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Research Paper

Rails of Progress? Exploring the nexus between railroad access and innovation in Italy (19th-20th centuries)

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ABSTRACT

This paper provides new evidence on the nexus between railroads and inventive activities in Italy in the period 1861–1936. We develop two new georeferenced datasets on railroad stations and patents covering about 8,000 municipalities. By adopting a staggered difference in differences identification strategy, we show that the impact of railroad construction on innovation is noticeable for the first wave of construction of the period of the *Destra storica* (1861–1878), when the network was expanded following a state building strategy. However, these effects became noticeable only after two decades and concern mostly independent inventors and low-quality patents. Finally, we show that railroad access fostered innovation, particularly in locations with more advanced pre-existing capabilities.

1. Introduction

The 19th century was an age of profound transformation in which railroads revolutionized not only economies but also the geography of knowledge and invention. Railroads collapsed distances, integrated markets, expanded state capacity, reframing how ideas, people, and goods moved. For economic historians, they offer a unique vantage point on how transport infrastructure shapes knowledge flows and inventive activities.

Italy provides a particularly intriguing case for studying this relationship. Unlike Britain, France, or Germany, Italy entered the age of railroads as a latecomer to industrialization. In the second half of the 19th century, the newly unified country faced the dual challenge of building modern transport infrastructures while also nurturing a weak and fragmented innovation system (Nuvolari and Vasta, 2015a). Yet, despite these constraints, in this period, Italy was able to develop autonomously a significant number of breakthrough inventions, including some 'macroinventions' à la Mokyr (1990).

Another distinctive feature of the Italian case is the deep and persistent regional divide in economic and human capital endowments — what Abramovitz (1989) called "social capabilities.", which adds a further layer of complexity in terms of spatial heterogeneity. The historical rollout of the Italian railroad system thus provides an ideal lens for exploring whether and how a modern transport system could help overcome such disparities, integrate lagging regions, and stimulate inventive activity in an industrializing developing economy.

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This paper asks whether improved railroad access fostered invention—and along which margins (accelerated knowledge diffusion, expanded market access, or agglomeration) and in which places (cores vs. peripheries, large cities vs. small towns).

Our contribution is threefold. First, we assemble two new granular, georeferenced datasets at the municipality level: (i) the full universe of patents granted to Italian residents, 1855–1936 (97,745 patents), and (ii) an expanded dataset on railroad construction covering all stations and opening years. Second, we estimate the causal impact of railroad access using an event-study difference-in-differences design for staggered adoption (Callaway and Sant'Anna, 2021). Third, we open the black box of "innovation" by studying who benefits (independent inventors vs. firms) and what margins respond (micro- vs. macro inventions).

Previewing our results, the opening of a train station had a significant but delayed effect on patenting. Effects are strongest for the first wave of railroad expansion under the *Destra storica* (1861–1878), focused on North–South backbone routes and weaker for the *Sinistra storica* (1879–1896), which prioritized more remote areas.[1] Impacts are concentrated in the Centre–North, largely among independent inventors and lower-quality patents; population growth was affected more quickly than patents per capita at municipal level. Finally, we find that the effect of railroads took place mostly by means of agglomeration effects on population leading, over time, to spillovers and other externalities, rather than access to information or to the development of market for technologies.

Taken together, our results highlight how the relationship between transport infrastructure and innovation depends on the broader level of economic development and human capital endowment. This is in contrast with the results obtained by Tsiachtsiras (2025) for the French case and by Andersson et al. (2021) for Sweden, where railroads rapidly fostered knowledge diffusion and access to technology markets. The Italian case suggests a slower, more indirect process driven by population agglomeration.

The rest of the paper proceeds as follows. Section 2 reviews the related literature. Section 3 discusses the historical background of the development of the Italian railroad system. Section 4 describes the sources and the construction of the datasets. Section 5 presents our empirical strategy, while Section 6 illustrates our results. Section 7 contains a discussion and interpretation, and Section 8 concludes.

2. Background literature

Economists of innovation have devoted considerable efforts to study the spatial dimensions of inventive activities. It is widely recognized that knowledge diffusion may be spatially bounded and that there are agglomeration forces driving the concentration of inventive activities in specific locations (Feldman and Kogler, 2010). In this perspective, the expansion of transport infrastructures, by reducing transport and communication costs is likely to play a significant role in shaping the geography of inventive activities. In an important contribution, Agrawal et al. (2017) document a strong impact of the development of the American interstate highways on regional innovation rates in the 1980s. This issue has received attention also by economic historians, who have exploited the transport revolution of the 19th century, particularly the expansion of the railroads, as an insightful perspective to study the connection between transport systems and inventive activities. In a pioneering study, Sokoloff (1988) established a direct link between inventive activities (measured using patents) and the proximity to navigable waterways in the US during the 19th century.

Recently, thanks to the increasing availability of georeferenced datasets on both transport systems and inventive activities, this research theme has been further explored. We can point to the studies of Perlman (2016), Andersson et al. (2021), Tsiachtsiras (2025), and Chiopris (2025).[2] Perlman (2016) finds a positive impact of railway access on patenting activities in the US during the 19th century. Andersson et al. (2021) show that the development of the railroad network in late 19th century and early 20th century Sweden expanded both markets for technologies and patenting activity. These two factors prompted an increasing 'technological proximity' between local and national innovation patterns. In 19th century France, according to Tsiachtsiras (2025), the access to the railroad network and navigable waterways, by integrating peripheral towns in a wider network of large cities, fostered the diffusion of knowledge and increased innovative activity. In particular, he stresses the importance for peripheral locations of being connected with the "global city" (Paris), which acted as a gatekeeper of technological knowledge linking the French national innovation system to the global innovation network. Chiopris (2025) shows that in Germany (1750–1914), the railroad network increased knowledge production and specialization, primarily measured in terms of number of bibliographic records. This effect is explained by an increase in the mobility of scholars and by an increased mobility and diffusion of ideas. Relatedly, some recent studies have found that transport networks can enhance collaborative activities among inventors. In another historical study, Berger and Prawitz (2024) find that the development of the Swedish railroad network (1840–1910) enhanced collaborative patents between inventors in different locations.[3]

[1] The period of *Destra storica* refers to the governments of liberal conservative outlook which held power in the two first decades after the political Unification of the country in 1861, while the *Sinistra storica* refers to the moderately liberal reformist governments of Agostino Depretis in 1876 until the authoritarian reaction of the end of century. In this paper, we adopt the following periodization: 1861-1878 for the railway expansion of the *Destra storica* and 1879-1896 for the *Sinistra storica*. The actual political turning point was in 1876 with the first government of Agostino Depretis. Since there is a delay between political decisions concerning the expansion of the railway systems and their actual implementation we have adopted a 3 year buffer between the two political phases.

[2] Recently, several studies have examined also the nexus between the expansion of transport systems and technology adoption in historical perspective in Japan (Yamasaki 2023), China (Liu, Wan and Zhang 2020) and Brasil (Américo 2025). Tang (2014) studies the relation between railroads and the creation and growth of firms in Meiji Japan. Paik and Vechbanyongratana (2024) show that railroads fostered economic development in Thailand during first half of the 19th century. In a broader perspective, other recent studies have analysed the relationship between railroads and economic growth (Atack et al. 2010, Hornung 2015, Donaldson and Hornbeck 2016, Berger and Enflo 2017, Banerjee, Duflo and Qian 2020, Bogart et al. 2022, Braun and Franke 2022).

[3] For a study showing the impact of high-speed railroads on collaborative innovation in 21st century China, see Dong, Zheng, and Khan (2020).

These recent empirical studies focus on three main mechanisms linking railroad expansion to inventive activities: acceleration in knowledge diffusion, improved market access and agglomeration. Firstly, when connected to the railroad network, inventors could get in touch with leading scientific and technological centers and develop new inventions by accessing this expanded knowledge base. Secondly, railroads fostered the expansion of market access of the connected locations, acting as a stimulus for inventors as in the "demand pull" tradition emphasized by Schmookler (1966). Thirdly, railroads prompted a reallocation of population, possibly leading to agglomerations in the connected locations. These agglomerations, over time, could result in an expansion of inventive output due to knowledge spillovers and other externalities (Carlino and Kerr, 2015).

3. Historical context

3.1. The expansion of the Italian railroad system

The development of the Italian railroad system can be divided into four major stages (for a full history, see Maggi, 2019, 2020).[4] The maps of Fig. 1 show the expansion of the Italian railroad system up to the outbreak of the WWI. Figure A1 in the Appendix offers a complementary perspective of the evolution of the network by showing the location of railroad stations in three different benchmark years.

About 2,000 km of lines were built before the political unification of the country (1839–1860) as shown in Fig. 1a. The lines were highly fragmented, with a concentration in the North-West, namely in Piedmont and Liguria, although one major track crossed the entire Northern part of the country from West to East connecting Turin to Venice. In this phase, the South remained largely uncovered except for Naples and its surroundings.

The governments of the *Destra storica* (1861–1876) can be regarded as a "second phase" in the periodization of the historical evolution of the Italian railroad system. During this period, more than 5,500 km of lines were constructed (Fig. 1b). Most of the lines built in this phase ran from North to South along the coasts and they aimed to connect the entire new Kingdom. It should be noted that these new railroads were constructed for "political rather than economic reasons" (Antonielli, 1872; see also Kalla-Bishop, 1971, pp. 39–40 and Giuntini, 1999, pp. 558–559). The railroads were seen as a fundamental component of the "nation-building" process, in a context in which the broad legitimacy of the new Kingdom could not be taken for granted, especially in the Southern provinces. Throughout the 1860s there were riots and other forms of violent resistance which required a strong military intervention to be repressed (Pinto, 2020). In this perspective, the main impulse behind the first wave of railroad construction was not an economic rationale but rather political and military objectives. The ultimate goal was the creation of an infrastructure that would enable the swift deployment of the army across the country.[5] Overall, in this phase, the growth of the network is still biased towards the North-West, but we see a progressive establishment of main connections throughout the entire country, including an expansion in the two major islands of Sardinia and Sicily). In 1860, only 249 (3 %) of the Italian municipalities had a railroad station, while in 1880, the number of municipalities with a train stop became 833 which amounts to 10 % of the total.

The period of the *Sinistra storica* (1879–1896) can be regarded as the third phase in our periodization.[6] During this stage, more than 12,000 km of lines were constructed (see Fig. 1c). According to the 1879 Baccarini law, the goal of this wave of railroad construction was the connection of remote locations as documented by Bonfatti et al. (2022) and, for Sardinia only, by Gragnolati et al. (2023). However, pork-and-barrel dynamics as well as the pursuit of "sordidly political returns" (Fenoaltea, 2011), exerted a major influence on railroad construction, with many politicians using their influence to favor their own constituencies. In principle, the railroad tracks constructed in this phase, being elicited by more genuine economic incentives, could potentially provide a more salient contribution to economic growth than the previous wave of the *Destra storica*. However, according to Fenoaltea (2011), travel costs remained high due

[4] The impact of Italian railroads on economic growth and productivity has been a subject of a lively debate since the seminal contribution by Gerschenkron (1955), who argued against their significant effects. Besides Gerschenkron, the original debate featured Romeo (1959), Sereni (1966) and Fenoaltea (2011, but summarizing contributions of the 1970s). More recent historical studies have found positive effects of railroads on industrial growth (Ciccarelli, Magazzino and Marcucci 2021), manufacturing productivity (Pontarollo and Ricciuti 2020) and population growth (Ramazzotti 2021).

[5] This interpretation is supported by coeval authors. Among others, the prominent railroad engineer Federico Gabelli argued that "More than in any other country it is necessary in Italy for the Government to have in readiness all the means of resistance [...] It will be said that we are not rich and cannot spend what is necessary to equip the existing railroads with what would become necessary to make them suitable for the movements of a large army [...] I do not think that similar objections should stop us" (Gabelli 1997, pp. 103-109 [1887]; our translation). Recently, Fenoaltea summarizes the issue concluding that "The new lines were too often justified by more than their economic benefits: [in particular…] by their strategic value, to ensure military control of the regions newly annexed by the Piedmontese crown" (Fenoaltea, 2011, p. 243). Basile, Ciccarelli and Groote (2021) provide a similar interpretation of the drivers of railroad construction citing other coeval publications. (see also Tajani 1939).

[6] Our periodization distinguishing between pre-unification, *Destra storica*, and *Sinistra storica* considers railway stations according to the year of the opening of the line. However, it is important to note that some lines experienced delays between the planning of the line and its activation, so, it is possible that the year in which the planning started belonged to one phase, while the activation belonged to the next. For example, the Cecina-Saline di Volterra railway line was inaugurated in 1863, but its planning began in 1860 (pre-unification phase). This study focuses on the year of activation as this is more relevant for the purpose of studying the effect of access to the railroad than the year of the start of planning.

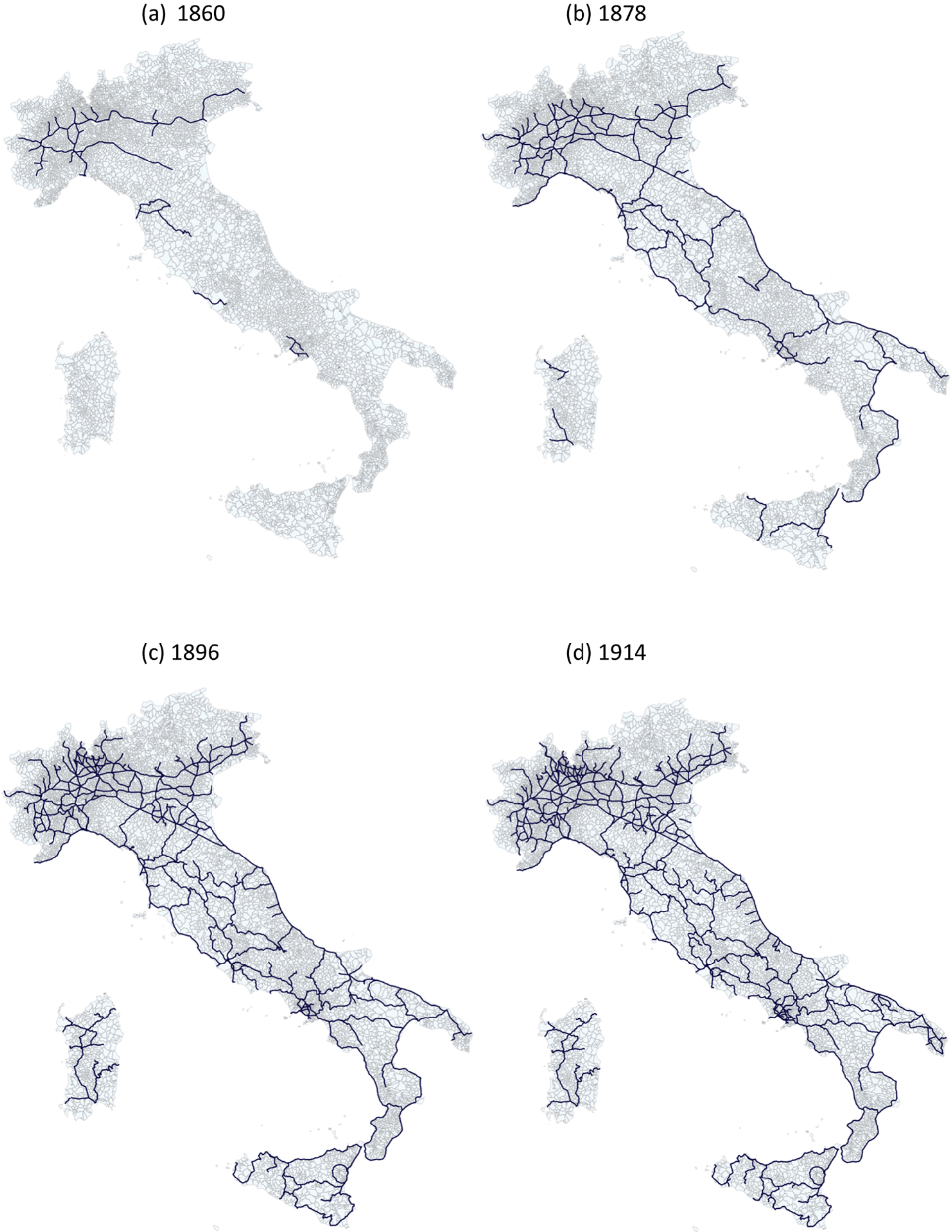

Fig. 1. The Italian railroad system, 1860–1914.
Sources: our elaborations from Ciccarelli and Groote (2017). Both standard and narrow-gauge lines are included.

to the orographic features of Italian geography and the concomitant mismanagement of the network, so the economic impact of this second wave of railroads construction remained limited. At the end of the *Sinistra storica* period, the number of municipalities with a station was 1365 (17.7 %).[7]

After the phase of the *Sinistra storica* in 1896, in the fourth and last phase of our periodization, the network witnessed a further minor expansion until WWI (as shown in Fig. 1d). Fig. 2 shows the evolution of the number of municipalities reached by a station during the period. It documents the two major waves of station construction, associated respectively with the *Destra storica* and the *Sinistra storica* governments. Interestingly, Fig. 2 confirms the existence of a two-wave pattern even when considering different

[7] Ramazzotti (2021, p. 213) observes that by 1901, slightly more than 70% of the municipalities had access to the railroad, which contrasts to our access measure of about 17.7%. However, Ramazzotti considers as exposed to railroads all municipalities within 10 km of a railroad line. When adopting the same definition, we also find a share of 70%.

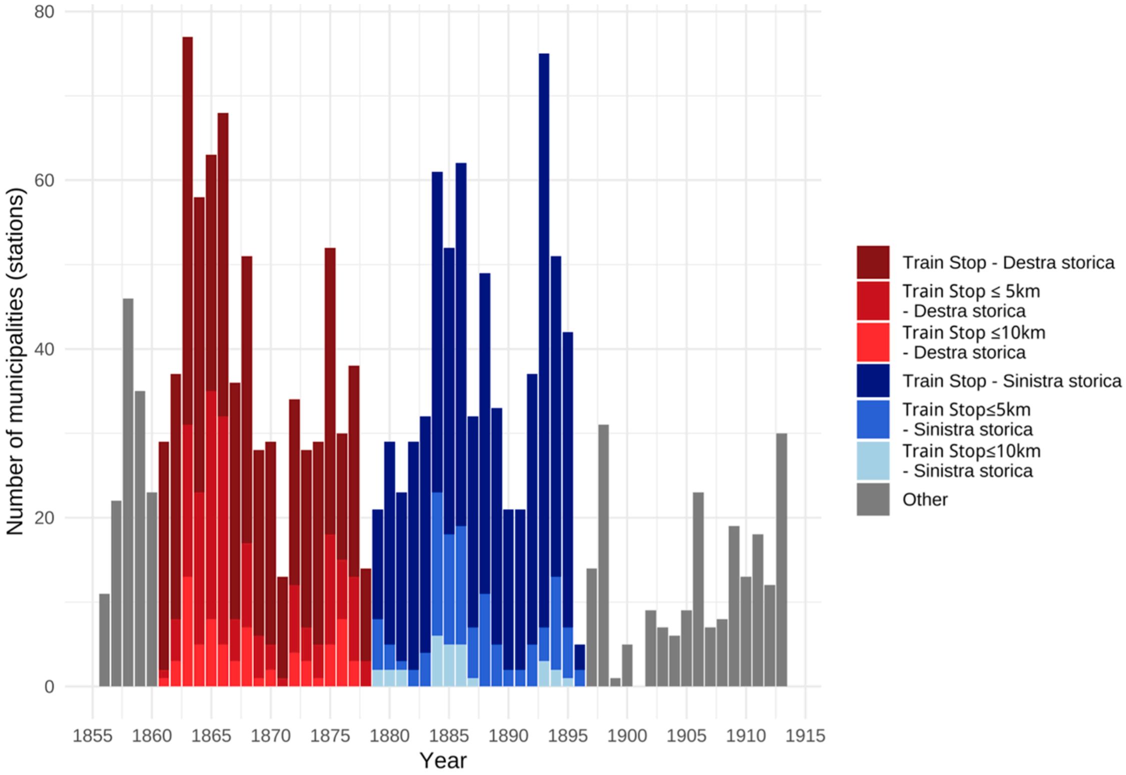

Fig. 2. Municipalities (pseudo) with a new station (TS).

measures of access to the network (a station located within 5 km or within 10 km from the town hall of a municipality).

Before the nationalization of the railroad system in 1905 and the creation of the state-owned company of the *Ferrovie dello Stato*, railroads were managed by private franchise companies. However, the construction of the new railroads had always to be approved by the government, and it was carefully examined on the basis of public policy considerations, including military and strategic ones (Schram, 1997, p. 43; Maggi, 1995, p. 178).[8]

Fig. 3 displays the available statistics on passenger traffic over the period 1880–1902. Interestingly enough, until 1892 there was a limited use of the railroad network. The per-capita figure shows that a significant increase of traffic took place only at the beginning of the 20th century.

3.2. Innovation and the Italian patent system during the 19th and 20th century

In 1860 Italy was a latecomer country, characterized by a very limited industrial base. During the so-called Liberal Age (1860–1913), the country slowly begun its process of industrialization, even if this remained partial and incomplete until the 1950s. Several indicators of technological performance suggest the existence of "technology gap" between Italy and other leading industrializing countries such as the UK, Germany and the US. At the same time, however, there is also some evidence of catching up in certain sectors and technologies, particularly through some macroinventions developed by Italian inventors (Nuvolari and Vasta, 2015a).[9] Overall, the country remained heavily dependent on technology flows from abroad, as witnessed by the very large share of patents registered by foreign applicants in the Italian patent system, which was consistently about 2/3 of the total (Nuvolari and Vasta, 2015b). This initial phase of development was based on a peculiar combination of the technological trajectories of the First and of the Second Industrial Revolution (Fenoaltea, 2011). It is worth noting that, in some of the key technologies of the Second Industrial Revolution,

[8] In 1885, there was a major reorganization, with the entrusting of the network to three new companies: *Rete Adriatica, Rete Mediter*ranea, and *Rete Sicula*. In this case, the opening of new lines was regulated by Parliament via the Baccarini Law (see Bonfatti et al. 2022 for the pork-and-barrell character of these connections).

[9] Among the most noteworthy examples of macroinventions in 19th century Italy, one can point to the cases of nitro-glycerine (discovered by Ascanio Sobrero in 1847), electric dynamo (invented by Antonio Pacinotti in 1860) and radio transmission (developed by Guglielmo Marconi in the 1890s). In a broader sectorial perspective, as noted by Zamagni (1993, p. 75): "[By 1910], all the modern industries were present in Italy, some more some less advanced: from the metallurgical industry to the energy industry, from the production of tyres to that of cars, from chemical fertilizers to sugar".

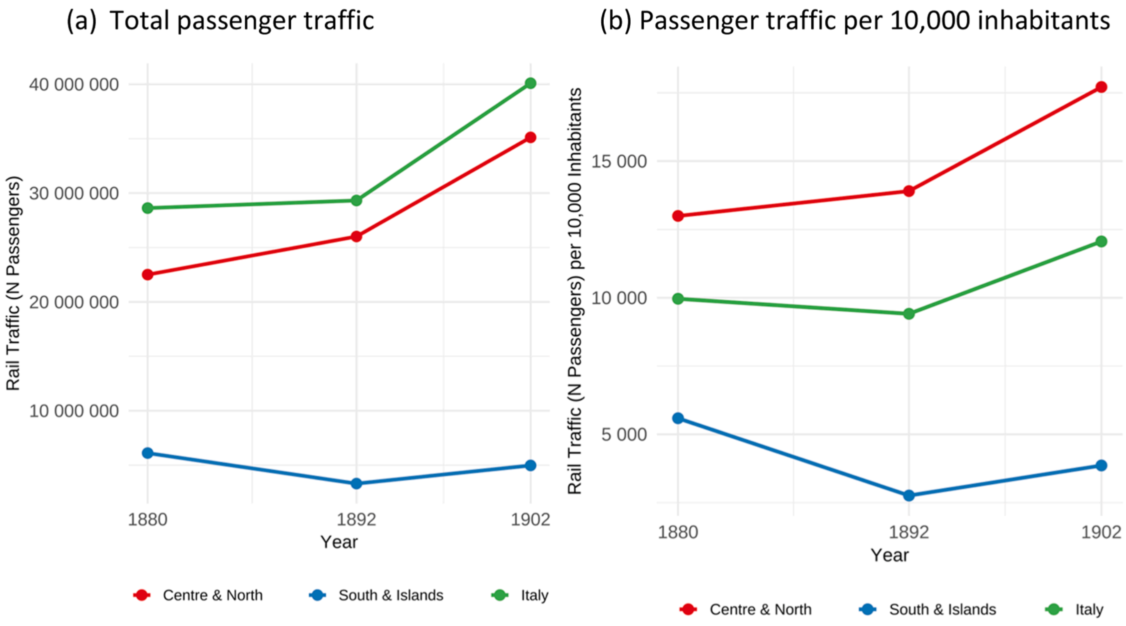

Fig. 3. Railroad passenger traffic, 1880–1902.
Note: Panel (a) shows the total passenger traffic in the three benchmark years for which the data are systematically available (1880, 1898, 1904) across macro-areas of Italy. Panel (b) provides the same data, normalized by the population of each macro-area. *Sources*: Ministero dei Lavori Pubblici (1881, p. 300; 1898, pp. 475–477; 1903, pp. 282–286).

such as electricity generation and electromechanical instruments, Italian firms were able to develop original innovations (Vasta, 1990).[10]

In Italy patent activities during the Liberal Age were unevenly distributed from a geographical point of view. They were characterized by a North – South gradient (with the South having significant less patents than the North). Furthermore, within the North, the provinces of Milan, Genoa and Turin, the "so-called" "industrial triangle" were systematically leading in patenting per capita, pointing to a connection between patents and the localization of industrialization (Nuvolari and Vasta, 2017, 2019).

In this paper, we use patents to measure the scale and scope of inventive activities.[11] It is worth recalling the main institutional features of the Italian patent system of the time, which was regulated by the Law no. 1657 of 31st January 1864. The system had three main features. First, it was a registration system and, accordingly, there was no examination of the actual novelty of the invention patented. Second, in the Italian system, patents could be registered either in the name of individual inventors or in the name of firms. Third, the system was relatively cheap and accessible when considered in international perspective (Nuvolari and Vasta, 2015b).

In Italy, an inventor could freely decide, up to 1923, the duration of the patent, ranging from one to 15 years.[12] There was an initial fee proportional to the number of years for which the patent was requested (10 Italian Lire for one year, 20 Lire for two years, and so on, up to 150 lire for 15 years). Additionally, it was necessary to pay an annual renewal fee for maintaining the patent alive. This fee increased over time: 40 Lire for the first three years, 65 Lire from the fourth to the sixth year, 90 Lire for the seventh up to the ninth year, 115 Lire for the tenth to the twelfth year, and 140 Lire for the last three years.

4. Data

The main source of this study are the 97,745 patents issued in Italy and registered by Italian residents from 1855 to 1936. The historical sources for these data are the official serial publications of the *Ministero di Agricoltura, Industria e Commercio* (MAIC various years).

Using the information on the residence of the patentee, we have been able to assign each patent to a municipality. Article 24 of the

[10] The 'Italian' Edison company succeeded in building one of the world's first electric power stations (see Guagnini 2014).

[11] The use of patents to measure inventive activities has two well-known limitations: (i) not all inventions are patented, and (ii) patents differ considerably in quality, ranging from small improvements to major radical innovations (Streb 2024). However, as pointed out by Griliches (1990, p. 1661): "In this desert of [innovation] data, patent statistics loom up as a mirage of wonderful plenitude and objectivity." Following the pioneering contribution of Schmookler (1966), the cautious use of patents as innovation indicators has developed into a consolidated research tradition. For a survey of this stream of literature, see Moser (2016) and Streb (2023).

[12] The new Law of 1923 established a simpler fee structure by which all patents had the same duration (15 years), but they were still required to pay an annual renewal fee.

Regolamento related to the (patent) Law no. 1674 of 31st January 1864 prescribed that patent applications must be submitted to the *Ministero di Agricultura, Industria e Commercio* (MAIC) via the local *Prefettura* or *Sotto-prefettura* (Nuvolari and Vasta, 2017). This means that, from an institutional point of view, the accessibility of the patent system was evenly distributed on the national territory, since patentees were not forced to undertake major travels to register a patent. Thus, the residence of patentees can be reliably employed to characterize the geographical distribution of inventive activities (Nuvolari and Vasta, 2017). If a patent is taken by more than one inventor, we have used fractional counting. For example, if a patent is taken by two inventors, one living in Florence and the other in Venice, each of these municipalities is assigned a 0.5 of this patent.

The borders of Italian municipalities have varied substantially from the Unification of 1861 to 1936, following several administrative reforms. This makes it difficult to identify the precise area included in the borders of a municipality at each point in time. In order to deal with this issue, Buscemi and Insa-Sanchéz (2024) have constructed a set of 'pseudo' municipalities with time-invariant borders for which population data are provided from 1861 to 1936.[13] In this way, we can allocate all patents into a set of time invariant geographical units ('pseudo'-municipalities), based on the administrative borders of 1921.[14] This process yields a patent dataset covering 7941 pseudo-municipalities for each year from 1855 to 1936 (82 years), for a total of 651,162 observations. We normalize these data by population using the population censuses of 1861, 1871, 1881, 1901, 1911, 1921, 1931 and 1936 (linearly interpolating in the intervening years), obtaining the number of patents per 10,000 inhabitants for each pseudo -municipality as our main outcome variable.[15]

Besides the sheer number of patents, we also consider their technological and economic impact. We use patent duration to construct a simple quality indicator similar to renewal rates in contemporary patents (Bessen, 2008). The intuition is that since patents with longer duration require a more significant investment by the inventor, they are more likely to cover more important inventions from a technological or economic perspective (Nuvolari and Vasta, 2015b and Nuvolari et al., 2023 for an application to the case of France).[16]

To assess railroad access at the municipality level, we use the maps of railroad construction and the related shapefiles from Ciccarelli and Groote (2017, 2018), which report the year in which a railroad first crossed a given municipality. Furthermore, we integrate these data with information on the construction of railroad stations at municipality level retrieved from the volume *Sviluppo delle Ferrovie Italiane dal 1839 al 31 dicembre 1926* (DGFS 1927). In this way, we can establish the date of activation of all the 574 main stations of the railroad network. To extend the coverage to minor stations, we also complement these data with information from the official train timetables *Orario Generale delle Ferrovie Esercitate dallo* Stato (DGFS 1914) for the period 1899–1926 indicating which of all 1776 intermediate railroad stations were in operation at any moment in time. We retrieve the year of activation of these stations from *Wikipedia* and other specialized websites on the history of municipalities and railroads.[17] Overall, our dataset contains 2,350 stations.[18]

Our dataset includes also other transport systems and information infrastructure which were relevant for Italy at the time: distance to seaports and post offices, respectively (see Figure A3 in the Appendix).[19] By using GIS coordinates, we extract the location of main ports from the map *Carta Generale delle Strade Ferrate Italiane* published by the *Ferrovie dello Stato* in 1912 and of intermediate and minor ports from Calamai (1912), and we construct an indicator of distance of each municipality from the closest seaport. We retrieve the list of the post and telegraphic offices that were built in each municipality from the yearly *Bollettini Postali* published by the *Ministero delle Comunicazioni* (1861–1918). We construct a measure of the distance of each municipality to the closest post office from this data. For each municipality, we also add the information about its latitude and altitude (measured using the town hall position) retrieved respectively from Google API and ISTAT.[20] Finally, since there is an established connection between human capital and inventive activities we have included in our dataset a number of measures of the former variable constructed at the municipality level: *i*) the number of male and female students in primary schools per capita in 1862; *ii*) per capita expenditure of each municipality in schools, and *iii*) per capita share of expenditures invested by the government in elementary schooling over the total of expenditures (Ministero della Pubblica Istruzione 1865). Descriptive statistics are reported in Table A1 in the Appendix.

[13] The "pseudo-municipalities" approach has been also used by Beltrán-Tapia, Díez-Minguela, and Martinez-Galarraga (2018) for the case of Spain.

[14] In the remaining of this paper, when we refer to a municipality, we mean one of the pseudo-municipalities of Buscemi and Insa-Sánchez (2024).

[15] Figure A2 in the Appendix illustrates the spatial diffusion of the patent activity in Italy by showing all municipalities with at least one patent over four subperiods.

[16] Andersson, Berger and Prawitz (2021) and Perlman (2016) in their studies on the nexus between railroads and innovation in Sweden and in the U.S. also use quality-adjusted patents.

[17] The main sources used are stagniweb.it [last accessed March 2025], trenidicarta.it [last accessed March 2025], and ferrovieabbandonate.it [last accessed April 2025].

[18] We have also considered the issue of line closures. We retrieved this information from the formidable reconstruction by Morando (1997, 2001, 2009), who has listed in detail all the changes in the railroad network since 1839. Overall, in our period, there were 52-line closures. Of these, 41 remained within the boundaries of the same municipality and thus do not affect our exercise. The remaining ones touched more municipalities but did not alter the structure of the connecting networks, i.e. the new lines were built in parallel to the old ones and were activated concomitantly with the closure.

[19] We do not include roads and navigable waterways in our analysis. Despite the wave of construction of the Napoleonic period, roads were not very well developed in early 19th century Italy, and after Unification, most infrastructure expenditure was in railroads (Bortolotti 1985 and Martinez 2024). Also, there are no exhaustive sources charting the evolution of roads' construction besides Roman roads, which however do not consider minor ones that would have been useful to connect inner villages. Navigable waterways and canals were not commonly used as a means of transportation in Italy besides a few exceptions in the North.

[20] Nuvolari and Vasta (2017) document a positive correlation between patenting activities and human capital in Italy in this historical period.

5. Empirical strategy

Our main empirical strategy follows the estimation procedure of Callaway and Sant'Anna (2021).[21] This empirical approach, unlike the standard two-way fixed effects (TWFE) difference in difference regression, can effectively deal with heterogeneous treatment effects among groups that receive the treatment (railroads in this case) in different time periods.[22] Indeed, the railroad roll-out in Italy occurred, as previously shown (Fig. 2), in a highly staggered fashion which makes important to consider the heterogeneity in the timing of the treatments. We consider a municipality exposed to a railroad as a "treated" municipality. Specifically, for each treatment group $g = \{1861, 1862, \ldots, 1896\}$, we estimate the Callaway and Sant'Anna (2021) staggered version of the following standard TWFE equation:

$$y_{it} = \gamma_i + \varphi_t + \beta RAIL_{it} + X_{it} + \in_{it} \quad (1)$$

where y_{it} is the outcome variable (number of patents per 10,000 inhabitants) in year t in municipality i, γ_i is the municipality fixed effect, φ_t is the year fixed effect, $RAIL_{it}$ is a variable taking a value of 0 when the municipality is untreated, and X_{it} includes the covariates, and the coefficient β captures the impact of railroads on inventive activities at the municipality level. The effects are estimated using the so-called "doubly-robust" DiD estimator (Sant'Anna and Zhao, 2020).[23] Additionally, to recover event-study interpretations, we compute the so called 'dynamic aggregation' of the effects, obtained as a weighted average of the treatment effects in any given year after the adoption.

Our baseline treatment is represented by the activation of an operating railroad station in the municipality, which we call "train stop" (TS). This case is represented in Fig. 4a, where the treated municipality is highlighted in green, and the two municipalities used as controls in red. The construction of railroad stations may be subject to endogeneity concerns: the opening of stations should be less costly given the existence of a railroad line, and perhaps dependent on the level of economic development of the municipalities where the station will be constructed. Thus, we also explore other, less strict, definitions of railroad access. The first less restrictive notion of railroad access is the simple crossing of the borders of the municipality by a railroad line without the actual stopping of the train, which we label "pass through" (PT). The second notion of railroad access comprises all TS municipalities plus the municipalities which do not have a train station in their territory but whose town hall is within 5 km or 10 km from a train station of another municipality (Fig. 4b). The untreated, or control, municipalities are the ones not-yet connected to the railroad system at the time of interest in our dataset.

Our main outcome variable is the number of patents per 10,000 inhabitants for each municipality. We compute this as a centered rolling moving average of a 3-year window to smooth the data from year-to-year volatility. In addition, we explore the impact of railroads also on alternative outcome variables that capture the quality of patents and the characteristics of patentees. As for patent quality, we consider as low-quality patents those with two years or less of duration, and as high-quality all patents with six years or more of duration. As for the characteristics of the patentee, following Nuvolari and Vasta (2015b), we distinguish between independent inventors and firms. Moreover, we also consider the case of "collaborative" patents, that is patents registered by inventors with residence in different municipalities.

Lastly, the doubly-robust estimation approach includes pre-determined covariates in a propensity score matching fashion (Rosenbaum and Rubin, 1983). In this way, each group-time treatment effect compares the post-treatment outcome against control municipalities that are most like the treated ones, at least according to the variables used for the propensity score matching. In our case, we use geographical covariates or variables with their values corresponding to the closest pre-treatment period: distance to ports, distance to postal stations, latitude and altitude of each municipality. Furthermore, we include the set of pre-determined (1862–63) variables to proxy human capital discussed above: the share of primary school students (male and female) on total population of each municipality, per capita primary education expenditures by each municipality and by the government.

Intuitively, under parallel trends and no anticipation assumptions, the Callaway and Sant'Anna approach estimates average treatment effects on the treated for groups of municipalities that receive a railroad line or station in different years. These individual effects are then averaged into an overall effect. We study three main intervals of group-years associated with the railroad construction: the entire Liberal Age period (1861–1896), the *Destra storica* (1861–1878) and the *Sinistra storica* (1879–1896). With this periodization, we can observe the effect for 40 years for the case of the entire Liberal Age and the *Sinistra storica,* and 60 years for the case of the *Destra storica*.

As main supporting statistical evidence of the parallel trend assumption, we show that the characteristics of the treatment and control groups are similar after conditioning on the covariates that we use for the propensity score matching and the p-values for the test of pre-trends do not indicate pre-trends in our specifications.

[21] In the literature, we find two main alternative approaches: the least-cost path method introduced by Banerjee, Duflo and Qian (2020), and the market access approach developed by Donaldson and Hornbeck (2016). These two approaches are not particularly suited to the Italian case. Concerning the least-cost path method, it is difficult to take precisely into consideration the rugged geography of the Italian territory. The market access approach instead seems more suited for the estimation of the impact of the railroads on economic activities, rather than the specific effect on innovation.

[22] The approach of Callaway and Sant'Anna (2021) considers each treatment period to be different, and instead of estimating an average treatment-on-the-treated for the whole sample, it estimates specific "group-time treatment effects" which can subsequently be aggregated by time or in an event study context. See Baker, Larcker and Wang (2022), Borusyak and Jaravel (2024), and Roth et al. (2023) for an overview of difference in difference models with heterogeneous treatments.

[23] The doubly-robust estimation procedure uses pre-determined covariates (similar to the controls X_{it} of the TWFE) to implement the conditional trend assumption (see Callaway and Sant'Anna 2021, p. 220).

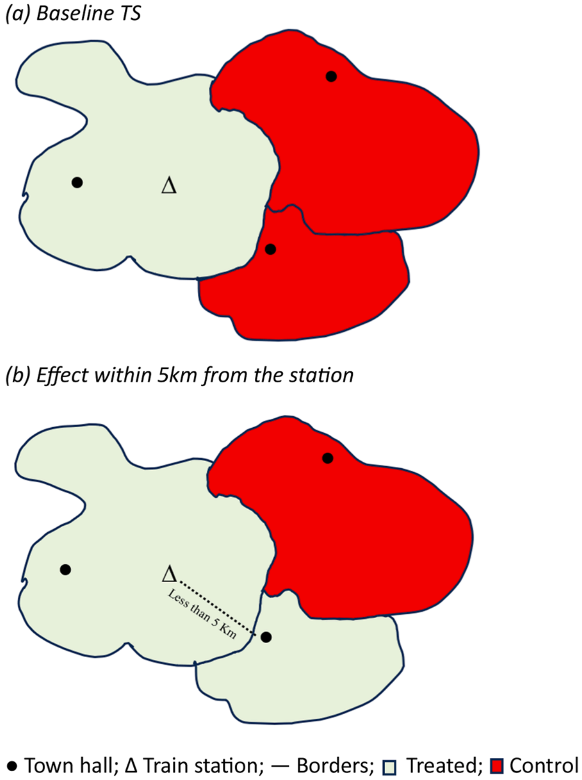

Fig. 4. Treated and control groups.
● Town hall; Δ Train station; — Borders; Treated; Control

6. Results

Fig. 5 compares the evolution of the three-year moving average of number of patents per 10,000 inhabitants in treated and control (never treated and not yet treated) municipalities. *Prima facie,* Fig. 5 shows that the municipalities "treated" were characterized by a sizable increase in their inventive activities which, however, took place with some delay. The growth of inventive activities in the treated municipalities has accelerated since the mid-1890s, when most rail lines were completed. There are no major differences in patent activity between the "not-yet-treated" and "never treated" municipalities.

Table 1 presents the results of our estimates using the Callaway and Sant'Anna (2021) approach, reporting the aggregation of the estimated coefficients.[24] Panel A shows that TS treatment had a positive and significant effect on inventive activities for the entire period 1861–1896. In terms of the size of the coefficients, we find that a railroad station increases the number of patents per 10,000 inhabitants of a factor ranging between 0.015 and 0.035 depending on whether only the municipalities receiving a train station are considered as treated or treatment also includes neighboring municipalities. Since the yearly average number of patents per 10,000 inhabitants in our dataset is about 0.05, this can be regarded as a strong effect.[25] Panel B presents the impact of train stops on different types of patents, showing that this only affected independent and low-quality patents. Panel C shows the impact of train stops located within 5 km from the municipality. Here we find an impact only on independent inventors' patents. Panel D disaggregates the results by macro-area, indicating that the effect was visible only in the North and in the Centre of Italy.

Fig. 6 shows the event study ATT coefficients estimated for the case of the TS treatment of the *Liberal Age* period.

The results suggest a positive impact of the treatment, without any pre-treatment effect.[26] It should be noted, however, that the

[24] In Table A2 in the Appendix, we provide a robustness check using three alternative estimators (the standard two-way fixed effects, Roth and Sant'Anna (2023) and Sun and Abraham (2021) approaches) finding consistent results. Table A3 in the Appendix shows that the results hold using alternative approaches for smoothing yearly variations (no rolling and anticipation of one year) as well as for patents not normalized by population levels.

[25] We should notice that we do not include in our estimation major municipalities with an already operating railway station before 1861 such as Milan, Turin and Genoa which were already characterized by high patenting activity. If we consider patenting activity for all Italian municipalities for the entire period, we have a yearly average value of 0.31 patents per 10,000 inhabitants.

[26] The validity of the framework is also confirmed by a test for parallel trends in pre-treatment observations.

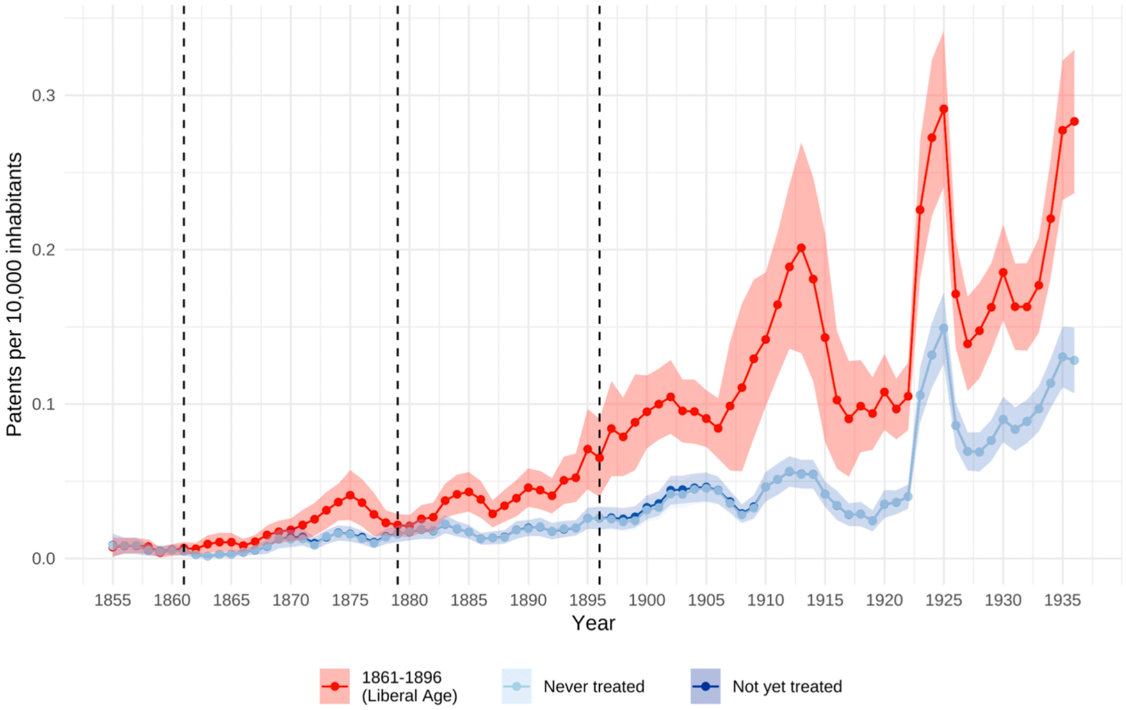

Fig. 5. Impact of TS on patenting activity during the Liberal Age, 1855–1936.
Note: The 95 % confidence intervals are computed using the mean and standard error of the patents per capita in each year. The 'never treated' group includes municipalities that will never be exposed to the train. The 'not yet treated' group includes the 'never treated' municipalities plus the municipalities that will be treated later.

Table 1
The impact of railroads on patenting activity 1861–1936 for railroads constructed during the Liberal Age (1861–1896).

Dependent variable:	Patents per 10,000 inhabitants				
Panel A: By indicator of network access					
	Pass Through	Train Stop	Train Stop within 5 km	Train Stop within 10 km	
	0.0148***	0.0347***	0.0151***	0.0150***	
	(0.0069)	(0.0070)	(0.0054)	(0.0041)	
Panel B: By subgroup (for train stop)					
	Independent patents	Firm patents	Low quality patents	High quality patents	Collaborative patents
	0.0319***	0.0008	0.0101***	0.0000	0.0001
	(0.0064)	(0.0023)	(0.0026)	(0.0019)	(0.0004)
Panel C: By subgroup (for train stop within 5 km)					
	Independent patents	Firm patents	Low quality patents	High quality patents	Collaborative patents
	0.0119***	0.0023	0.0016	0.0010	−0.0016
	(0.0049)	(0.0019)	(0.0021)	(0.0011)	(0.0027)
Panel D: By macro-area (for train stop)					
	North	North-Centre	Centre	South + Islands	Continental South
	0.0661***	0.0563***	0.0393***	0.0063	0.0047
	(0.0147)	(0.0115)	(0.0149)	(0.0084)	(0.0064)

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Notes: (*i*) Group-time staggered diff-in-diff regressions (Callaway and Sant'Anna, 2021). The group-time ATTs are aggregated into event-study ('dynamic') effects. The table displays the effect of different indicators of network access (Pass Through, Train Stop, Train stop within 5 and 10 km from the closest municipality) on the number of patents per 10,000 inhabitants. The effect is observed for up to 40 years. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. The count of patents for 10,000 inhabitants is a rolling mean with three-year windows. Clustered standard errors are given in parentheses. The outliers of Vado Ligure and Villar Perosa are excluded. P-values for the pre-test of parallel trends assumption are always below the 0.05 threshold.
(*ii*) 'Low quality' patents have a duration of 1–2 years. 'High quality' patents have a duration of 6 or more years. The coefficients for high and low-quality patents are aggregated over a period of 25 years, because the dataset has duration data only up to 1924.
(*iii*) Collaborative patents include patents registered with individuals or firms who reside in different municipalities.

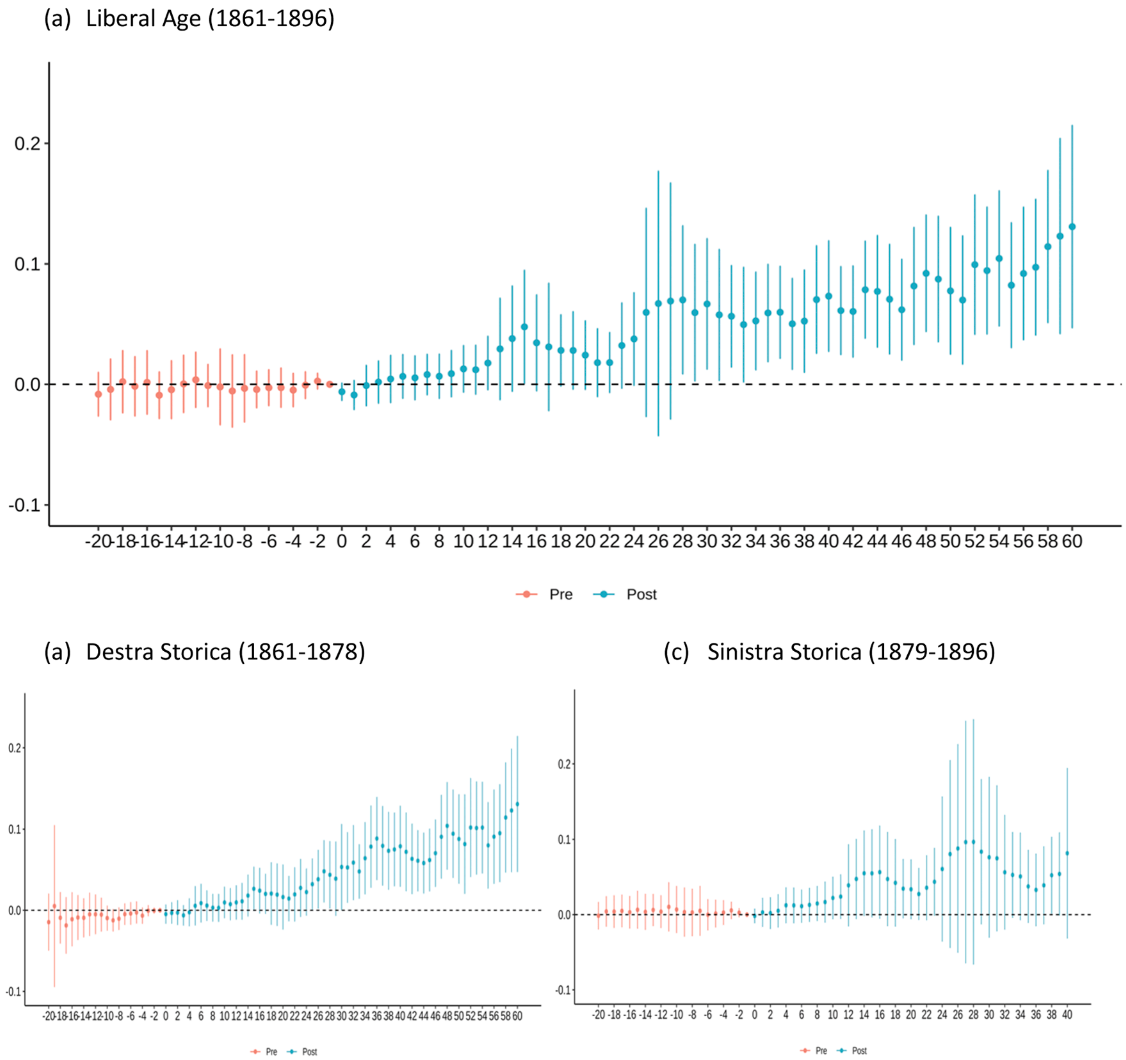

Fig. 6. Impact of railroads on patenting activity.
Note: The dependent variable is number of patents (rolling mean with three-year windows) for 10,000 inhabitants. The event-study graphs are produced using the R commands *att_gt* and *aggte* by Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021). Control group comprises 'not yet treated' municipalities. Panel (a) includes as treated all the municipalities that received a TS, while Panel (b) includes as treated all the municipalities that received a TS during the *Destra Storica* period and Panel (c) includes as treated all the municipalities that received a TS during the *Sinistra Storica* Period. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. See Table 2 for more details.

impact is long delayed: the coefficients become significant 28 years after the treatment and after that period they range from 0.05 to 0.11, remaining significant until the end of our period of observation which is 60 years after treatment.[27] Figure A4 in the Appendix considers the case of municipalities treated using the 5 km distance definition.[28] We find similar patterns to those of Fig. 6a, but the effects are not significant.

The effects of the railroads constructed during the *Destra storica* are comparable in magnitude to the overall effects (see Table 2, panel A). The impact of the railroad construction of the *Sinistra storica* is reported in Fig. 6c (see also Table 3). In this latter case, it is possible to identify a gradual growth in the ATT coefficients after 20 years, with a successive decline and a final rebound. However, in contrast with the case of the *Destra storica*, the coefficients are never significant.[29]

Furthermore, we consider as outcome patents registered by independent inventors (Fig. 7). In this case, for the Liberal Age the coefficients become significant after 28 years ranging from 0.05 to 0.13. For the *Destra Storica* they become significant after 25 years and remain strongly significant afterwards, suggesting that the railroads exerted a stronger impact of this type of patents. Again, we do not find instead a significant impact for the period of the *Sinistra storica*.[30] The period from the introduction of the railroad and its effects may seem long, but it is consistent with the evidence of Chiopris (2025) on the diffusion of ideas following the introduction of the railroad for Germany in the period 1750–1914. In particular, she finds that the effects of the railroad on different measures of innovations and creativity, such as the introduction of new words in the titles of German publications, the specialization of inventors' activities in multiple fields, and on the adoption of new ideas in different scientific disciplines are only significant after 20–30 years.[31] Moreover, our data allows us to investigate patents of different quality. In Fig. 8, we examine the impact of railroads on low-quality patents (those with duration $\leq$ 2 years).

In this case, we find a positive and significant effect for the *Destra storica*, with coefficients becoming significant after 30 years and ranging between 0.01 and 0.03. The railroad constructions of the *Sinistra storica* instead do not have a statistically significant impact.[32]

The TS treatment (coefficient = 0.0299) has a stronger and significant impact than all other types of treatments (PT, 5 km and 10 km) on patents per 10,000 inhabitants (see Table 2). Concerning patent quality, we find railroads exerting a sizeable significant impact on low quality patents (coefficient = 0.0153), but not on high quality ones.[33] We also observe a positive and significant impact of railroads on independent inventors' patents (coefficient = 0.0288), while the coefficient on firm patents is smaller and not significant (0.0023). The size of the coefficients for the *Destra storica* is comparable to that of the entire Liberal Age (see Table 1). The coefficients for the *Sinistra storica* are not significant except for those for the TS treatment on patents (see Table 3, panel A). Remarkably, in contrast to the Swedish case studied by Berger and Prawitz (2024), we do not find effects on collaborative patents among inventors in different locations. As already pointed out by Nuvolari and Vasta (2015b), in Italy, in this historical phase, there was a very limited network of patent agents, and, relatedly, a very limited circulation of information concerning ongoing patenting activities, possibly constraining the opportunities for collaborative inventions.

7. Discussion

Overall, our findings highlight a positive impact on inventive activities of the railroad expansion and especially the one taking place

[27] Table A3 in the Appendix (column 6) explores the extensive margin of railroad connections. We find that being connected had a significant impact on the probability that a municipality began to engage in patenting activities. This suggests that railroads fostered a 'democratization of invention' in the sense of bringing the patent system where before it was not used. Column 7 of Table A3 in the Appendix explores a more restrictive definition of patenting activities, considering each year in which a municipality has at least one patent.

[28] Table A4 in the Appendix reports the results of railroad access for municipalities located at different distances from the station, excluding, in each interval, the municipalities located at shorter distances from the train station. This allows to consider possible short-distance relocation of population due to railroad's access. The size of the coefficients remains similar to those of our main tables and gradually fades away beyond a distance of 20km from the train station.

[29] Figure A5 in the Appendix reports the results excluding the observations of the municipalities of Veneto and the province of Udine after 1914 to minimize the possible impact of the localities involved in World War I. In this case, we obtain similar results to those of Figures 8, 9 and 10.

[30] Figure A6 in the Appendix reports the analysis for patents granted to firms. In this case there is no significant effect for both waves of railway construction.

[31] It is worth noting that our estimated effects are robust to the use of different sets of covariates (Table A5 in the Appendix). In column 5 of Table A5, we also include Roman roads as a covariate (see Dalgaard et al. 2022 for an appraisal of their long-term impact), and the results are consistent with our main findings.

[32] Since the measure of quality is patent duration in years and Italian patents had precise information on the duration only up to 1924, we had to restrict our time window to 25 years for the entire period and to 45 years for the *Destra storica*. Figure A7 in the Appendix considers the case of high-quality patents (defined as those with duration $\geq$ 6 years). In this case, we do not find a significant effects.

[33] In micro-economic terms, this result suggests that railroad connections had an impact in pushing the return for the marginal inventor over the threshold cost for innovation for low-quality inventions but were unable to do so for high-quality ones (see Hall and Helmers 2024, chapter 3 for a general discussion of the micro-economics of inventive activities). In other words, railroad connections may have given easier access to the resources necessary for low-quality patents, but the resources for high quality patents remained spatially concentrated, and inventors had to move to more developed locations to make high-quality inventions. Indeed, as already emphasized by Nuvolari and Vasta (2017), in Italy, high-quality inventions remained spatially concentrated throughout the whole Liberal Age.

Table 2
The impact of railroads on patenting activity 1861–1936 for railroads constructed during the *Destra storica* (1861–1878).

Dependent variable:	Patents per 10,000 inhabitants				
Panel A: By indicator of network access					
	Pass Through	Train Stop	Train Stop within 5 km	Train Stop within 10 km	
	0.0182***	0.0299***	0.0118	0.0094***	
	(0.0052)	(0.0060)	(0.0062)	(0.0038)	
Panel B: By subgroup (for train stop)					
	Independent patents	Firm patents	Low quality patents	High quality patents	Collaborative patents
	0.0288***	0.0023	0.0153***	0.0017	−0.0004
	(0.0052)	(0.0019)	(0.0028)	(0.0028)	(0.0007)
Panel C: By subgroup (for train stop within 5 km)					
	Independent patents	Firm patents	Low quality patents	High quality patents	Collaborative patents
	0.0100	0.0012	0.0021	0.0005	−0.0035
	(0.006)	(0.0012)	(0.003)	(0.0016)	(0.0055)
Panel D: By macro-area (for train stop)					
	North	North-Centre	Centre	South + Islands	Continental South
	0.0643***	0.0548***	0.0485***	0.0088	0.0072
	(0.0143)	(0.0116)	(0.0209)	(0.0073)	(0.0068)

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Notes: (*i*) Group-time staggered diff-in-diff regressions (Callaway and Sant'Anna, 2021). The group-time ATTs are aggregated into event-study ('dynamic') effects. The table displays the effect of different indicators of network access (Pass Through, Train Stop, Train stop within 5 and 10 km from the closest municipality) on the number of patents per 10,000 inhabitants. The effect is observed for up to 40 years. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. The count of patents for 10,000 inhabitants is a rolling mean with three-year windows. Clustered standard errors are given in parentheses. The outliers of Vado Ligure and Villar Perosa are excluded. P-values for the pre-test of parallel trends assumption are always below the 0.05 threshold.
(*ii*) 'Low quality' patents have a duration of 1–2 years. 'High quality' patents have a duration of 6 or more years. The coefficients for high and low-quality patents are aggregated over a period of 25 years, because the dataset has duration data only up to 1924.
(*iii*) Collaborative patents include patents registered with individuals or firms who reside in different municipalities.

during the period of the *Destra storica*. The lines built during this period ensured a broad national integration of the country, by means of the construction of the major backbone tracks of the system.[34] It is likely that these connections offered some relatively marginal locations the opportunity of becoming involved in inventive activities improving the generation of patents. It must be noted, however, that these effects are visible only after about two decades and concern mostly independent inventors and low-quality patents. One possible explanation of the delayed effect is the slow growth of the passenger's railroad traffic until the 1890s (see Fig. 3). After 1885, railroad fares were made uniform across Italy. Traveling remained still costly, but discounts were applied especially for individuals of lower income.[35] Alternatively, another interpretation of this finding is that the railroad system did not result in a rapid improvement in access to knowledge, or in an increasing interaction between inventors in different locations. Indeed, in these cases, one would have expected a much more rapid effect of the railroad treatment. Instead, it is plausible to assume that access to railroads triggered a slow and gradual accumulation of inventive capabilities in peripheral locations. This slow accumulation might have been the outcome of processes of learning by doing associated with new economic and socio-cultural opportunities brought about by the railroads, including the growth of population.

Fig. 9 shows that the impact of railroad access on the population at municipality level was more direct and rapid than that on inventive activities. Note that there is no impact of railroads on population growth for the municipalities treated in the 1900–01–02 cohort. This is consistent with the limited impact of the railroad construction of the *Sinistra storica*

This is also confirmed in Fig. 10 which shows that the impact of railroads on the raw number of patents was also more rapid than that on patents per capita (compare with Fig. 6). This suggests that railroads exerted first an impact on patenting activities via the growth of population, and only with a significant delay on patenting per capita. One could alternatively argue that the delayed effect was not due to the slow unfolding of learning-by-doing type of processes, but because the rail network was initially incomplete preventing its full productive use. As a result, alternate modes of transportation such as coastal navigation were necessary to complement rail access. However, if we exclude municipalities located 10 km or less from the nearest of the 385 ports in our database, we find that our results are largely unchanged (see Appendix, Figure A11).

[34] In this perspective, our findings chime with the recent study of Paik and Vechbanyongratana (2024) showing that the railroad infrastructure erected in Thailand in the late 19th and early 20th century mostly for political reasons had nonetheless a significant impact on the economic development of the connected locations.

[35] Interestingly enough, inventors and other participants to congresses and expositions received discounts on train tickets of up to 60% (Tajani 1905, 208-211). In his short story "The Aeroplanes at Brescia", Franz Kafka recounts a journey by train with two friends to attend an air show in Brescia, in 1909. The narrative vividly captures their train travel, along with that of other participants heading to the event. The air show featured some outstanding pioneers of the early days of aviation, such as Bleriot and Curtiss, showcasing ground-breaking advancements in airplane technology (Kafka 2012, pp. 3-10).

Table 3
The impact of railroads on patenting activity 1879–1936 for railroads constructed during the *Sinistra storica* (1879–1896).

Dependent variable:	Patents per 10,000 inhabitants				
Panel A: By indicator of network access					
	Pass Through	Train Stop	Train Stop within 5 km	Train Stop within 10 km	
	0.0113	0.0430***	0.0219***	0.0217***	
	(0.0113)	(0.0123)	(0.0074)	(0.0072)	
Panel B: By subgroup (for train stop)					
	Independent patents	Firm patents	Low quality patents	High quality patents	Collaborative patents
	0.0354***	0.0032	0.0151***	−0.0011	0.0006
	(0.0117)	(0.0048)	(0.0042)	(0.0024)	(0.0004)
Panel C: By subgroup (for train stop within 5 km)					
	Independent patents	Firm patents	Low quality patents	High quality patents	Collaborative patents
	0.0050	0.0035	0.0031	0.0017	0.0001
	(0.0034)	(0.0021)	(0.0035)	(0.0015)	(0.0002)
Panel D: By macro-area (for train stop)					
	North	North-Centre	Centre	South + Islands	Continental South
	0.0676***	0.0578***	0.0276	0.0024	0.0043
	(0.0261)	(0.0188)	(0.0172)	(0.0179)	(0.0176)

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Notes: (*i*) Group-time staggered diff-in-diff regressions (Callaway and Sant'Anna, 2021). The group-time ATTs are aggregated into event-study ('dynamic') effects. The table displays the effect of different indicators of network access (Pass Through, Train Stop, Train stop within 5 and 10 km from the closest municipality) on the number of patents per 10,000 inhabitants. The effect is observed for up to 40 years. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. The count of patents every 10,000 inhabitants is a rolling mean with three-year windows. Clustered standard errors are given in parentheses. The outliers of Vado Ligure and Villar Perosa are excluded. P-values for the pre-test of parallel trends assumption are always below the 0.05 threshold.
(*ii*) 'Low quality' patents have a duration of 1–2 years. 'High quality' patents have a duration of 6 or more years. The coefficients for high and low-quality patents are aggregated over a period of 25 years, because the dataset has duration data only up to 1924.
(*iii*) Collaborative patents include patents registered with individuals or firms located in different municipalities.

Additional insights on the connection between population agglomeration and patenting activities are provided by Fig. 11, which reports the Lorenz curves of concentration between population (horizontal axis) and patents (vertical axis) by municipalities. We find that from 1861 until 1881 there is a growing concentration of patenting activities in the most populated municipalities. Thereafter, the distribution appears to be relatively stable. Overall, Fig. 11 confirms the existence of agglomeration effects in the generation of inventions.[36] To sum up, railroad expansion raised invention chiefly via population-driven agglomeration and the gradual build-up of capabilities—not through rapid knowledge flows or market access. Effects were long delayed and concentrated among independent inventors and lower-quality patents, and remained modest for the later *Sinistra storica* lines.

Fig. 12 shows that the effects of railroad connection were mainly driven by the inventors located in the North and Centre of the country, rather than by those residing in the South (see also panel D of Tables 1–3, and Figures A8, A9 and A10 in the Appendix).[37] This disaggregation of the results by macro-area suggests that the access to the railroads system had an impact especially in locations with a

[36] Table A6 in the Appendix explores the impact of railroad connections of municipalities of different size and remoteness, the latter measured using altitude. We find that for the *Destra storica*, the effect is stronger for municipalities with more than 10,000 inhabitants. Instead, for the *Sinistra storica*, we find the opposite result, namely, a stronger effect for municipalities below 10,000 inhabitants (panel A). This is probably because most cities above 10,000 inhabitants were indeed connected during the *Destra storica* period. The effects are plausibly stronger for less remotely located municipalities in the *Destra storica* period, and for more remotely located municipalities in the *Sinistra storica* period (panel B). This is consistent with the rationale of the railroad construction for stimulating economic and social development in more peripheral locations, envisaged in the 1879 Baccarini Law (see Bonfatti et al. 2022).

[37] In Table A7 in the Appendix, we consider the effect of railroad connection for municipalities located within 200km, from Milan, Turin and Genoa, the so-called 'Industrial Triangle', corresponding to a train journey time of 6-7 hours around 1900 (DGFS 1900). We conduct two separate exercises: *(i)* comparing municipalities with a railroad connection with other municipalities without a railroad connection both located within 200km from Milan, Turin and Genoa*; (ii)* comparing municipalities with a railroad connection located within 200km from Milan, Turin and Genoa with those non-connected within the same radius and all the other more distant municipalities. We find that the impact of railroads for these municipalities was stronger than the overall effects, both throughout the entire period and the two sub-periods (*Destra storica* and *Sinistra storica*). *Cfr*. Table 1, 2, and 3 with Table A7 in the Appendix.

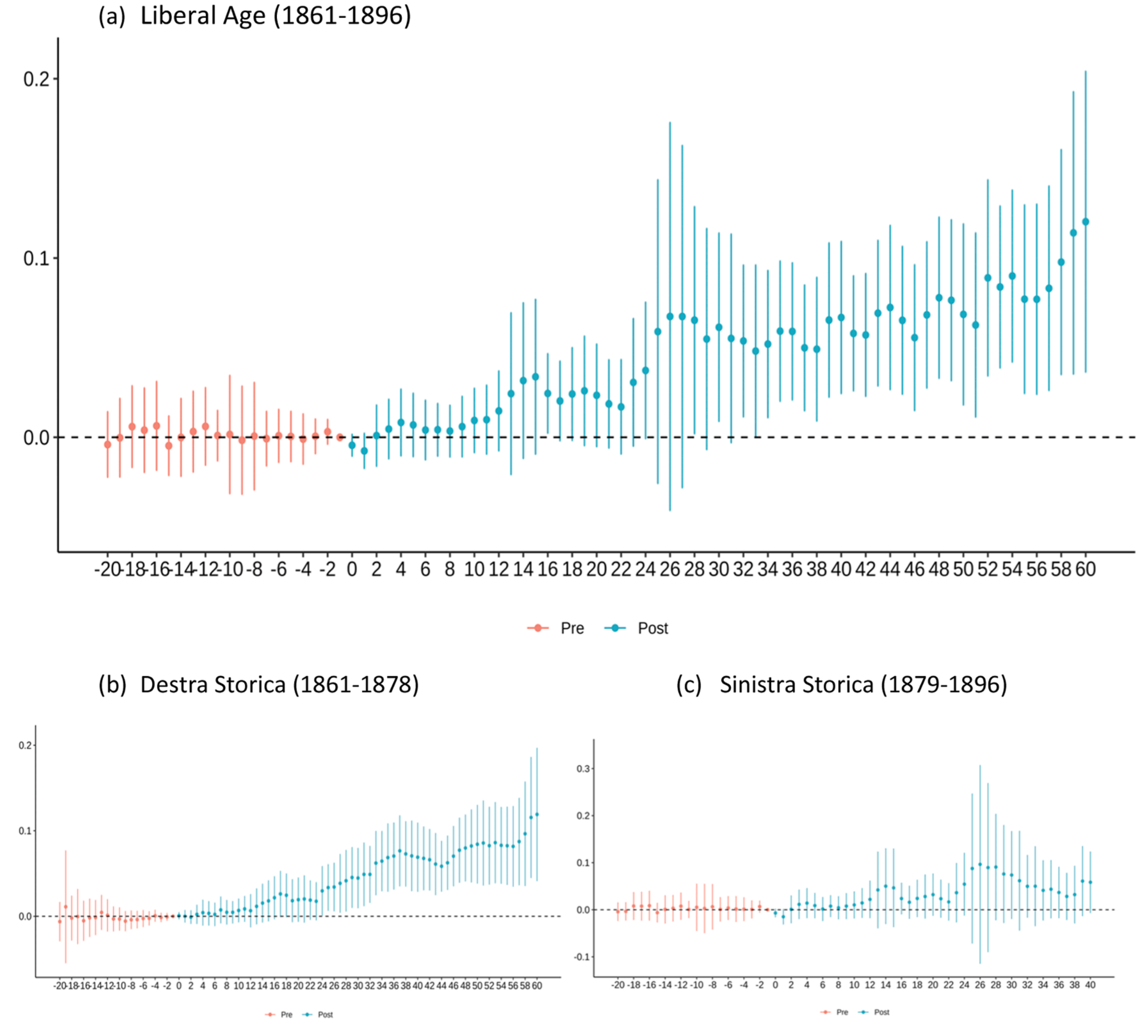

Fig. 7. Impact of railroads on independent inventors' patenting activity.
Note: The dependent variable is number of patents (rolling mean with three-year windows) for 10,000 inhabitants. The event-study graphs are produced using the R commands *att_gt* and *aggte* by Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021). Control group comprises 'not yet treated' municipalities. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in primary schooling. See Table 2 for more details.

certain level of technological capabilities.[38]

Suggestive evidence about the relative importance of these effects is provided by Table 4, which probes further into different dimensions of spatial heterogeneity in terms of pre-existing scientific and technological capabilities. In particular, Table 4 assesses the effect of railroads access, splitting the sample of municipalities into two groups of relatively high and low technological capabilities using a set of indicators capturing upper-tail human capital, lower-tail human capital and industrial specialization. In other words, we perform the Callaway and Sant'Anna estimation independently for each of the two groups of municipalities and then we compare the coefficients.

Panel A studies the role of upper-tail human capital, which is computed as the distance to 'knowledge-access institutions' (Dowey, 2017) *à la* Mokyr (Mokyr, 2005; see also Meisenzahl and Mokyr, 2012). We consider as knowledge access institutions: civic libraries, universities, and scientific and learning academies. We have retrieved detailed information about these institutions from the meticulous surveys contained in the three monumental volumes of the *Atlante della Letteratura Italiana*, edited in 2011 by Luzzato and Pedullà: Farinella (2011, p. 819), Irace and Panzanelli Fratoni (2011, p. 417), and Irace and Scotto di Luzio (2011, p. 446). The

[38] It is also possible that the North-South difference reflects greater output markets and higher demand for innovation in the Northern regions. Unfortunately, there are no suitable proxies for this kind of effects at municipality level, and therefore, we leave this issue unexplored.

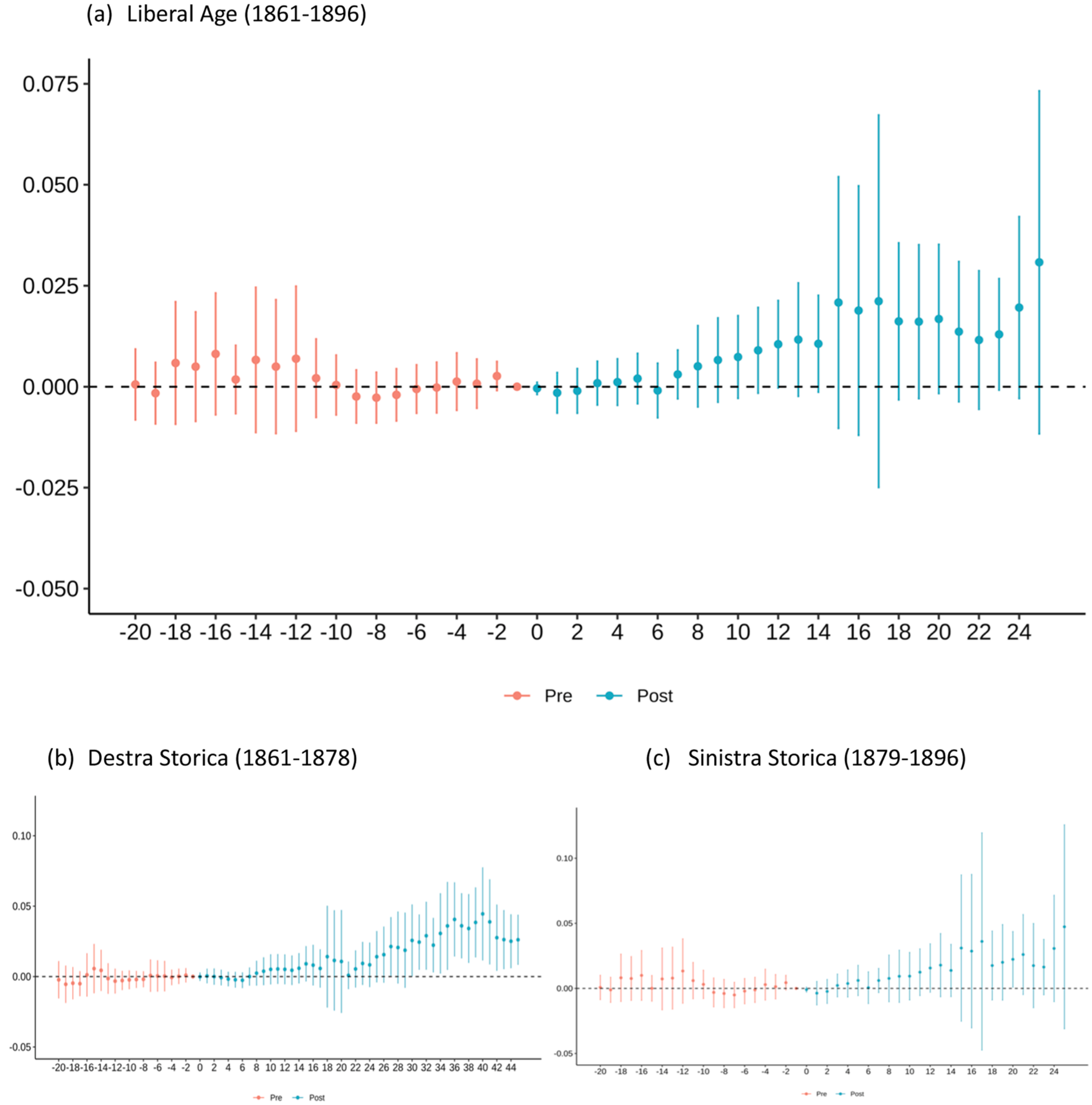

Fig. 8. Impact of railroads on low-quality (duration ≤ 2 years) patenting activity.
Note: The dependent variable is number of patents (rolling mean with three-year windows) for 10,000 inhabitants. The event-study graphs are produced using the R commands *att_gt* and *aggte* by Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021). Control group comprises 'not yet treated' municipalities. Panel (a) includes as treated all the municipalities which received a TS, while Panel (b) includes as treated all the municipalities whose town hall is located within 5 km from the closest train station (see Fig. 7). Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in primary schooling. See Table 2 for more details.

intuition is that locations close to these centers of knowledge generation will be endowed by a higher density of upper-tail human capital. In panel B, we study the role of lower-tail human capital, measured with the share of male and female students in primary schools on total population of the municipality in 1862. This indicator reflects a very basic level of education, and we believe that in this period, the generation of low-quality patents did require a deeper level of human capital than literacy or few years of schooling. Still, it is the only comprehensive indicator on lower-tail human capital available at municipal level (Cappelli and Vasta, 2020). Finally, in panel C, we study the role of the pre-existing industrial base, proxied by the indicator of relative industrialization introduced by Ciccarelli and Fenoaltea (2013), which is likely to capture several effects from the supply- and demand-side (number of firms, number of entrepreneurs, industrial markets for goods, markets for technology, etc.). In this case, we find that the intensity of railroads' effects is higher for provinces with a more developed industrial base in 1871 (Table 4, panel C). It is worth noting that all these

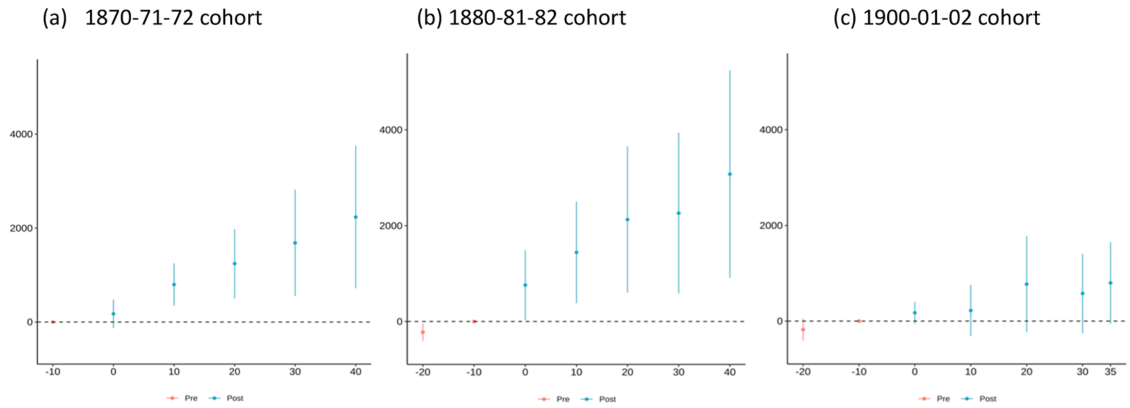

Fig. 9. Effects of train stops constructed over three-year cohorts on the exposed municipalities' population.
Note: The effects are computed every ten years because the Italian municipal population is available on a decennial basis.

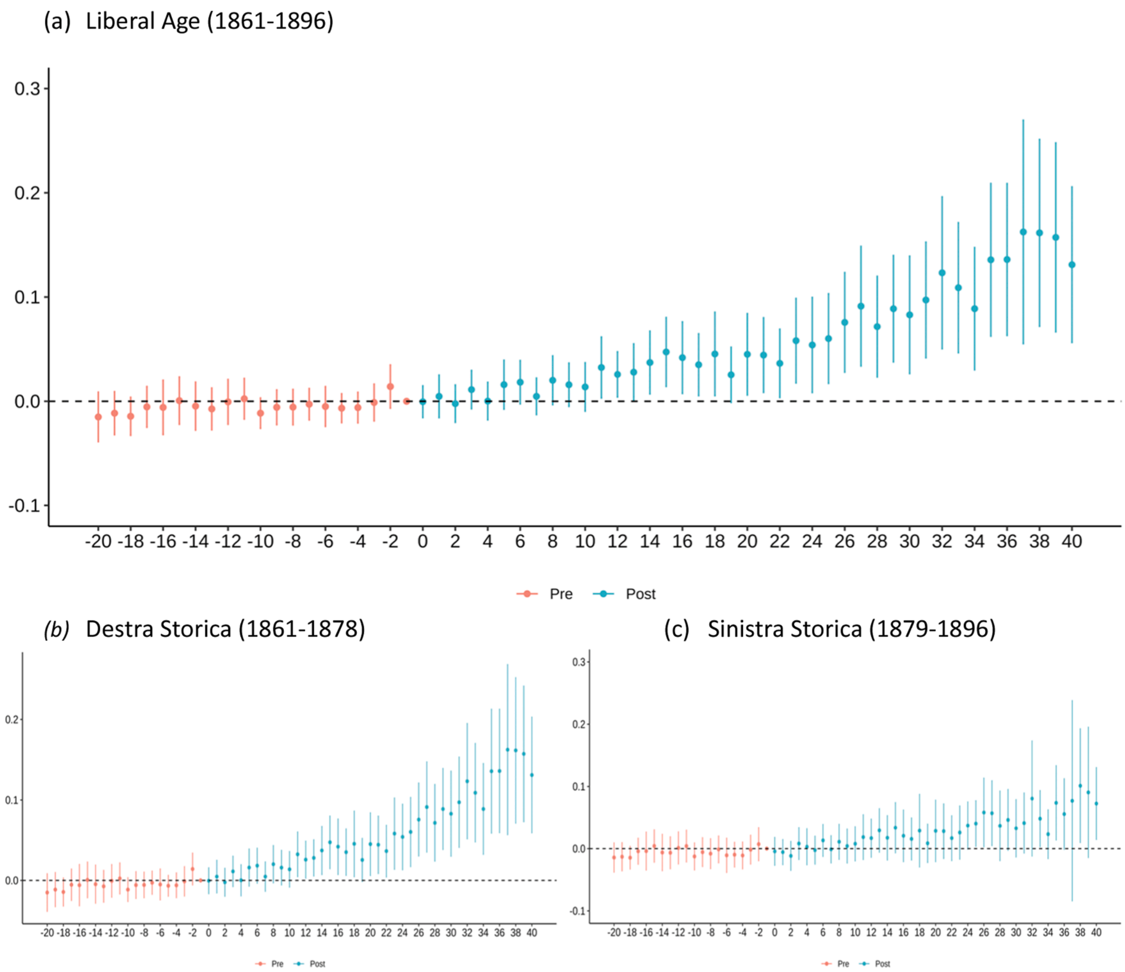

Fig. 10. Impact of railroads on the raw number of patents.
Note: The dependent variable is number of patents (rolling mean with three-year windows). The event-study graphs are produced using the R commands *att_gt* and *aggte* by Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021). Control group comprises 'not yet treated' municipalities. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. See Table 2 for more details.

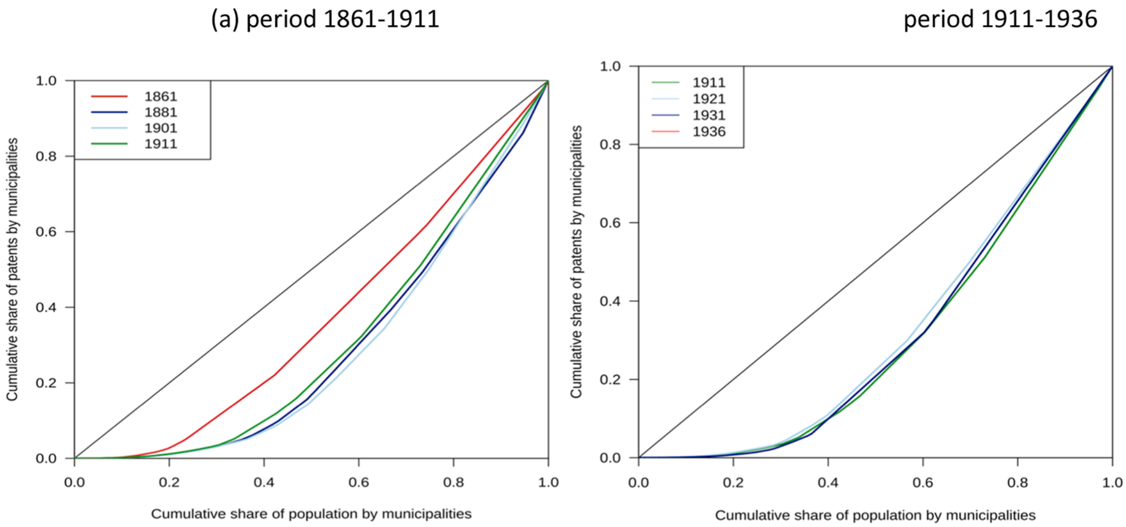

Fig. 11. Lorenz curves of population (horizontal axis) and patents (vertical axis).
Note: The patents in each benchmark year are obtained by averaging the patents of years *t, t + 1 and t-1*.

three dimensions of heterogeneity in technological capabilities are characterized by a North-South divide.[39]

Overall, our findings reveal a clear heterogeneous impact of railroad connections, displaying a stronger effect in municipalities with more advanced technological capabilities. Nonetheless, even in less developed areas, rail access still has a significant—though more limited—impact on innovative activity.

8. Conclusions

In this paper, we have provided an appraisal of the impact on innovation of the railroads constructed in Italy during the two major political phases which characterized the Liberal Age. The development of the railroad system represented a very important improvement in the transport infrastructure for a country characterized by relatively high degree of geographical "ruggedness" such as Italy. For instance, before railroads construction a journey from Florence to Rome lasted five days, while thanks to the railroads, in 1866, it took less than seven hours (Maggi, 2020). Hence, in principle, one could have expected a strong impact of railroads to the geography of innovation in Italy in this period. However, the historiography on railroads has pointed to the relatively high costs of railroad use, at least before 1905 when the system was nationalized, while the literature on innovation has insisted on the weak capabilities of the Italian innovation system in this historical phase (Nuvolari and Vasta, 2015a, 2017).

Overall, we find that the impact of the railroads on inventive activities is visible, especially for the first stage of railroads construction during the governments of the *Destra storica*. However, it should be considered that this effect may not be entirely due to the railroad connections built during the *Destra storica* period. The subsequent expansion of the network during the *Sinistra storica*, aimed at reaching more remote areas, might also have played a role. Although the increase in patenting activity in the newly connected municipalities during the *Sinistra storica* appears less pronounced, this later expansion may have further stimulated inventive activities in the municipalities already connected in the earlier phase, helping to explain the delayed and persistent effects observed in those locations. A back-of-the-envelope calculation suggests that the construction of the *Destra storica* railroads generated an additional 16.1 patents per year at the national level.[40] This is a substantial effect, corresponding to a 4.4 per cent annual increase in total patenting. To put this into perspective, overall patenting in Italy, which includes the innovation hotspots of Genoa, Turin, and Milan, grew by 7.5 per cent per year between 1861 and 1911.

Our results mask a substantial heterogeneity. In general, it seems that railroads have fostered an important "democratization of invention" on a national scale, significantly enlarging the access to the patent system by independent inventors resident in relatively

[39] The municipalities located within 30 km from the closest knowledge access institution are 2,226, out of which 1,951 in the Centre-North and 362 in the South and in the islands. Nuvolari and Vasta (2017) also observe that patenting activity was already concentrated in the Industrial Triangle (Milan, Turin and Genoa) in the early years after Unification. Enrollment rates were higher in the North-Centre regions (Bozzano, Cappelli and Vasta 2024): the municipalities with a number of male or female primary schools above the median of two schools are 2,270 in the Centre-North and 554 in the South-Islands. Finally, the industrial specialization variable is also skewed towards Northern provinces (only three out of 69 provinces in the South are relatively specialized in industrial activities).

[40] We consider a coefficient of 0.0299 patents for 10,000 inhabitants for the municipalities with TS treatment during the period 1861-1878 (see Table 1). This is multiplied by the population of the 'treated' municipalities.

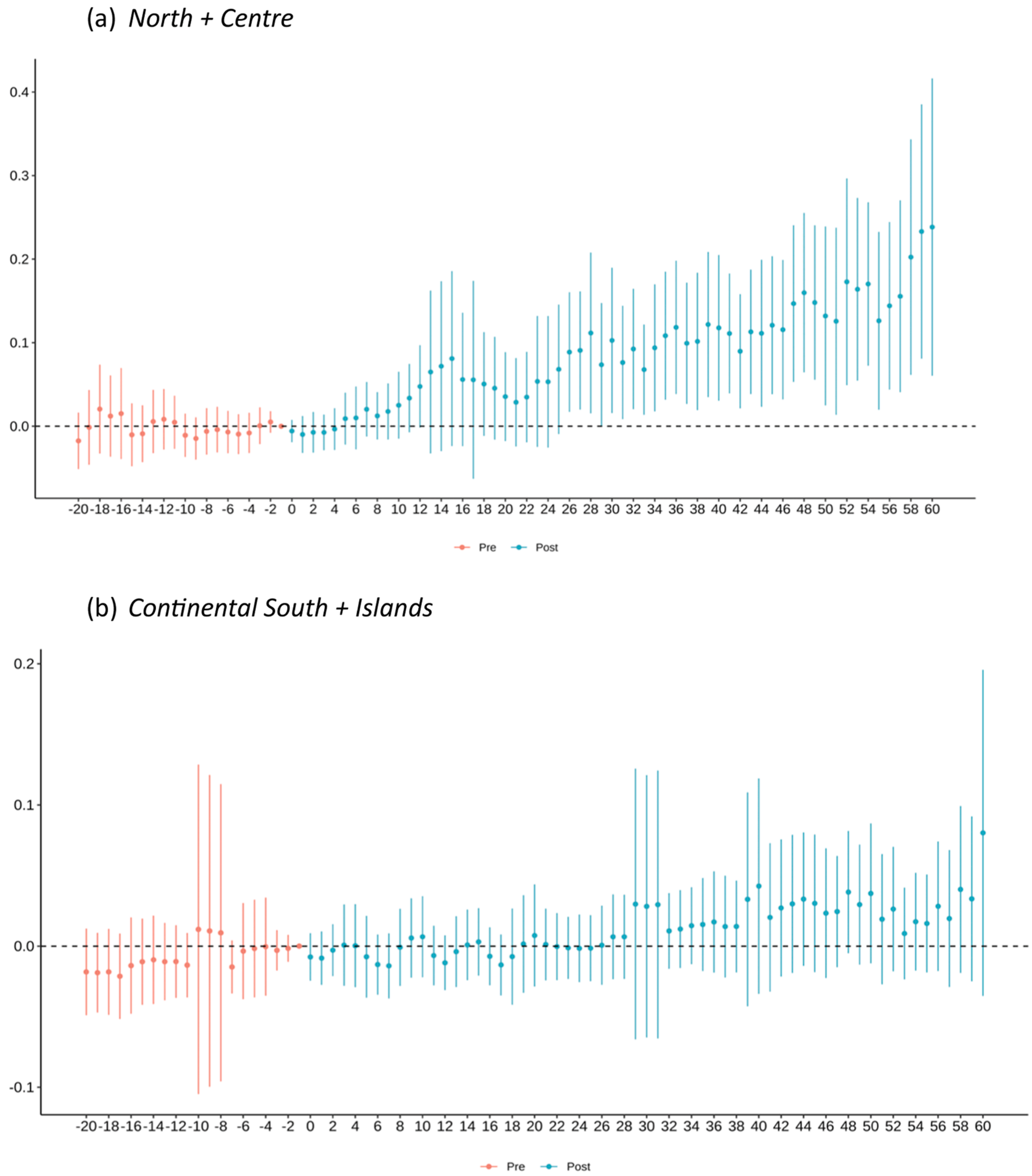

Fig. 12. Impact of railroads by geographical macro-area of Italy.
Note: The dependent variable is number of patents (rolling mean with three-year windows) for 10,000 inhabitants. The event-study graphs are produced using the R commands *att_gt* and *aggte* by Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021). Control group comprises 'not yet treated' municipalities. Panel (a) includes as treated all the municipalities that received a TS in Northern and Central Italy, while Panel (b) includes as treated all the municipalities that received a TS in Continental South, Sicily and Sardinia. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. See Table 2 for more details.

Table 4
Effects of different indicators of technological capabilities on the railroad-innovation nexus.

Panel A: Upper-tail human capital (before 1860)			
Distance from closest civic library, University or scientific academy (<30 km)	Liberal Age (1861–1896)	*Destra storica* (1861–1878)	*Sinistra storica* (1878–1896)
	0.0411***	0.0389***	0.0441***
	(0.0081)	(0.0087)	(0.0136)
Distance from closest civic library, University or scientific academy (≥30 km)	Liberal Age (1861–1896)	*Destra storica* (1861–1878)	*Sinistra storica* (1878–1896)
	0.0245***	0.0174***	0.0305
	(0.0117)	(0.007)	(0.0207)
Panel B: lower-tail human capital (1862)			
Share of male and female primary school students on total population in municipality (above median)	Liberal Age (1861–1896)	*Destra storica* (1861–1878)	*Sinistra storica* (1878–1896)
	0.0350***	0.0602***	0.0391***
	(0.0082)	(0.0180)	(0.0142)
Share of male and female primary school students on total population in municipality (below median)	Liberal Age (1861–1896)	*Destra storica* (1861–1878)	*Sinistra storica* (1878–1896)
	0.0256***	0.0170***	0.0224
	(0.0085)	(0.0057)	(0.0145)
Panel C: industrial specialization in 1871 (provincial-level)			
Index of relative industrial specialization (above median)	Liberal Age (1861–1896)	*Destra storica* (1861–1878)	*Sinistra storica* (1878–1896)
	0.0353***	0.0698***	0.0404***
	(0.0074)	0.0167)	(0.0131)
Index of relative industrial specialization (below median)	Liberal Age (1861–1896)	*Destra storica* (1861–1878)	*Sinistra storica* (1878–1896)
	0.0330***	0.0212***	0.0377***
	(0.0070)	(0.0073)	(0.0122)

Note: Group-time staggered diff-in-diff regressions (Callaway and Sant'Anna, 2021). The group-time ATTs are aggregated into event-study ('dynamic') effects. The table displays the effect of the main indicator (Train Stop) of network access on patenting activity. The effect is observed for up to 40 years. Local geography controls include: the altitude of a municipality and its latitude. Pre-rail controls include: the distance from the closest post office, the distance from the closest port, the share of male and female students in primary schools on total population of the municipality in 1862, the per capita municipality expenditure in schools, and per capita share of expenditures invested by municipalities in elementary schooling. The count of patents every 10,000 inhabitants is a rolling mean with three-year windows. Clustered standard errors are given in parentheses. The outliers of Vado Ligure and Villar Perosa are excluded. P-values for the pre-test of parallel trends assumption are always below the 0.05 threshold.
Sources: For upper-tail human capital (panel A), Irace and Panzanelli Fratoni (2011, p. 417), Farinella (2011, p. 819), and Irace and Scotto di Luzio (2011, p. 446); for lower-tail human capital, Ministero della Pubblica Istruzione (1865); for industrial specialization, Ciccarelli and Fenoaltea (2013).

peripheral locations.[41] However, these effects are mostly visible for inventors located in the Centre-North, the most developed areas of the country. Relatedly, it must be noted that this impact remained essentially limited to low-quality patents.[42] Ultimately, while railroads played a significant role in stimulating inventive activities, the overall quality of the innovations remained limited.

The moral of our historical case study is that in a latecomer country the roll out of a transport system can create new opportunities for innovation, but it does not necessarily translate in high quality inventions, particularly when other proximate drivers of technical progress, such as knowledge access institutions, upper- and lower-tail human capital, entrepreneurship and financial resources are not sufficiently developed and remain spatially concentrated.

CRediT authorship contribution statement

Marco Martinez: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alessandro Nuvolari:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Michelangelo Vasta:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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[41] The term "democratization of invention" has been originally suggested by Sokoloff and Khan (1990) and by Khan (2005) to describe the wide accessibility of the US patent system during the 19th century.
[42] On the limited contribution of independent inventors to the development of technological capabilities in Italy, see Nuvolari and Vasta (2015b).

participants of the XIX World Economic History Congress (Paris 2022) and the XX World Economic History Congress (Lund 2025). We gratefully acknowledge support from the Italian Ministry of University and Research (MUR), PRIN 2017 project: “Lost highway: skills, technology and trade in Italian economic growth, 1815–2018″ (prot. 2017YLBYZE).

Data availability

Data and code are available on open ICPSR (Martinez et al., 2025). https://www.openicpsr.org/openicpsr/project/237481/version/V1/view.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.eeh.2025.101718.

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