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Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: ten years ex post evaluation and future perspectives

Ennio Cascetta[a], Armando Cartenì[b], Ilaria Henke[a,*], Francesca Pagliara[a]

[a] Department of Civil, Architectural and Environmental Engineering, Università degli Studi di Napoli Federico II, Via Claudio, 21, 80125 Napoli, NA, Italy
[b] Department of Engineering, University of Campania "Luigi Vanvitelli", via Roma 29, 81031 Aversa, Caserta, Italy

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ABSTRACT

The deployment of HSR services in the recent decades has been, arguably, the most significant innovation for intercity travel around the globe. HSR has brought impacts which have been widely studied in different countries in relation to the different socioeconomic, territorial and transport characteristics.

This paper analyses the economic growth, the transport accessibility and the social impacts observed in Italy after ten years of HSR operation, as well as the estimated impacts of the system completion. The Italian case study is of particular interest since along the 1,467 km of new high speed line (300 km/h), a combination of major cities distances and a unique HSR competitive market, producing prices reductions and more daily trains, brought a 200% increase of HSR demand (from 15 to 45 millions of passengers/year). Estimations results show that, on average, HSR in Italy contributed to a significant increase in transport accessibility (+32%) for the zones along the HSR network, while only marginal for the others (+6%). Impacts on the economic growth show that HSR has contributed to an extra growth of per capita GDP of + 2.6% in 10 years and would have contributed to a further increase of 3.6% if the final project scenario (HSR_N) would had been completed by 2018. Regional (horizontal) equity impacts were evaluated in terms of the Gini indexes variations with respect to the distribution of the transport accessibility. It results that HSR in Italy has decreased equity in terms of users' travel time accessibility of 11%, increasing the differences between the zones served by HSR and those not. If the HSR_N scenario would have been completed equity indices would have increased of 29% with respect to the pre-HSR 2008 scenario, thus reducing regional inequalities in the country.

Results show that the HSR project was a country-level "game changer" in Italy, suggesting that the wider economic benefits, the assumptions on market regulation, the effects on regional disparities and the compensatory measures should be included in the ex ante and ex post evaluation of similar projects.

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[*] Corresponding author.

E-mail addresses: ennio.cascetta@unina.it (E. Cascetta), armando.carteni@unicampania.it (A. Cartenì), ilaria.henke@unina.it (I. Henke), fpagliar@unina.it (F. Pagliara).

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1. Introduction and motivations

In the last decades many investments have been made out around the globe in High Speed Rail (HSR) systems resulting in more than 40 thousand kilometers of new lines in several countries which is the most significant innovation in intercity travel. In 2016, the European HSR network was more than 8,100 km long and it is planned to reach more than 22,000 km by 2025 (Cascetta, 2019). In China public expenditure in HSR lines has been justified as a socially desirable public investment; 25 thousand kilometers have been built in the last years and a further one thousand kilometers are planned by 2025.

The deployment of new HSR services has brought impacts which have been widely studied and analyzed in different countries (e.g. Australia, Belgium, China, India, Italy, France, Spain, Turkey, United Kingdom, USA as detailed in the following references) in relation to the different socio-economic as well as transport service characteristics (e.g. train speed, frequencies, modal shares). Cartenì et al. (2017) proposed a classification and a list of the possible effects induced by HSR services grouped in transportation system impacts (internal), socio-economic impacts (external) and environmental impacts (external). The first ones deal with the demand level, modal share and transport accessibility variations (e.g. Delaplace et al., 2016; Martin et al., 2014; Borjesson, 2014; Chai et al., 2018; Wan et al., 2016, Cascetta and Coppola, 2017). Socio economic impacts deal with the analysis of the externalities in terms of land-use changes (e.g. Willigers and Van Wee, 2011 for the case study in Netherlands, Ibeas et al., 2012; Moyano et al. 2018 for the case study in Spain, Cao et al. 2013 for the Chinese case study), tourist attraction (e.g. Masson and Petiot, 2009; Albalate and Fageda, 2016; Campa et al., 2016; Guirao and Campa, 2016; Moyano et al. 2016; Pagliara et al, 2017c, Pagliara and Mauriello, 2020) and wider economic impacts (e.g. Guirao et al., 2017; Vickerman, 2018; Preston and Wall, 2008; Graham and Melo, 2014; Connolly et al., 2014). Finally, the environmental system effects refer to the complex of externalities associated to transport systems, e.g. changes in pollutant emissions, greenhouse gas emissions, accidents variations, climate change costs (e.g. D'Alfonso et al., 2016; Connolly et al., 2014; Chen et al., 2016; Chang and Kendall, 2011; Robertson, 2018).

Starting from these considerations, the focus of this paper is on a systematic analysis of the economic growth, transport accessibility and social impacts observed in Italy after 10 years of HSR services in a uniquely competitive market as well as the estimated impacts of the system completion. Specifically, the social effects have been studied in terms regional equity issues, while the economic ones have analyzed in terms of the incidence of the transport accessibility variations on per capita GDP growth.

In the field of transportation systems, equity has been mainly defined from the transport user's point of view, in terms of transport accessibility to facilities and services (e.g. Church et al., 2000; Vasconcellos, 2001; Keynon et al. 2003; Stanley and Lucas 2009; Lucas and Musso 2014; Macario,2014; Lucas et al., 2016, Lucas and Porter 2016; Lucas, 2018; Banister, 2018; Cascetta et al 2017), even if there are also applications dealing with other issues like the environmental justice, which focuses on the equity impacts of the environmental-related outcomes of transportation systems (Forkenbrock and Schweitzer, 1997; Feitelson, 2002). Low transport accessibility means, for example, having low accessibility to job opportunities, health and education facilities (Lucas et al., 2016). Two types of equity can be defined: vertical and horizontal (e.g. Le Grand, 1984; Litman, 2002; Delbosc and Currie, 2011). By vertical equity (also called social justice or social inclusion, e.g. Litman, 2002) it is meant the analysis of the distribution of the costs and/or benefits among the different groups of people differing in the (transportation) needs, income, social class etc. (e.g. Litman, 2002, Falcocchio et al., 2018). On the other hand, the horizontal equity deals with the equal distribution of the benefits/costs (monetary or otherwise) distributed to the maximum number of people independently of their needs (e.g. Litman, 2002). Horizontal equity is based on the concept of equal treatment, i.e. all people/groups are equal in ability and (transportation) need and should benefit from equal opportunities (e.g. activities, transport services). According to this definition, equal people/groups should receive equal resources/benefits, bear equal costs and be treated in the same way (e.g. Litman, 2002; Currie, 2004; Manaugh et al., 2015; Fransen et al., 2015; El-Geneidy et al.; 2016a; Cascetta et al., 2017; Martínez et al., 2017; Ben-Elia, Benenson, 2019).

Quantitative impacts of HSR systems on equity issues from the users' point view have been less studied in the literature. For example, Cass et al. (2005) in UK qualitatively indicated that HSR has both positive (e.g. increased accessibility to activities for commuting users) and negative (e.g. on *spatial equity/ physical exclusion* between locations or territorial areas) social impacts. The study carried out on the HSR in Spain by Monzón et al. (2013) showed that the increased speed from 220 km/h to 300 km/h has produces significant negative impacts on spatial equity among territorial areas before and after the new rail services. Chen and Wei (2013) reported the case study of Hangzhou East Rail station in China, where HSR has been still not affordable for the majority of the population (vertical equity implication). Hou and Li (2011), with reference to the HSR network under construction in the area of the Greater Pearl River Delta (in China), estimated an increase in disparity (in terms of transport accessibility) in the early stages of construction, predicting that this low accessibility would persist until the final completion of the project (expected in 2020) after which a rebalancing stage might be expected. However, at the same time, Zheng and Kahn (2013) showed from a qualitatively point of view that there were positive effects of the HSR deployment even for people who lived far from the "*core area*" (that is the area directly connected with the HSR network) as a result of the urban agglomeration. Kim and Sultana (2015) studied the impacts of HSR extensions on accessibility and spatial equity changes in South Korea. They showed that the increase of accessibility has been mainly perceived by the cities along the main HSR corridor near the well-established Seoul capital area, while the rest of the country has been practically cut off from the benefits of this transport intervention.

The other aspect considered in this research is represented by the impacts produced by the transport services/infrastructures on economic development (e.g. Costa-Font and Rodríguez-Oreggia 2005, Pereira and Andraz 2006; Cosci and Mirra; 2018). Any intervention aimed at improving the transportation system can: *i)* foster the local production, making producers access to distant markets and bringing inputs from a larger area (e.g. Hong et al. 2011); *ii)* attract foreign direct investments, which is considered an important engine of the economic growth (e.g. Hong 2007); *iii)* accelerate industrial agglomeration producing lower transport costs (e.g. Baldwin and Forslid, 2000; Krugman, 1991); *iv)* increase labour productivity, due to the concentration of economic activities (e.g. Ciccone and Hall, 1996). However, some studies have shown contrasting impacts of transport investments on the economic growth as a function of the territorial scale (e.g. national, regional and local vs. urban and rural), the time period analysis (e.g. Gagliardi and Percoco, 2017; Mohmand et al., 2017; González, Nogués, 2019; Ji et al. 2019) and the transport mode (e.g. Ji et al. 2019, Agbelie, 2014).

With respect to HSR, there are several studies in the literature evaluating its impacts on economic development (e.g. Ahlfeldt and Feddersen, 2018; Chen and Haynes, 2017; Diao, 2018; Jia et al., 2017; Ke et al., 2017; Kim et al., 2018; Meng et al., 2018; Vickerman, 2018; Yang et al., 2018). For example, in Spain, HSR investments have brought benefits to the economy and to the GDP of the Country (Vickerman, 1997; Banister and Berechman, 2000). In China (Chen, 2019) the increase in rail accessibility has led to an increase in the GDP of the regions served (the weight of the HSR on GDP growth was estimated in about 8% in 11 years). Other authors, however, showed that HSR had a positive effect on the economy of some cities, but negative on others (Vickerman, 2018; Wang and Duan, 2018; Sasaki et al., 1997). Chen and Haynes (2017) confirmed that the regional economic disparity in China increased with the introduction of HSR and this statement was also confirmed by Yu and Yao (2019) who, through the Gini coefficients, measured the income disparity level at the national scale and within urban and rural areas in China.

The Italian case study is of particular interest for the analysis of all the above mentioned impacts for a number of reasons. Ten years have passed since the inauguration (in 2009) of HSR services using mostly the new 1,467 km line from Turin to Salerno. In subsequent years, HSR services grew considerably passing from 15 millions of passengers/year in 2009 to 45 millions of passengers/year in 2018 (+200%). As far as the authors know, there is no other major HSR project in the world showing these levels of demand and supply growths. These results are certainly due to the Italian geography, with a chain of medium sized city aligned between 150 and 250 km apart, but also to the introduction of the first fully competitive market with two HSR companies providing comparable services on the same, publicly owned and regulated infrastructure and operating without public subsidies. This competition has brought lower prices and higher frequencies for travelers. On the other hand, despite the unprecedented success of HSR services during the last ten years, the HSR topology has remained substantially unchanged, as no new sections have been added to the network. This block in the system deployment, due among other things to the economic crisis post 2008, has allowed to observe the trajectories of two parts of the same country: one enjoying the significant increase in accessibility due to HSR services and another, very significant both in geographic and population terms, excluded by these benefits. Furthermore, during these ten years, no other significant transport infrastructures were added to the Italian network nor medium range new intercity services competing with HSR services were started, so the main observed transport accessibility variations are those related to HSR services. In 2017 the Italian Government defined the "*HSR development project*" (Ministero dell'Economia e Finanza, 2017) aimed at extending the current HSR network to other areas of the country through a mixture of new lines and the upgrading of the existing ones (HSR_N project scenario), allowing also an *ex-ante evaluation* in terms of the expected social and economic impacts.

Starting from these considerations, regional impacts have been quantified through the estimation of active transport accessibility indicators (in terms of travel times, ticket prices and a combination of them) able to quantify the variation in accessibility observed for different zones of the country due to HSR services. Specifically, accessibility decay functions have been calibrated using an ad hoc RP surveys carried out on 2,805 HSR travelers. The economic growth impacts have been computed through a multiple regression model relating 10 years per capita GDP percentage variations, observed in different areas, to socioeconomic and transport variables, in order to quantify the incidence of transport accessibility changes due to HSR.

Finally, the spatial horizontal equity effects (impacts) induced by HSR in Italy have been computed through the estimation of GINI indexes variations, with respect to both the economic growth (per capita GDP) and the rail transport accessibility. Social and economic impacts have been estimated with respect to three different scenarios: *i)* basic scenario (2008, before HSR); *ii)* current scenario (2018, ex-post); *iii)* HSR_N project scenario (ex-ante).

The paper is organized as follows. Section 2 reports the case study of the ten years of HSR in Italy and the survey results. Section 3 describes the quantitative impacts results estimations. Finally, conclusions and research perspectives are reported in Section 4.

2. The case study: ten years of HSR in Italy

The story of the HSR network in Italy is a long and controversial one[1]. It begun in 1975, only 10 years after Japan and before the French TGV, with the construction of the "*Direttissima*" Rome-Florence, line with a design speed of over 250 km/h and with the aim of connecting two of the main Italian cities without intermediate stops. The construction of this rail section was completed only in 1992 when the service began. The decision-making and implementation process of the Italian HSR network started in 1986 with the *National General Transportation Plan* which identified a network of HSR lines as a tool for both relaunching the national rail transport and complying with EU directives. Only in 2005 the second section of the network, the "Naples-Rome" line, became operational and in 2009 the entire "Turin-Salerno" line was completed. After these interventions, few HSR stations have been inaugurated and the section "Milan-Brescia", 95 kms long, was opened in 2016. Overall, the entire network is 1,467 km long with fourteen HSR stations (Fig. 1) and a population of more than 20 millions of inhabitants (34% of the total) live within 0.5 h/30 km from a HSR station[2].

Today in Italy there is the only example of in the market competition for HSR services (e.g. Cascetta and Coppola, 2015). The history of the liberalization of the Italian HSR market starts with the transposition of European directive CEE 440/1991 (implemented

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[1] Further details on the history of the HSR deployment in Italy can be found in Cascetta (2019).

[2] Travel times/distances have been estimated through the current (2018) Italian transport network and refer to the faster transport mode (car, bus, train).

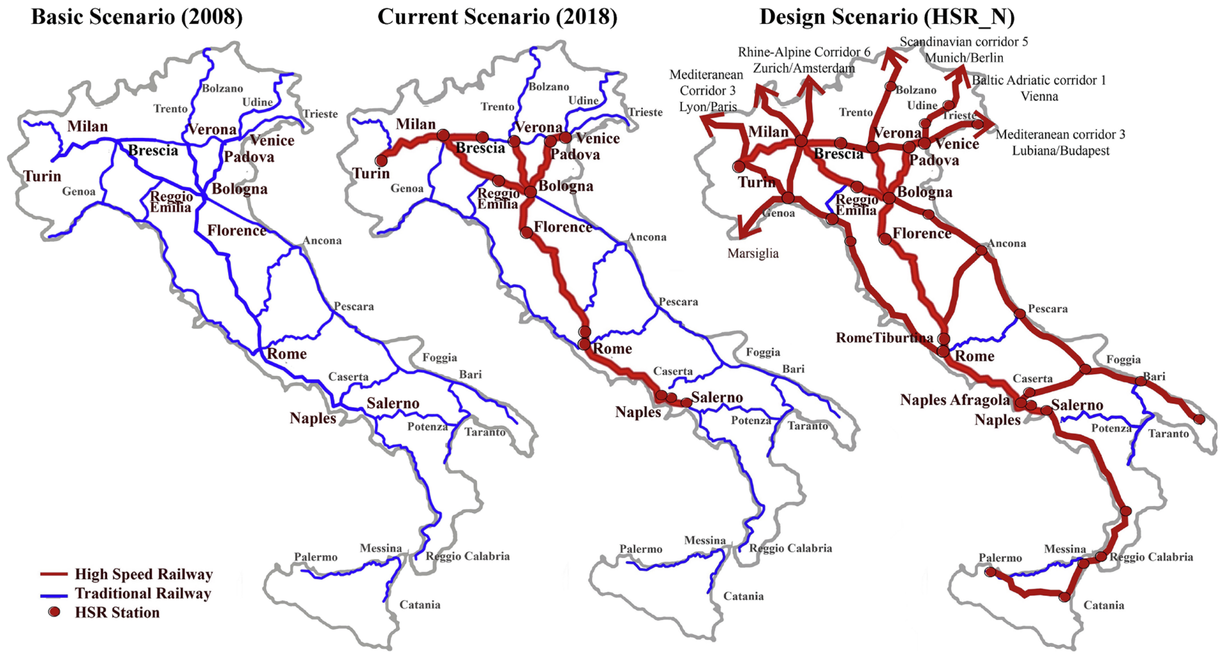

Fig. 1. The Italian HSR Network: basic scenario, current scenario and project development.

in Italy with the acts DPR277/1998, DL146/1999, DL188/2003) aimed at developing the European railways network. The European “*First Railway Package*” (EU directives 12/2001, 13/2001 e 14/2001) in 2001 regulated the separation between the management of the rail infrastructure and the operation of transport services. In 1997, the rail service company “*Italiana Trasporti Ferroviari*”, renamed in 2000 into “*Trenitalia*” was separated from the unique company Ferrovie dello Stato (FS) holding 100% of the shares. In 2001 the Italian Government supported the emanation of the “*Italian Railway Network*” (RFI), a company managing the railways network (supply-side) belonging to the holding Italian State Railways (FSI). In 2007 with the Italian law DL162/2007 (in response to the European “Second Railway Package”), the “National Rail Safety Agency” for controlling/regulating the use of the Italian rail network was established. In 2007, the European “*Third Railway Package*“ was emanated (implemented in Italy with the law 99/2009), which established the rights to use the international passenger rail network. With the opening of the rail market competition, in December 2006 ”*Nuovo Trasporto Viaggiatori*“ (NTV) was born with an initial investment of 1 billion Euros by private investors and without any subsidy from the Italian State, becoming Trenitalia's unique competitor in the HSR market. In February 2007 NTV obtained the railway company license but only in 2012 it started operation of HSR services competing with those provided by the incumbent Trenitalia. By 2018, 213 trains per day are produced by the state rail company Trenitalia and 90 by the private rail company NTV.

In Italy the HSR services have been integrated with a number of “costumers care” features going from a yield management system for tickets proposing a variety of offers for the same trip, on board dedicated personnel, dedicated waiting rooms etc. HSR services are perceived as a real “brand”, as proposed by Cartenì et al. (2017), the symbol of a comfortable and quality travel. Attention has been dedicated to terminals as well from 2000 onwards new stations have been built, and existing ones have been substantially renewed following the principle that a station, besides being functional and useful, should be beautiful and comfortable. Among the distinguished architects, who have designed the railway stations in Italy, there are Santiago Calatrava for the “Reggio Emilia” and Zaha Hadid for the “Napoli Afragola” stations respectively. The Porta Susa station in Turin and the “Roma Tiburtina” station show that rail stations can be an opportunity also for urban regeneration.

Ten years after the opening of the “Turin-Salerno” line, it is possible to evaluate the impacts that HSR has produced. Several authors have studied the main impacts induced by HSR in Italy. Regarding the transportation system (internal impacts), HSR services have brought a reduction of the travel times between the main cities larger than 30%. The average speed on the Italian HSR lines is around 164 km (including intermediate stopping times), 32% higher than the one observed on the traditional rail network. In addition to an increase in the average speed, the introduction of HSR has increased the services for travelers.

Concerning the prices, the choice among 30 different ticket typologies, has produced an average ticket price reduction of about 40% with respect to the year 2008. This is mainly due, as stated, by the entry in the year 2012 t of the NTV private operator in the HSR market, which has started competing with the state operator Trenitalia, with effects comparable to those produced by the low-cost airlines in the air market. By contrast, for the traditional railway services a much more marginal decrease in ticket prices has been observed, quantified in about −15%.

In addition, to the reduced travel times, a significant increase in frequencies has also been observed. For example, between Naples and Rome before HSR, 34 trains per day travelled on an average weekday (Cascetta et al., 2011). Today, 10 years after the introduction of the HSR service, about 94 trains travel on the Rome-Naples section on an average weekday with a frequency in the peak hour of one train every 6 min. Also the HSR demand, as stated, has increased very significantly, passing from 15 millions passengers/year in 2009 to 45 millions passengers/year in 2018 (Cascetta, Coppola 2017; Ministero dell'Economie e Finanze, 2018). Of the 43 millions of travelers, 7 millions are estimated as deviated from the traditional railway services, 19 millions have been attracted from other transport modes (private car, buses and air) and 17 millions represent a generated demand (Cascetta, Coppola 2017; Ministero dell'Economie e Finanze, 2018).

In order to analyze the demand of HSR services and estimate the transport accessibility models described in the following Section 3.1, between October and December 2018, an ad-hoc computer-assisted web interviewing survey was carried out in five main HSR stations, Naples, Rome, Florence, Bologna and Milan. Travelers (aged $>$ 18 years old) were interviewed[3] while they were waiting for a HSR train. Information were gathered on the socio-economic characteristics (e.g. age, gender, education level) and travel habits (e.g. destination, ticket type; trip purpose and frequencies). 2,805 HSR passengers were interviewed (with a sampling rate of about 2% of the average HSR daily trips), randomly selected and stratified according to the cities population census data. The main results of the survey show that the average Italian HSR traveler is comparable with ones of the national population census data. Specifically, 51% of the respondents were men and 83% were 25–65 years old. The average education level of the HSR user was high (university and/or PhD degree) for the 56% of the travelers and higher than the average national ones (19%). This result was consistent with those observed by Wang et al. (2017) for the Chinese passengers. Concerning the travel behavior characteristics, the results of the surveys showed that about 91% of HSR users were Italian for whom the 37% of the trips were for business purposes, 19% for commuting, only the 13% were for tourism and the 31% for other purposes. By contrast, with respect to the non-Italian HSR users, the 61% travelled for tourism purpose, the 6% for business, the 2% for commuter, the 14% for other purposes and the 17% prefer not say.

Finally, the HSR network has produced external impacts also on the environmental system: the external cost of the HSR is 70% lower than that of car and of 59% less than that of the airplane (International Union of Railways,2010). The amount of CO_2 saved for people travelling with the HSR service compared to the car and the airplane is about 700 thousand tons /year. 700 thousands of tons of CO_2 are equivalent to the emissions related to the trips of a city of 1 million of inhabitants, this means that with the HSR train the environment has saved the emissions produced in a year by a metropolis for urban journeys (e.g. Naples in Italy).

Despite the success of HSR services, no significant extensions and a slowdown of the project have been observed, due, among other things, to the economic crisis post 2008. This, as stated, has produced a geographical separation between parts of the country, i.e. those benefiting from the new HSR basic accessibility and those which are not. This questions was addressed at the planning stage in the "*Allegato Infrastrutturale al Documento di Economia e Finanza*" (Ministero dell'Economie e Finanza, 2017) which aimed at extending the current HSR network to other areas of the country in order to increase both the rail transport accessibility and the equity. The design scenario will extend the HSR network up to more than 5,000 km by the year 2030 and to 30 HSR stations (red lines in the "HSR_N design scenario" of Fig. 1). This result will be achieved by a mix of new lines with lower "maximum speed" (200–250 km/h) and commercial speed increases on the existing (traditional) lines where it will be possible to reach commercial speeds exceeding 150 km/h. This project scenario is called "High Speed Railways Network" (HSR_N) with more than 32 millions of inhabitants (56% of the total) served by a HSR station within 0.5 h/30 km (and 76% of inhabitants served by a HSR station within 1 h/70 km).

3. Transport accessibility, economic growth and equity impacts induced by the HSR services in Italy

As stated, the aim of this paper is to quantify the economic growth, the transport accessibility and the regional equity impacts induced by the HSR in Italy. For this reason, this section has been structured into three sub-sections representing the three main aspects of this research. In turn, each sub-section is proposed as "*self-contained*", describing the methodology proposed, the (minimal) references supporting the methodological choices and the main results obtained.

3.1. Impacts on accessibility

In order to quantify the transport user's impacts, an accessibility analysis has been performed. The concept of accessibility has been long discussed in the research on transportation planning as a measure of "*the extent and quality of the interaction between land development patterns of a given area and the transportation systems serving it*" (Cascetta et al., 2016). From a theoretical point of view, accessibility reflects either the ease of a user to reach opportunities in a territorial area to carry out an activity (active accessibility), or the ease with which an activity can be reached by potential users (passive accessibility). For further details on these dual concepts and the corresponding methodological problems involved, see for example Ben-Akiva and Lerman (1979), Cascetta (2009), Geurs and van Wee (2004) and Pirie (1979). Accessibility measures are commonly used in transportation planning for the evaluation of the projects/plans involving both transportation and land-use systems.

Accessibility can be quantified through synthetic indicators (measures) based on level-of-service and the land-use indicators suitable for considering the relationships between transport and activity systems. Within this class of accessibility indicators, isochrones, cumulative-opportunity and gravity-type measures are commonly used as aggregate place/zonal accessibility indicators (this is the case in this research), while utility-based models, space–time measures and perceived opportunities models are generally implemented for individual (disaggregate) user accessibility estimation (e.g. Kwan, 1998; Handy and Niemeier, 1997). For example,

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[3] Daily time from 7:30 am to 6:00 pm, considering both business days and holidays and weighting different days according to the average number of passengers/day.

González and Nogués (2019) believe that gravity-type measures (e.g. infrastructure- and location-based indices) are more suitable for the assessment of the relation between transport planning and regional development and these long-standing formulations of accessibility measures are still widely adopted in the field literature (e.g. Odoki et al., 2001; Recker et al., 2001; Halden, 2002; Geurs and Wee, 2004; Bertolini et al., 2005; Straatemeier, 2008; Geurs et al., 2010; Chen et al., 2011; Condeço-Melhorado et al., 2011; Ferrari et al., 2011; Delmelle and Casas, 2012).

For the scope of this research, an active rail-based accessibility gravity-type model, AA_o, has been estimated to evaluate the (zonal) regional accessibility variations induced by the HSR in Italy. Gravity-type indices are characterized by an attraction variable O_d related to the number of opportunities available at destination zone d (e.g. total number of employees/firms) and an impedance function measuring the spatial separation (e.g. level of service attributes) between the origin zone o and the destination zone d. It has been observed in many cases that the perception\availability of an activity/opportunity is not linearly proportional to the level of service attributes (e.g. distance, travel time), and it possibly follows a distance–decay principle. The most common non-linear functions proposed in the literature for quantifying the distance–decay effect are the inverse power function and the negative exponential function (e.g. Cheng and Bertolini, 2013; Martínez and Viegas, 2013; Hooper, 2014, Kwan, 1998), although other less popular specifications can be used (e.g. Gaussian, Fotheringham and O'Kelly, 1989).

Starting from these considerations, different distance–decay specifications (i.e. inverse power, negative exponential function and Gaussian formulations) jointly with different attraction variables (O_d) and level of service decay attributes (X_{od}) have been tested:

$$AA_o = \sum_{d=1}^{Nd} NEIST_d^{\alpha} \cdot f(X_{od}) \tag{1}$$

$$\begin{aligned} &\text{Inverse power:} && f(X_{od}) = X_{od}{}^{-\beta} \\ &\text{Negative exponential:} && f(X_{od}) = exp(-\beta \cdot X_{od}) \\ &\text{Gaussian:} && f(X_{od}) = exp(-\beta \cdot X_{od}{}^{2}) \end{aligned}$$

where:

AA_o is the active accessibility measure related to the origin traffic zone o towards all the zones of the study area considered;

N_d is the number of traffic zones considered in the study area;

$NEIST_d$ is the number of opportunities available in traffic zone d, i.e. the total number of employees in industry, service and trade[4].

X_{od} is level of service attribute between the od pair, i.e. the rail travel time in hours (*RTT*), the rail travel cost in € (*RTC*) and the rail generalized transport cost in € (*RGTC*), a weighted combination of the travel time and travel cost according to the Value of Travel Time VOT (VOT · travel time + travel cost). The reference VOT values (€/hour) considered for the estimations are those proposed by the Italian Government in the "Guidelines for the evaluation of public investments" (2017), ranging between 7 €/hour (tourism purpose) to 35 €/hour (business purpose), with a purpose percentage distribution estimated through the survey reported in Section 2).

α and β are the model's parameters.

The latter have been calibrated starting from the HSR users survey results. Specifically, the 2,805 observations described in Section 2, have been used to estimate the Italian HSR origin–destination (od) percentage distribution in 2018, where the generic element, $P_{od}{}^{ob}$, represents the percentage of HSR daily trips between the od pair, with$\sum_{d=1}^{Nd} P_{od}^{ob} = 1$. The α and β parameters have been estimated by minimizing the sum of the square differences between the od percentage distribution observed in the sample ($P_{od}{}^{ob}$) and those predicted by the models ($P_{od}{}^{mod}$):

$$P_{od}^{mod} = \frac{NEIST_d^{\alpha} \cdot f(X_{od})}{\sum_{d=1}^{Nd} NEIST_d^{\alpha} \cdot f(X_{od})} \tag{2}$$

Parameters' estimation was carried out through the application of a constrained gradient projection algorithm (with α and $\beta \geq 0$ consistently with the model's formulations (1) and (2)). Furthermore, since the convexity of the objective function wasn't proved, the optimization procedure was applied repeatedly from different starting points directly exploring the admissibility domain with a step forward of 0.1 within the interval [0,3], in accordance with the literature reporting estimates of these parameters strictly lower than 3 (Cascetta et al., 2016; Kwan, 1998), and confirmed from the estimation results reported in Table 1.

The study area (Italy) has been divided into the 102 administrative provinces of the country (traffic zones reported in Fig. 2) excluding those of the Sardinia island not considered for lack of territorial continuity.

In order to estimate the best accessibility indicator, all the impedance function formulations jointly with the different transport attributes considered (*RTT, RTC, RGTC*) have been tested. From the estimation results (Table 1), it emerges that the best model formulation (with respect to both the Root-Mean-Square Error, RMSE, and the Mean Absolute Error, MAE) is the Negative exponential one with the rail generalized transport cost (*RGTC*) as impedance function (result comparable with those obtained in El-Geneidy et al., 2016b), even if all the formulations of the Inverse power and Negative exponential formulations provide comparable

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[4] The total number of employees in industry, trade and services is the attraction variable ($NEIST_d$) that have produced the best results in term of validation test (RMSE and MAE in Table 1). Other variables have been tested (e.g. total number of employees/firms in different economic sectors) and not reported for brevity.

Table 1
Active rail-based accessibility model estimation results.

Attributes	Impedance function								
	Inverse power			Negative exponential			Gaussian		
	Est.	*RMSE*	*MAE*	*Est.*	*RMSE*	*MAE*	*Est.*	*RMSE*	*MAE*
NEIST	*0.981*	*0.062*	*0.043*	*0.943*	*0.060*	*0.043*	*1.102*	*0.081*	*0.056*
RTT	*0.720*			*0.192*			*0.092*		
NEIST	*0.922*	*0.064*	*0.044*	*0.903*	*0.061*	*0.042*	*0.903*	*0.086*	*0.065*
RTC	*0.699*			*0.031*			*0.031E-02*		
NEIST	*0.913*	*0.059*	*0.041*	*0.989*	*0.055*	*0.039*	*0.945*	*0.071*	*0.052*
RGTC	*0.653*			*0.012*			*0.001E-03*		

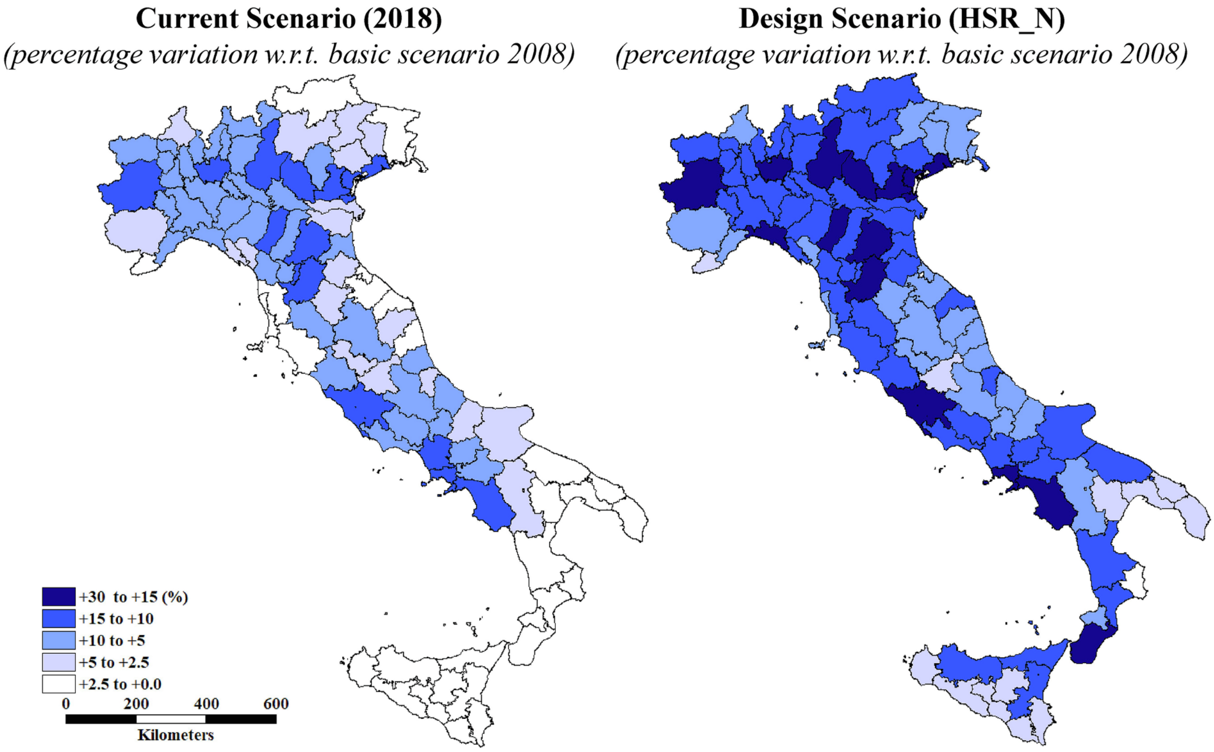

Fig. 2. Rail active transport accessibility (percentage variation with respect to basic scenario 2008): current scenario (ex-post) and project scenario (ex-ante).

RMSE (MAE) values ranging between 0.055 (0.039) and 0.064 (0.044). Gaussian specifications are always the worst in terms of RMSE and MAE estimations.

In order to evaluate the transport user's impacts, the proposed active transport accessibility measure has been computed with respect to three different scenarios: *i)* basic scenario (2008, before HSR); *ii)* current scenario (2018, ex-post); *iii)* project scenario (HSR_N, ex-ante).

For each origin–destination, the door to door rail travel times and the ticket prices have been quantified considering the past/current/design Italian transport network referring to the faster rail service (HSR when available and traditional rail service otherwise) on the minimum travel path. Furthermore, station access/egress travel times have been also calculated considering the regional transport network (with average traffic congestion condition) and referring to the fastest transport mode (car, bus, regional train). Specifically, transport attributes have been observed for the 2008 and 2018 scenarios and estimated for the project scenario. Table 2 reports the average values of percentage accessibility variations at national scale.

In the year 2018, the HSR contributed to an increase of rail travel time accessibility significantly larger for the zones along the HSR network (+26%) but relevant also for the overall rail network (about + 5%). Furthermore, it is interesting to note that also for the zones not located along the HSR network (traditional rail network) an increase, although less significant, in the average rail accessibility has been observed (about + 3%). This result is due to the fact that also these zones could benefit from HSR services; through one (or more) transfer, from a traditional rail service to a HSR one, it possible to reach zones of the country located along the

Table 2
Rail active transport accessibility (percentage variations) induced by the HSR in Italy: current scenario (ex-post) and project scenario (ex-ante).

Impedance function	Scenario	% variations of rail active accessibility		
		Total network	*HSR network*	*Traditional network*
Negative exponential with rail travel time attribute	current scenario (2018) vs. basic scenario (2008)	4.54%	26.15%	2.75%
	project scenario (HSR_N) vs. basic scenario (2008)	15.74%	53.64%	6.30%
Negative exponential with rail ticket price attribute	current scenario (2018) vs. basic scenario (2008)	24.51%	60.80%	22.71%
	project scenario (HSR_N) vs. basic scenario (2008)	28.15%	62.73%	22.19%
Negative exponential with railgeneralized transport cost attribute	current scenario (2018) vs. basic scenario (2008)	7.91%	31.76%	6.23%
	project scenario (HSR_N) vs. basic scenario (2008)	17.90%	55.17%	9.21%

HSR network and vice versa (e.g. from Reggio Calabria to the Naples HSR station through a traditional rail service, and from there to Rome or Milan with a faster HSR service – see Fig. 1).

The development of the project scenario would bring to a further increase of the rail accessibility, higher for the zones along the extended HSR_N network (of almost 54%) but relevant also for the overall country (total network) with an average increase of around 16%. A 6% increase has been estimated for the zones which remain located on the traditional rail network.

The same accessibility analysis has been performed with respect to the variation of average ticket prices, producing an average increase in transport accessibility by about 25% with peaks of 61% for the HSR network due to reduced rail ticket prices resulting from the competition in the rail market.

Finally, accessibility variations have been also estimated with respect to a weighted combination of travel times and costs (generalized transport cost - *RGTC*), producing an average national increase in accessibility of 8% with peaks in the HS network of almost 32%, and an increase of about 6% for the zones located outside the HSR network (traditional rail network). The development of the project scenario would bring to a further increase in rail *RGTC* accessibility, higher for the zones along the HSR_N network (of almost 55%) but relevant also for the total network with an average increase of around 18%. A 9% increase has been estimated also for the zones located on the traditional rail network.

Finally, variations of the rail-based active accessibility with respect to the 2008 basic scenario have been mapped, for the Italian provinces (traffic zones), in Fig. 2, estimated considering equation (1) with a Negative Exponential impedance function and the rail generalized transport cost (RGTC) as transport attribute.

3.2. Impacts on economic growth

Economic impacts brought by transport infrastructures/services can be estimated following three main approaches (e.g. Rokicki and Stępniak, 2018): *i)* Cost-Benefit Analysis (CBA); *ii)* Computable General Equilibrium (CGE) models, *iii)* econometric analysis (e.g. regression model, structural equation model). The CBA is mainly adopted for the ex-ante evaluations and it is based on a monetary comparison of all the benefits (e.g., travel time and cost savings, greenhouse gases reductions, noise pollution reductions s, accidents reductions) induced by an intervention against all the costs borne (e.g. construction, management and maintenance). There are similar applications worldwide with respect to HSR services (e.g. De Rus, 2011; Gleave, 2004; Ali et al., 2016). However, through a CBA it is possible to estimate the “marginal” benefits of a project mostly for comparative purposes among different projects, rather than its wider impacts on the whole economy (which is the aim of this paper).

The second approach commonly used to quantify the economic impacts of a transport infrastructure adopt Computable spatial General Equilibrium models (CGE) represented by a set of simultaneous equations describing the interactions among different economic sectors, prices level and transportation variables and a very detailed database consistent with these equations aiming at obtaining an equilibrium solution (e.g. Lofgren et al, 2002; Haddad et al., 2010; Chen et al., 2016; Robson and Dix, 2017; Chen, 2019). These models are very complex and require detailed data, which are not available for the application in this case study and more in general for the overall assessment of the single infrastructural projects. For, example CGE models (e.g. Chen, 2019; Hiramatsu, 2018) have been developed in order to quantify the effects of HSR services on a multiple range of sectors which both directly and indirectly influence the economy (e.g. HSR could increase the employment and the price of houses near the stations and therefore indirectly contribute to the increase of the GDP of a city).

The third and most commonly used method to quantify aggregate economic impacts brought by large-scale transport infrastructure projects, is based on econometric analyses. With these methods a transportation infrastructure can be considered as an input, in addition to other (macro) economic and territorial variables, to explain the economic development of an area (e.g. Nation, Region scale) without explaining all the economic interdependences. A basic tool for econometrics analysis is represented by the multiple linear regression model (e.g. Greene, 2012).

In applications to HSR case studies (e.g. Sun and Mansury, 2016; Chen and Haynes, 2017; Li et al. 2018; Lin et al. 2018; Meng et al., 2018; Chong et al. 2019), the independent variables have been be grouped into three macro categories: *i)* economic variables (e.g. industrial production, value of investments in the transport sector, annual volume of passengers/goods, *ii)* territorial variables (e.g. population number/density, urbanization rate, geographical location); *iii*) transportation variables (e.g. HSR accessibility and/or travel between the cities, HSR stations accessibility, competing transport modes against HSR). In this way it is possible to separate the effects of one group of variables (e.g. accessibility variables) with respect to the others, or, in other words to estimate accessibility effects other things being equal.

Starting from these considerations, different linear regression models have been tested evaluating the statistical significance of several zonal-specific attributes. The variations/percentage variations of GDP/GDP pro-capita between the basic scenario (2008, before HSR) and the current scenario (2018, after HSR) have been considered as dependent variables. Among the independent variables, the ones that have been taken into account are the number of industries, the export/import of goods, the total/foreign/Italian tourists number/incidence, the population number/density, the number/density of employees, area-size dummies variables, dummy relative to above the average production area, transport accessibility variables (e.g. active transport accessibility, minimum travel time/distances to the nearest HSR station, number of HSR daily trains, number of destinations reachable through a direct HSR rail service). Therefore, four models were estimated:

Model [1] is characterized by both territorial and transport variables:

- *Dummy per capita GDP above the average* (1–0), is a territorial variable equal to 1 if the traffic zone is located in a region with a per capita GDP in the year 2008 higher than the average value among all the Italian regions;

- *Daily HSR frequency* (number) is the average number of HSR trains/day in a business day, for the zones with a HSR station (transport variable);
- *Access to HSR station travel times* (minutes) is the access to station travel times relative to the faster transport mode available (e.g. car, bus, train), for all the zones considered (transport variable).

Model [2] differs from the previous one in the introduction of two economic variables:

- *Export propensity in 2008* [0,1] is the ratio between the zonal export of goods and the total regional production for the basic scenario, 2008 (before HSR). This variable measures the attitude to export of a local economy before the 2008 crisis and the opening of HSR;
- *Foreign tourism propensity in 2008* [0,1] is the ratio between the foreign tourists and the total number of tourists visiting the zone in 2008 before the crisis and the opening of HSR. This variable measures the zonal attitude to attract foreign tourism that, generally, has a high willingness to spend (impacting to the zonal GDP).

In Model [3], a *Daily HSR frequency distance-decay* variable has been introduced replacing the "*Daily HSR frequency*". For the proposed case study different distance-decay measures have been specified with an inverse power or a negative exponential function, and different transport accessibility attributes (e.g. car distance; car travel time; minimum travel time over all available transport modes). The best calibration results have been obtained for the negative exponential decay function with the minimum travel distance (among the transport modes available, e.g. car, bus, train), d_{od}, as a decay attribute:

$$DailyHSRfrequencydistancedecay_o = \frac{HSRd\_freq}{\exp(\beta \cdot dist_{o,HSRstat.})} \tag{3}$$

where:

HSR d_freq is the average number of HSR trains/day in a business day, serving the nearest HSR station (with the fastest transport mode available);

$dist_{o,HSR\ stat.}$ is average distance between the zone o and the nearest HSR station (in km). This attribute is consistent with those proposed by Meng et al. (2018) underlying that the economic development varies depending on the distance from the provinces to the HSR station (as the distance increases the impact decreases);

β is a model parameter equal to 0.09, calibrated on data to maximize the Adj. R-Squared of the regression Model [3].

Model [4] differs from the previous one by the introduction of a transport accessibility variable replacing the "*Access to HSR station travel times"* variable. *Rail Accessibility percentage variation* is the 2018–2008 percentage variation of the active rail accessibility measure (AA_o^i) estimated through the equation (1) in Section 3.1, with a Negative Exponential impedance function and the rail generalized transport cost (RGTC) as transport attribute[5].

The territorial scale of application has been the same proposed for the accessibility analysis, i.e. the 102 administrative provinces of the country. The estimation results relative to the best models (with respect to the validation tests) are reported in Table 3. All the parameters are statistically significant and with the expected sign. The R-Squared (Adj. R-Squared) ranges between 0.26 and 0.33 (0.24 and 0.30). Values lower than 0.5 are not an unusual result as observed in other case studies for this type of models (e.g. Herranz-Loncan2007; Sun and Mansury, 2016; González and Nogués, 2019; Chen and Haynes, 2017).

The "*Dummy variable per capita GDP above the average*" is significant in all models, suggesting that regions having stronger economies (higher per capita GDP in the year 2008) have been able to better react to the post 2008 crisis everything else being equal with an extra per capita GDP growth of + 2.25/+4.44% in 10 years (depending on the estimated model).

Export propensity and foreign tourism propensity in the year 2008 (internationalization has been a major driver for the Italian economy over that decade, see for example Cascetta, 2019) are also significant in the models, producing an extra per capita GDP growth of + 3.8/+5.6% in 10 years. It is worth noting that the calibrated models reproduce the reaction of the Italian economy to the economic crisis post 2008. As a whole in 10 years the growth of the Italian nominal GDP has been very low (+5.8%) with respect to most of the UE countries (e.g. Germany, France, Spain). The local recovery trajectories have been very different for the Italian zones ranging from −6% to + 24% in terms of per capita GDP variations. The above differences are explained in the model by a stronger economic structure before the crisis (above the average per capita GDP in 2008), larger fraction of exported production in 2008 and a significant foreign tourism inflow in 2008.

The choice (confirmed by the corresponding statistical significance) of considering only HSR- related accessibility variables is justified by the fact that the deployment of the HSR services represents the only significant change in accessibility at the national scale, since most investments for other transport modes (e.g. motorways, extra urban roads) have been delayed due to the economic crisis in the last 10 years. Furthermore, several authors (e.g. Sun and Mansury, 2016; Chen and Haynes, 2017; Jiao et al., 2017; Li et al. 2018; Lin et al. 2018; Meng et al., 2018; Chong et al. 2019) have linked the economic development to specific HSR variables (e.g. HSR travel time, frequency, access to station travel time), also in less extreme situations assuming that this transport infrastructure has the potential of affecting economic growth more than other (partial) investments at the national scale.

Model [4] (the one with the highest Adj. R-Squared) has been applied to the current scenario 2018 allowing the estimation of the contribution of HSR to different per capita GDP variations in different areas. These have been computed as the difference between the

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[5] Similar results have been obtained with the other formulation estimated and not reported for brevity.

Table 3

GDP model estimation results ($*p < .10$; $**p < .05$; $***p < .01$).

	Model [1]			Model [2]			Model [3]			Model [4]		
Variable/test	*Est.*	*Std. Error*	*t-value*	*Est.*	*Std. Error*	*t-value*	*Est.*	*Std. Error*	*t-value*	*Est.*	*Std. Error*	*t-value*
Constant	6.45***	1.17	5.51	1.33**	0.66	2.02	1.24*	0.65	1.91	−3.93**	1.75	−2.24
Dummy per capita GDP above the mean	4.44***	1.38	3.22	2.44**	1.23	1.99	2.25**	1.06	2.12	2.91**	1.23	2.36
Export propensity in 2008				14.02**	6.38	2.20	14.07**	7.02	2.00	18.11***	5.90	3.07
Foreign tourism propensity in 2008				6.84**	3.29	2.08	6.82*	3.47	1.97	5.90**	2.63	2.24
Daily HSR frequency	0.02**	0.01	2.00	0.01*	0.01	1.95						
Access to HSR station (travel time in min)	−0.02**	0.01	−2.00	−0.01*	0.01	−1.96	−0.01*	0.01	−1.96			
Daily HSR frequency distance-decay							0.14**	0.07	2.09	0.09***	0.03	2.85
Rail Accessibility percentage variation										0.30**	0.15	2.03
Number of observations	102.00			102.00			102.00			102.00		
Residual Sum of Squares	3366.06			3092.50			3052.04			3056.33		
R-Squared	0.26			0.32			0.33			0.33		
Adj. R-Squared	0.24			0.29			0.30			0.30		
F-statistic	11.73 on 3and 98			9.20 on 5and 96			9.58 on 5and 96			9.53 on 5and 96		

value estimated by the model in 2018 and in 2008 (given the model structure these would have been the per capita GDP values in 2018 without HSR accessibility changes). The rail service characteristics (both HSR and traditional service) for the year 2008 and 2018 have been those observed and collected from the official transport operators, while the other economic and territorial variables have been deduced from the official national census data. Model [4] has been also applied to estimate the contribution of the HSR_N project scenario to the future GDP growth. For this scenario, all territorial and economic variables have been kept equal to those observed in 2018, while new rail accessibility and frequency have been computed using data reported in the official National Plan "*HSR Network Project*" (Ministero dell'Economie e Finanza, 2017)

Average economic growth impacts brought by the HSR in Italy are shown in Table 4. HSR services have generated a 2.6% increase of the Italian per capita GDP in 10 years (about 0.3%/year) at a national scale. Furthermore, the HSR impact has grown up to + 5.6% (with maximum values of + 11.8%) for the zones located on the HSR network. Finally, it is interesting to note that also several zones not located within the network of HSR services have shown an increase of per capita GDP, although less significant (about 2.1%). This result is due to the fact that, as stated, also these zones benefit from HSR services (for example, transfers from traditional to HSR services). These results are consistent with that observed by Agbeli (2014) in terms of percentage increase of GDP due to a percentage increase in railway investments.

Finally, the completion of the HSR-N project scenario would have resulted in a further per capita GDP increase of 3.6% with respect to the current scenario 2018 (+6.2% with respect to the year 2008), everything else being equal (territorial and economic variables).

3.3. *Impacts on regional equity*

A horizontal equity analysis has been carried out to evaluate the regional distribution of both the economic and social impacts induced by HSR in Italy. The Lorenz curve (Lorenz, 1905) and the corresponding Gini index (Gini, 1912) are the most adopted measures of equity in the distribution of an attribute/variable in a population. Both indicators are commonly used in economics as well as in a wide range of disciplines, including transportation planning and accessibility analysis (e.g. Fridstrom et al., 2001; Delbosc and Curry, 2011; Welch and Mishra, 2013; Thomopoulos and Grant-Muller, 2013; Kaplan et al., 2014; Ricciardi et al., 2015; Xia et al., 2016; Jang et al., 2017; Guzman et al., 2017; Falcocchio et al., 2018; Ben-Elia and Benenson, 2019; Chen et al., 2019). Lorenz curve, $L(x)$, is a graphical representation of the cumulative distribution of an attribute (e.g. transport accessibility, wealth, per capita GDP) with that of population share (ranked by the attribute). The Gini index (G) is a measure of the statistical dispersion (inequality) in the

Table 4

Economic growth impacts induced by the HSR in Italy: current scenario (ex-post) and project scenario (ex-ante).

Scenario	HSR impact on the Italian per capita GDP(extra growth of per capita GDP in 10 years)		
	Total network	*HSR network*	*Traditional network*
current scenario (2018) vs. basic scenario (2008)	Minimum 1.0% Mean 2.6% Maximum 11.8%	Minimum 2.9% Mean 5.6% Maximum 11.8%	Minimum 1.0% Mean 2.1% Maximum 6.9%
project scenario (HSR_N) vs. basic scenario (2008)	Mean 6.2%	Mean 15.05%	Mean 3.1%

distribution of an attribute derived from the Lorenz curve:

$$G = 1 - 2\int_0^1 L(x)dx$$

Graphically, the Gini index is equal to one minus the ratio between the area below the Lorenz curve and the line of total equality (the bisector of the Cartesian plane). The Gini index assumes values between 0 (perfect equity; the Lorenz curve is precisely the equity line) and 1 (perfect inequality, the Lorenz curve tends to the x-axis). Perfect equity implies that each percentage of population, e.g. 30%, owns the same percentage of the attribute (e.g. wealth, transport accessibility). The smaller the Gini index is, the smaller portion of the population, e.g. 30%, owns more of their share of the attribute, e.g. 60%. There are several approximation methods of the Gini index (G) without knowing the Lorenz curve. For a discrete population with values y_i, $i = 1, \ldots, n$, one of the simplest formulations is:

$$G = 1 - \sum_{i=0}^{n} (x_i - x_{i-1}) * (y_i + y_{i-1})$$

where:

x_i is the cumulated proportion of the population variable, for $i = 0,\ldots,n$, with $x_0 = 0, x_n = 1$.

y_i is the cumulated proportion of the variable (e.g. income, accessibility,) indexed in non-decreasing order ($y_k > y_{k-1}$), for $i = 0, \ldots,n$, with $y_0 = 0, y_n = 1$.

In order to evaluate equity impacts induced by HSR services in Italy, Gini indices (and the corresponding Lorenz curves) have been estimated with respect to three different scenarios: *i)* basic scenario (2008, before HSR); *ii)* current scenario (2018, ex-post HSR); *iii)* project scenario (HSR_N, ex-ante). Horizontal equity impacts were estimated with respect to both the economic growth (per capita GDP) and the rail transport accessibility (social impact) in terms of rail travel times, ticket prices and generalized transport costs at a national scale.

Specifically, the estimated active transport accessibility measure (Section 3.1) and the per capita GDP regression model (Section 3.2) have been used to quantify the equity impacts (percentage variation of the Gini index) with respect to the transport users accessibility and economic growth respectively at a zonal scale (102 traffic zones considered).

The estimation results in terms of both the Lorenz curve and the Gini index are reported in Fig. 3. Consistently with the zonal aggregation considered, all the Gini indexes estimated are close to zero (0.080–0.177) and the corresponding Lorenz curves are very close to the bisector of the Cartesian plane, meaning an average equal distribution of the attributes considered (per capita GDP and transport accessibility). Estimated Gini indices are significantly lower than those commonly related to individual distributions (e.g. income levels ranging from 0.2 to 0.5) but are to be expected given the distribution of zone aggregated variables.

As for accessibility, the application of the model in equation (1) with negative exponential impedance function[6] using three different transportation attributes (average rail travel time, ticket price and generalized transport cost) has produced a Gini index equal to 0.16, 0.08 and 0.12 respectively for the basic scenario 2008. These indices grow in the current scenario (2018) to 0.177 and 0.125 for the rail travel time and generalized transport cost attributes respectively, underling a reduction of equity with respect to those parameters. The analyses of the ticket price impact in the current scenario shows an increase in equity (Gini reduction from 0.08 to 0.065). Different results have been obtained for the HSR_N design scenario for which the Gini indexes always decrease with respect to both the current scenario and the basic one.

For the objective of this research, the percentage variations of the estimated Gini indexes are most relevant than the absolute values. Specifically, results in Table 5 show a 11% reduction in equity with respect to travel time based accessibility from 2008 to 2018. This effect has been labelled in the Italian news as the emergence of a" *two-speeds*" country, the high speed one served by HSR and the part not having access to these services. This result is consistent with those reported in other case studies (e.g. China, UK and Spain), where it has been observed an increase in transport accessibility for the areas directly served by HSR with a consequence in inequity at national scale (e.g. Cass et al., 2005; Spain by Monzón et al., 2013; Chen and Wei, 2013; Hou and Li, 2011).

If the reduction in travel times on the new HSR network has produced in Italy a decrease in equity among provinces, comparable with those observed in other countries. The competition in the HSR services market has led to a reduction of the average ticket price on the HSR network greater than that those observed on the traditional rail network where only "Trenitalia", the state owned operator, provides traditional rail services (Table 5). The overall effect has been an increase in users' equity of 18% in 2018, which would exceed + 49% with the completion of the project scenario (HSR_N) when 56% (76%) of the population will be served with a HSR station within 0.5 h (1.0 h). This result can be considered as one (among the main) effects of the competition in the market. To confirm this, in other countries in which there is no competition between HSR operators, the overall effect has been an increase in ticket price. Pagliara et al. (2017a, 2017b) analyzed the price dynamics for UK and Spain where HSR tickets increased over time as compared to those of traditional rail services. Chen and Wei (2013) conclude that *"although China is undergoing rapid industrialization and thus workers' incomes are increasing significantly, HSR is still not affordable for the majority of the population"* due to the high ticket prices.

Finally, equity impact analyses with respect to the generalized transport cost have weighted the previous ones, showing a travelers' equity reduction of 4% in 2018 and an equity increase of 34% with the completion of the HSR_N project scenario.

With respect to the per capita GDP an increase in the Gini index has been observed (Fig. 3) for the current scenario (from 0.097 to 0.116, +19.6% with respect to 2008) similar to that observed for the rail travel time and generalized cost, leading to a reduction in

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[6] Similar results have been obtained with the other model formulation, not reported for brevity.

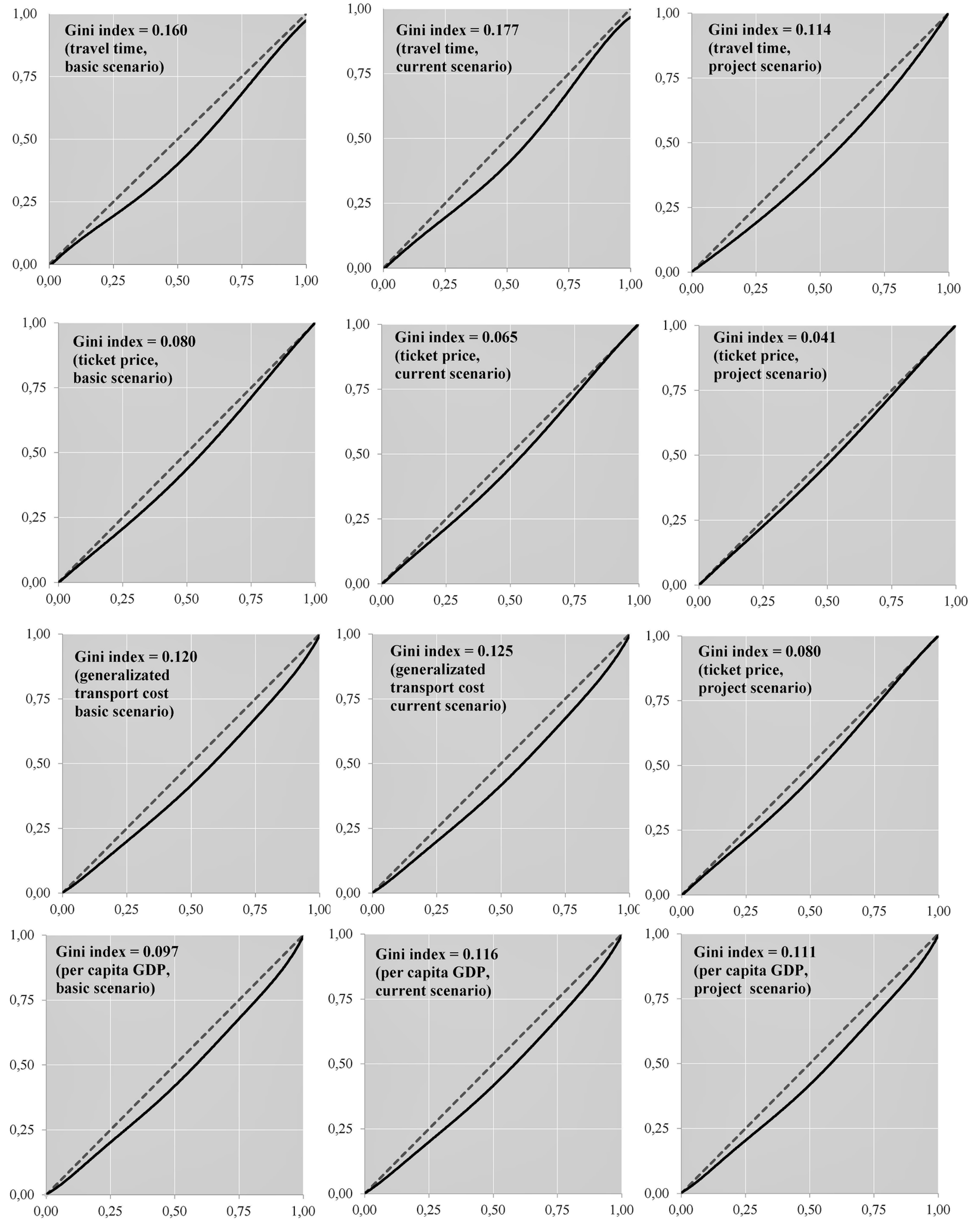

Fig. 3. Estimation results: Lorenz curves with correspondent Gini indexes.

equity. On the other hand, the Gini index for the project scenario is lower that its value for the HSR 2018 current scenario (increase in equity up to 5.2% with respect to 2018), however this doesn't bridge the gap of equity reductions observed in these 10 years (overall equity reduction of 14.4% with respect to 2008).

All the above results are consistent with those reported in other studies showing how HSR has brought positive effects on the

Table 5
Equity impacts produced by the HSR in Italy with respect to rail accessibility and economic growth.

(− % var. GINI index)	Regional equity impact (rail accessibility)			Economic equity impact
	travel time	ticket price	generalized transport cost	per capita GDP
current scenario (2018) vs. basic scenario (2008)	−10.5%	+18.1%	−4.2%	−19.6%
project scenario (HSR_N) vs. basic scenario (2008)	+28.8%	+48.9%	+33.8%	−14.4%

economy of the cities served, but increased differences with the other parts of the territory (e.g. Vickerman, 2018; Wang and Duan, 2018; Chen and Haynes, 2017; Yu and Yao, 2019). For example, Chen and Haynes (2017) estimated that the regional economic disparity in China increased with the introduction of the HSR and this statement was also confirmed by Yu and Yao (2019) who measured the level of inequality of the income from the county level and within the urban and rural areas of China.

4. Conclusions and further research perspectives

HSR infrastructures and related services have brought impacts widely studied in different countries in relation to the specific socioeconomic and territorial characteristics as well as to different level of service variables (e.g. average speed, frequencies, service lines).

This paper has systematically analyzed economic, transport users' and social impacts induced by HSR services in Italy after ten years of operation (2008–2018) along the most populated, 1,467 km long, north- south axis Turin-Salerno. In 2012 the HSR market in Italy was open to competition between the State-owned Trenitalia and the privately owned NTV, resulting in an increase of the daily frequencies and in the reduction of the average ticket prices more substantial than those observed for the non-HSR intercity services, operated under a monopolistic arrangement. Impacts of HSR on economic growth have been estimated through a multiple regression model expressing per capita GDP percentage variations as a function of the economic, territorial and transport variables observed in 2008 and 2018 for the Italian provinces. Transportation effects have been studied in term of variations of the rail-based active accessibility to activities, while the social impacts were quantified in terms of the regional inequalities in the distribution of the rail accessibility and the per capita GDP growth across Italian provinces, measured through the Gini indices.

Results show that the HSR project has been a "*game changer*" for the medium-long range intercity mobility in Italy and significantly affected the whole economy of the country. A combination of the geographical distribution of the major cities 150–200 km far from each other, distributed along the north south axis, the reduction of travel times on most origin–destination pairs in the range 1–2.5 h, a competitive market resulting in the reduction of the average ticket prices with a variety of commercial offers as well as an increase in daily frequencies, brought significant changes on travel demand (+200% in 10 years, well beyond ex ante forecasts) and measurable effects on the overall Italian per capita GDP. HSR was estimated to contribute to an average extra national growth of the per capita GDP of + 2.6% in 10 years, with a peak of + 5.6% for the areas directly located on the HSR network. Rail-based accessibility also increased, more for the zones along the HSR network (almost + 32%) but also at the overall rail network level (about + 8%). Beyond the bare numbers, it is widely perceived that HSR has contributed significantly to the change of the social and economic relationships among the cities served.

From the general planning perspective the study suggests that the ex-ante evaluation of infrastructural projects of this size should include an analysis of Wider Economic Benefits, as they could be substantial, and should be combined with explicit assumptions on regulatory measures that could significantly impact the overall effects. This was not the case of Italy, where the HSR infrastructural project was designed and evaluated following the "*marginal"* cost-benefit approach assuming the ongoing monopoly of the incumbent State Railways (FS) operator. Paradoxically the success of HSR has increased the inequalities between the areas benefitting from it (more than 20 millions of inhabitants, 34% of the total) and other areas of the country excluded. Ten years of HSR produced a reduction of equity in terms of users' travel time (generalized transport cost) accessibility of 11% (4%). This has been labelled in the Italian news as the emergence of a "*two-speeds*" country, the high speed one served by HSR and the "*low-speed*" part not having access to HSR services. The reduction in travel times on the new HSR network has produced in Italy a decrease in equity comparable with those observed in other countries. After a stop of ten years due to the post-2008 economic crisis and public investments cuts, the completion of the projects was decided in 2017. The new projects, named High Speed Rail Network or HSR_N, aim to extend the coverage of HSR services to the whole country through less expansive, lower maximum speed sections were no rail capacity problems were envisioned, increasing the overall rail generalized transport cost accessibility of 18% (+55% for the zones along the HSR_N network). The effects of the extended project were also simulated with respect to a hypothetical scenario assuming that, everything else being equal, the HSR_N network would be in place by 2018. This scenario showed a further increase of the per capita GDP of + 3.6% with respect to the current 2018 scenario and + 6.2% with respect to the basic scenario (2008); as to say that the HSR_N project would have produced greater economic benefits than those observed in this 10 years for the HSR network (current scenario 2018). Furthermore, the HSR_N scenario would have produced a reduction in disparities (with respect to both rail accessibility and per capita GDP) ranging between 5% and 39% with respect to the current scenario 2018, and also up to 49% with respect to the 2008 pre-HSR state (basic scenario). These results show that major country-level projects should include regional disparity analysis and, when decided, they should be implemented within a limited time framework and\or introduce other compensatory measures (e.g. tickets reductions) in order to prevent the unintended widening of disparities among regions.

From a practical point of view, the results discussed have significant implications from the transport planning perspective. The debate on whether and how much transport planning should aim at reducing the inequalities of users/territories is today actual but also controversial. Often transport infrastructures and services are implemented where there are more opportunities and transport demand to justify them. In these areas there are often major transport and environmental problems (e.g. congestion, pollution) and it is easier to obtain an economic return of public investments. On the other hand, it is sustained that transport policies and investments should also aim to increase equity (e.g. minimal levels of accessibility to opportunities, economic development of underdeveloped areas). Results exposed in this paper show that this could be possible. This is particularly important on the eve of the new economic crisis, this time worldwide, due to the COVID-19 pandemic, which will change the economic and social (equity) balances of (and within) states.

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