identification of the first day registering significant fares variations; therefore, it is possible to identify different regions of fares. The next step concerns the development of curves representing the average pattern of fare structure inside the identified regions (e.g. the curve could be a sub-horizontal line: c = cost, in the region farther from the given day of trip t*). The output of this analysis gives back the estimated curve describing the dynamic fare structure along the time variable p.

The fare structure analysis characterized by the approach along t concerns in an initial calculation of descriptive statistics associated to the observed fares. The next part regards the analysis of fares frequencies with a clustering approach, grouping into a homogeneous number of classes. Therefore, each fare cluster is analysed and curves of the density of probability are estimated. The output of this analysis gives back the estimated pattern describing the dynamic fare structure along the time variable t.

4 Pilot Experimentation on the Rome-Milan Relationship

The framework described in Sect. 3 is tested in a pilot experimentation on the Italian High Speed Rail (HSR) relationship Rome-Milan in Italy (Fig. 2). The opening of the HSR line between Rome and Milan in 2009 generated a modal competition, causing the diversion of travel demand from air services and the induction of new traffic due to several factors such as the increased level of service offered by HSR (e.g. reduction of on-board travel time, reduction of access-egress times from HSR stations). According to [29] the passenger flows in the year 2008 were about 2,4 millions/year by air and 1,0 millions/year by conventional rail; whereas in the year 2018 the flows were around 1,2 millions/year by air and 3,6 millions/year by HSR.

The above demand flows data shows clearly that there is a diversion from air to HSR (considering the Conventional services equal to 0) of about 1,2 million passenger and the other rate of demand, that is about 1,4 million passengers, is due to the induced component of demand.

In Italy there are two HSR companies operating along this relationship, namely Trenitalia and Italo Nuovo Trasporto Viaggiatori (NTV), which compete each other. The frequency of HSR services was respectively 45 runs/day for Trenitalia and 33 runs/day for the NTV.Both companies operating in Italy organizes the ticket fares into two main branches, which are “Business” and “Economy”. On one hand, Trenitalia offers a wide set of fares classifiable mainly in which the ticket fare is determined on the basis of the classes (e.g., “Super Economy”, “Economy”, “Base”) and the levels of service (e.g., “Standard”, “Business” “Premium”,…), according to the services offered to the travelers. On the other hand, Italo NTV determine the ticket fares into three classes “Low Cost”,

"Economy" and "Flex", hence each of these is characterized by different levels of service (e.g., "Smart", "Prima Business", …), in relation to the services offered to the travelers. The availability of the tickets, thus the number of classes and the levels of service may numerically vary in relation to several criteria, for instance the time interval k (1), thus on the basis of the companies' pricing policy.

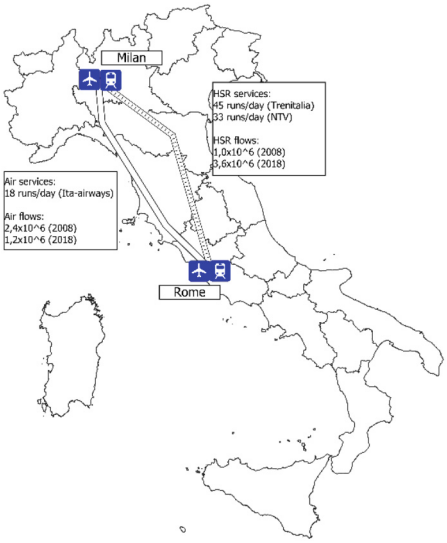


Fig. 2. Rome-Milan relationship

The paragraph describes the application of the first two steps of the framework presented in Sect. 3, which are: "definition of domain" and "observation and model estimation".

Step 1: Definition of Domain. The domain of analysis is formed by the following elements.

- *Number and type of HSR fares.* The fare "Super Economy – Standard" (in which "Super Economy", in row, is the fares' class and "Standard", in column, is the fares' level of service) offered by Trenitalia company is surveyed, which is the cheapest ticket available of the cheapest class (in row) fares offered at each day. Are excluded the fares of particular conditions, for instance: elder, or young passengers.
- *Day of trip.* The pilot case study considers a single day "t", assuming that a traveller chooses to make a trip at day $t^* = 3^{rd}$ of September, 2022 from Rome to Milan.
- *Day of ticket purchasing.* The observed set of days of ticket purchasing, p, concerns ranges from July the 26^{th} of 2022 to September the 2^{nd} of 2022, in which the survey of the selected fare in the selected day of trip is conducted.
- *Number of HSR runs.* The run $r^* = 9634$ was analysed from Rome to Milan relationship, operated by Trenitalia company belonging to the time window 6:00am.-9:00a.m., which consider the peak periods of traffic. The run 9634 is identified by the

criteria of the minimum intermediate stops, hence it is considered as a representative run in the defined time window.

Step 2: Observation and Model Estimation. The fares' observation was conducted by esk on the website of Trenitalia company in relation to the definition of domain.

The fare above mentioned, Super Economy-Standard, has been surveys during the period identified. In the case of absence of the fare in a day p, the decision was to survey the next fare belonging to the same class (e.g., "Super Economy" or "Economy"), and moreover in case of absence of the last fare belonging to the same class, the cheapest fare of the upper class was surveyed (e.g. "Super Economy-Premium").

As far as concerns the analysis along t, the diagram in Fig. 3 shows the evolution of the fares surveyed with the criteria above mentioned along the time variable *p* by considering the day of trip: ($t^* = 03^{rd}$ of September, 2022). If we define a day of ticket purchase, $p^* = 16^{th}$ of August, 2022, the distance between the given day of ticket purchase and the given day of trip, thus the interval $k^* = 3/09–16/08 = 21$ days.

Figure 2 shows that the fare structure is formed by two main regions:

- region 1, more distant from the day $t^* = 03^{rd}$ of September, 2022, is characterized by an evolution sub-horizontal, where the ticket fares are almost stable;
- region 2, closer to the day $t^* = 03^{rd}$ of September, 2022, where the fares evolution shows an increasing positive gradient due to the variation of the ticket fares.

It is possible to identify a threshold, correspondent to one or a group of days of ticket purchasing k*, that defines the boundary between the two above regions.

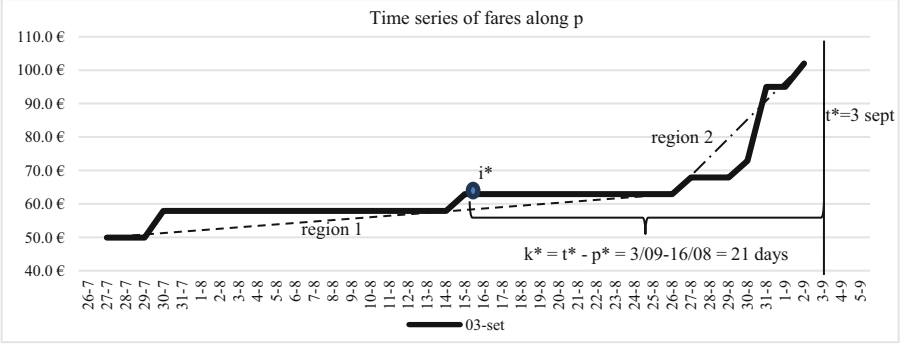


Fig. 3. Time-series of fares along p for a given $t^* = 03^{rd}$ of September, 2022

Regarding the analysis along the direction p, the Fig. 4 shows the pattern of the fares surveyed in the examined days of trip taking into account the time interval (1) $k^* = 21$.

The diagram should, but it is not univocally defined, a tendency where the fares' values increase in proximity of the weekend days and decrease during the working days. This trend must be further investigated with the support of a more extended range of observations.

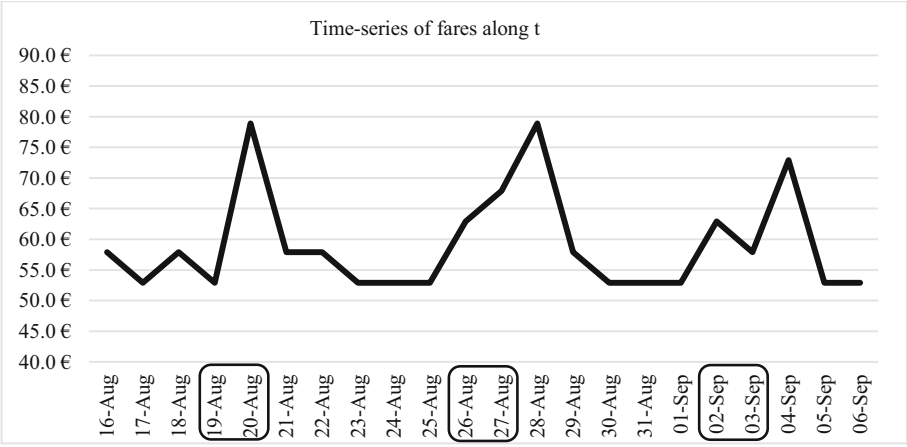


Fig. 4. Fares' time-series along t direction, for a given period k* = 21 days.

Table 2. Descriptive statistics of the time-series of fares along p (Fig. 3) and along t (Fig. 4)

	Figure 3 (p)	Figure 4 (t)
n.obs	37	22
Avg	64.8€	59.1€
Var	25.2	70.2
Min	62.9€	52.9€
Max	85.9€	78.9€
avrΔ(27/07–26/08)	1.35	n.a
avrΔ(27/08–02/09)	–	0.2
avrWE	66.2€	63.9€
avrWD	64.1€	57.3€

With: n.obs = number of observations; Avg = average; Var=variance; Min = minimum; Max = maximum; avrΔ = average gradient; avrWE = average in weekend days; avrWD = average in workdays; n.a. = not available

Finally, the Table 2 contains some descriptive statistics calculated for the time-series presented in Figs. 3 and 4. The results shows that the minimum value of fares is lower in the direction k* than in the direction t* while the maximum value of fares is higher

in the direction t* than the direction k*. The average variation is considerably greater for the t* direction, whereas on weekends and working days the average value of ticket fare is higher by analysing t* direction.

5 Conclusions

The paper deals with the analysis of the characteristics of the HSR fare structures in the context of the demand analysis. The analysis of dynamic structure of fare is an important issue in the transport supply and in travel demand estimation, because of the determination of the fares has an important impact on the transport services scheduling and on the users' choice behaviour.

The gaps in the current literature about fare structures shows that the theme of the analysis of fare structure patterns in the HSR market is not sufficiently studied. Thus, the paper contribution regards an experimental framework characterized by a double dynamic approach for analysis of HSR fares analysis, that concerns an analysis along the direction of the day of ticket purchasing and along the direction of the days of trip. The pilot experimentation on a HSR run along the Rome-Milan relationship in Italy shows a sample of dynamic structure of the fares. The variation of fares along k is characterized mainly by the distance between the day of travel and the day of ticket purchasing (the *i* time interval), and the day of the week (e.g., weekend days or workdays); whereas the variation of fares along t is characterized by the time interval *i*, the day of the week, the pricing policy of the HSR company.

Future research directions of development of the framework presented in this paper may concern the application of the steps concerning the specification and estimation of the curve of the fare structure that represent the data of the ticket cost observed during the period of analysis, thus the individuation of the variation criteria. Moreover, two or more types of economy and business fares will be analysed, representing the behaviour of two segments of travellers also in relation to fares of airline services.

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