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ORIGINAL PAPER

Technology transfer and domestic innovation: evidence from a new dataset of Italian inventors, 1855–1914

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Abstract

This paper studies the relationship between the exposure of Italian inventors to foreign technologies and the quality of their inventions from the Unification (1861) to WWI. The paper relies on two complementary individual-level datasets: The first dataset comprises all the more than 131,000 patents registered in Italy between 1855 and 1914 as presented in Martinez, Nuvolari and Vasta 2025, mimeo. The second dataset contains biographical information about notable inventors and thus allows to obtain both technology- and inventor-based measures of the quality of inventions. The findings indicate that the direct exposure to foreign technologies improved the quality of patents, but the benefits were not substantial. While exposure to technologically similar patents from France and Great Britain led to an improvement in the quality of patents, exposure to more technologically distant patents from Germany did not. These findings suggest that Italian inventors benefitted from the exposure to foreign technologies to a limited extent.

Keywords Technology transfer · Patents · Quality of invention · Technological distance

JEL Classification N14 · N73 · O14 · O34

1 Introduction

In 1863, the sharecropping family of Paolo Soprani, born in 1844 in Recanati (Marche), hosted an Austrian pilgrim. In 1829, the pilgrim had patented the accordion, a musical instrument. He gave one accordion to Paolo Soprani, most likely as a gift (Treccani 2018). Soprani contacted some local artisans to improve some of

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the features of the accordion, soon started a business of accordions production, and received the *Élysée* from the French President of the Republic at the Paris International Exposition in 1900.[1] The Soprani accordion family business still exists today.

This is just one example, but the relationship between technology transfer in developing countries and the potential for autonomous productivity enhancements has received considerable attention from economists and economic historians. Recent empirical evidence suggests that international technology transfers were successful in improving the innovative capacities of Italy after WWII (Giorcelli 2019), late nineteenth-century Spain (Saíz, 2014), late eighteenth-century Germany (Richter and Streb 2011; Burhop and Wolf 2013; Donges and Selgert 2019), and late eighteenth to half-nineteenth-century France (Nuvolari et al. 2023).

Liberal Age Italy (1861–1914) has historically relied extensively on foreign technologies, and the Italian patent system has been exceptionally open to the registration of new patents, also from abroad. This feature makes Italy an ideal scenario to study the role of foreign technological transfer, as many innovations were transferred through knowledge and technology flows from leading economies to Italy using patent protection.[2] Previous studies by Nuvolari and Vasta (2015a, 2017) have identified differences in quality between two main groups of patentees: Italian and foreign patentees. In particular, Nuvolari and Vasta (2015a) found that the average quality of Italian independent inventors remained lower than that of firms and foreign patentees over the Liberal Age. This indicates that, despite notable exceptions such as very creative independent inventors such as Guglielmo Marconi, a bottleneck impeded the development of cutting-edge technologies, which can be summarized as a lack of absorptive capacity, or the "capability to adapt and adopt foreign technologies" (Barbiellini Amidei et al. 2013, p. 397).[3]

The literature has expressed contrasting explanations for the relationship between the high quality and quantity of foreign inventions filed in Italy and the low autonomous innovation potential. Federico (1996) argued that the lack of independent innovation did not impede overall economic growth: As Italy was catching up, the best option for Italian firms was to invest their limited resources in importing directly foreign innovations and technologies. Giannetti (1998) and Barbiellini Amidei et al. (2013) have argued that Italy was successful in absorbing foreign technologies, especially in key high-tech sectors, but did not develop an autonomous innovative potential because the technologies it imported from abroad were not enough to industrialize. Finally, Vasta (1999), Nuvolari and Vasta (2015b) and Di Martino and Vasta

[1] Patent no. 112/224 of 1899, "Armonica," by Paolo Soprani, residing in Castelfidardo (Ancona).

[2] Other institutional frameworks, such as the German state of Württemberg, had more discriminatory policies against foreign technologies (Lehmann-Hasemeyer and Streb 2020). Besides the openness of the patent system, the Italian case is an ideal scenario to study foreign technology transfer because Italian economic growth during the Liberal Age has been comparable in size to that of most industrialized countries, at least in aggregate terms (Felice 2019, pp. 523–524). Italy also managed to catch up with sectors on the frontier of the second industrial revolution, looking at specific industries such as locomotives (Ciccarelli and Nuvolari, 2016) and cars (Enrietti et al. 2022).

[3] The idea of absorptive capacities relates to the appropriability of foreign technologies, that is, the degree to which social returns to innovation produced in other countries can be privately appropriated by domestic inventors. See also Nuvolari and Vasta (2015a, pp. 273–274).

(2017) consider human capital as an important factor in explaining the absorptive capacity of technologies in Italy. The lack of diffused technical knowledge would have impeded domestic absorptive capacity. In fact, the Italian educational system guaranteed primary school attendance to only about 20% of eligible students in 1861 and about 50% in 1911 (Cappelli and Quiroga Valle 2021, 766). The North–South gap was even more pronounced for technical education than for primary education (Nuvolari and Vasta 2017).

According to the hypothesis put forward by Vasta (1999) and Nuvolari and Vasta (2015b) and Di Martino and Vasta (2017), absorptive capacity is strongly influenced by the level of human capital within a country, and, I would add, by the 'technological distance' between the technological frontier of Italy and that of more advanced countries. This view would be supported if the most successful instances of technology transfer—both at the country and inventor levels—occurred between Italy and technologically closer countries, as smaller gaps in technological sophistication would support the assimilation of foreign innovations with relatively fewer demands for higher education. In this case, the ability to absorb and apply foreign technologies could be achieved only for low-tech technologies. On the other hand, and more in line with the perspective offered by Spadavecchia, Cantwell, and Barbiellini Amidei (2013), a different hypothesis suggests that even substantial technological gaps between Italy and more advanced countries might not necessarily impede successful technology transfer. In this context, observing consistent flows of technology transfers between most advanced countries and Italy could suggest that absorptive capacity was constrained by institutional factors, such as the weakness of R&D infrastructure and the limited ability of the small firms network to produce breakthrough innovations (Malerba 1993). Despite the importance of the Italian case in contributing to a broader debate on the role of technological transfers in economic history, a lack of adequate data has hampered formal testing of the theories put forward so far about the impact of foreign knowledge and technology transfer on the quality of Italian domestic invention.

This paper addresses this gap by introducing a third category besides domestic and foreign inventors and studying the role of exposure to foreign technologies in shaping the quality of domestic invention in Italy. Patents falling under the new category of "foreign connection" (or FC) are defined as those filed by Italian inventors who previously held patents abroad and by Italian inventors who collaborated with foreign inventors. This intermediate category of patenting activity is particularly relevant for the study of technology transfer, as it encompasses Italian inventors who have been exposed to international ideas and have subsequently resulted in the filing of new patents.[4] The paper relies on two novel datasets. The first dataset includes all patents registered in Italy from 1855 to 1914, which is discussed in detail by

[4] The FC variable cannot measure all international knowledge flows, as it measures which Italian inventors were most exposed to imported innovations and those who spent time in another country but did not patent during their stay there. However, the FC variable represents a major step forward in the characterization of Italian inventors by selecting a relevant subset of domestic inventors who have been exposed to foreign technologies among large group of foreign and domestic inventors. This group is crucial for understanding the domestic absorptive capacity of foreign technologies, a concept central to the theoretical framework discussed in the literature.

Martinez et al. (2025).[5] This dataset allows us to assess the quality of patents based on the fee structure, similarly to Nuvolari et al. (2023). The second dataset includes seven biographical sources. This novel dataset allows to develop a new indicator of patent quality based on the visibility of inventors in biographical datasets, similarly to Nuvolari et al. (2021). The biographical dataset is also used to provide supporting evidence for the empirical analysis and to exemplify on the underlying channels through which knowledge and technology flows occurred.

The extent of domestic exposure to foreign technologies is measured primarily through the foreign connection indicator. The empirical analysis is based on propensity score matching regressions with time, technology and province fixed effects. I also rely on an alternative measure of FC based on text analysis of the *Treccani* biographies. The findings suggest that "foreign connections" are only marginally associated with the likelihood of registering a patent of higher quality. Italian inventors exposed to Great Britain and France are significantly more likely to patent inventions of higher quality. German connections, on the other hand, are associated with marginally lower patent quality.

2 Italian patent law and foreign technological adoption, 1861–1914

The patent law n. 1657 of 1864 (Gazzetta Ufficiale 1864, n. 24) extended the applicability of the formerly Piedmontese patent law across Italy. The law established the *Ufficio della proprietà intellettuale*, a central office where creative works could be deposited and registered. The 1864 law treated foreign and domestic inventors equally and specified the precise administrative procedure that was required to file a patent. The key features of the Italian patent law system remained substantially unchanged until 1939 (Vasta 1999).

In Italy, as in Sweden and France, and unlike in Germany (after 1877), the patent system was based on registration rather than inspection. As a result, there was not a screening process besides an administrative check, and minor and low-quality patents could be filed relatively easily. The patent law set proportionally increasing costs as the patent duration increased. Unlike other countries, such as the United States of America (Akcigit, Grisby and Nicholas, 2017), Italian patents did not distinguish between assignees (those to whom the patent was assigned to when granted) and patentees (the "first and true inventor") and did not include a description of the prior art. Another feature of the Italian patent system was that there was no distinction between the intellectual property rights attributed to individuals and to firms: Patents could also be registered directly by firms. As a result, it is possible to determine whether a patent was assigned to an individual or a firm. However, since the patent law has not changed, we cannot use changes in property rights and the entry of foreign-owned firms into Italy to study the effects of technology transfer.

An inventor could freely choose the duration of the patent, ranging from one to 15 years. There was an initial fee proportional to the number of years for which the

[5] Large-scale efforts at patent data collection are blossoming. Published examples include Saíz (2004), Streb, Baten and Yin (2006); and Berkes and Gaetani (2021).

patent was requested: 10 Italian lira, about 50 euros at 2024 prices, for one year, 20 lira for two years, and so on, up to 150 lira for 15 years, about 700 euros at 2024 prices.[6] The patent also required an annual renewal fee. The renewal fee was 40 lire for the first three years, 65 lire for the fourth to the sixth years, 90 lire for the seventh up to the ninth years, 115 lire for the tenth to the twelfth years, and 140 lire for the last three years. For example, a one-year patent cost 50 lira (about 450 euros in 2024 prices). A ten-year patent cost 800 lira (100 lira in initial fees plus 700 lira in correspondingly escalating renewal fees). Patent fees in Italy were relatively low by international standards: in 1900 a full-term patent cost on average 22,694 1998 USD (about 20,300 2024 euros) in Germany, 4,341 1998 USD in Italy (about 3,800 2024 euros), 4,933 1988 USD in France (about 4,400 2024 euros), and 16,212 1998 USD (about 14,500 2024 euros) in the United Kingdom (Lerner 2000). Italian patent fees were more expensive than those in the United States, which cost USD 720 1998 (about 650 2024 euros).[7]

Figure 1 shows the number of patents registered in Italy from 1855 to 1914. Foreign patents in Italy outnumbered Italian patents throughout the Liberal Age. Patent quality, as measured by the patent duration, followed a slow but steady downward trend (Fig. 2). Figure 3 disaggregates the geographical origin of foreign patentees (see also Table 10 in Appendix). France was the leading foreign country in terms of patenting in Italy during the period 1855–1880. The share of British patents also decreased in the 1880s, while German patents surpassed French patents in the period 1880–1896.

3 Sources and methods

This section discusses the sources, the main measure of foreign connection and patent quality and the empirical design adopted to econometrically investigate the relationship between foreign connection and patent quality. It can be important to remark that patents are an imperfect indicator of innovative activity. As Griliches (1990) observed, the raw number of patents is not indicative of the quality differences among patents. And because the number of patents is often large compared to macro-inventions, "patent statistics loom up as a mirage of wonderful plentitude and objectivity" (Griliches 1990, 1661). Additionally, many important innovations were not patented (Moser 2005, 2012, 2013, and Domini 2020). For studies covering a long-time horizon such as this one, patents can still be considered the best available indicator of overall innovative activity.

[6] Istat data on price conversions is available at https://www.istat.it/it/archivio/269656.

[7] Nuvolari and Vasta (2015a, pp. 863) show that the cost of maintaining a patent in Liberal Age Italy was much lower than in Germany and Great Britain, when annual fees are measured by the average weekly wage of workers in the engineering sector.

3.1 Sources

The main source of this study is the complete set of 131,447 patent records registered in Italy from 1855 to 1914, presented by Martinez et al. (2025).[8] The historical sources for this dataset are the official serial publications of the *Ministero di Agricoltura, Industria e Commercio* (MAIC) (1855–1914). This dataset is not a sample, but it contains the full set of patents issued during the Italian Liberal Age. This makes it possible to follow the careers of inventors and to study their patterns of residence, which is essential for this study as it allows us to follow inventors and their exposure to foreign countries.[9] The resulting dataset allows us to gain definitive insights about the long-run evolution of inventive activities in Italy. Table 1 provides an extract of the key columns of the dataset.

The geographical information is fine-grained enough to distinguish the municipality of origin of patentees. Besides geographical information, a patent entry contains the following information: the date on which the patent was applied for (*data di deposito*); the date on which the patent was granted (*data di rilascio*); the official patent number in the register; the name(s) of the patentee(s) (this may be an individual inventor or a firm); the province of residence of the Italian patentee(s); the country of residence of the patentee(s); the initial duration of the patent; the number and duration of the extensions (*prolungamento*) of the patent; the patent typology (ordinary*, rivendicazione, prolungamento, importazione, riduzione*, and *completivo);* a short description of the invention; one of the 26 technological categories (i.e., electronical, chemical, etc.) in which the patent was classified. The patent class allows us to classify the technological content of the patent. I use the classification introduced by Nuvolari and Vasta (2017b) between "high-tech" and "low-tech" patents: High-tech patents are those related to the technological systems that were central to the first and second industrial revolutions: chemicals, electricity, machine tools and machinery, steam engines, and weapons.[10] Patentee names have been used to follow the innovative paths of inventors across time and space. For instance, a patent of F.I.A.T. in 1896 is associated with another patent of F.I.A.T. in 1906 (see also Appendix A.1).

This paper is also based on a novel dataset containing the names of individuals appearing in seven collections of eminent individuals, for a total of 245,448 potential name matches. To represent Italian inventors, the dataset includes the about 30,000

[8] The data collection project was sponsored by the MIUR, the Italian Ministry of Education, under the P.R.I.N. titled "Lost highways: skills, technology and trade in Italian economic growth, 1815–2018."

[9] The dataset only gives snapshots of the career of inventors when they patented in Italy, so it is possible, for example, that an inventor lived in Italy, then moved to France when the first invention was patented, and then returned to Italy. We would only observe the movement from France to Italy. This already gives a measure of exposure to foreign technology.

[10] Degner and Streb (2013) observe how different technologies were considered high-tech in different countries at different periods of time. Between 1877 and 1932, patents issued and registered in Italy, for example, were only high tech in the textile and automobile industries. The definition by Nuvolari and Vasta (2017) provides a general standard of technologies that can be considered of high technology at the time of the second industrial revolution. Although the technological frontier of a relatively backward country like Italy may be less high-tech than the standard of the second industrial revolution, this was the high-tech standard at the time for most foreign inventors patenting in Italy.

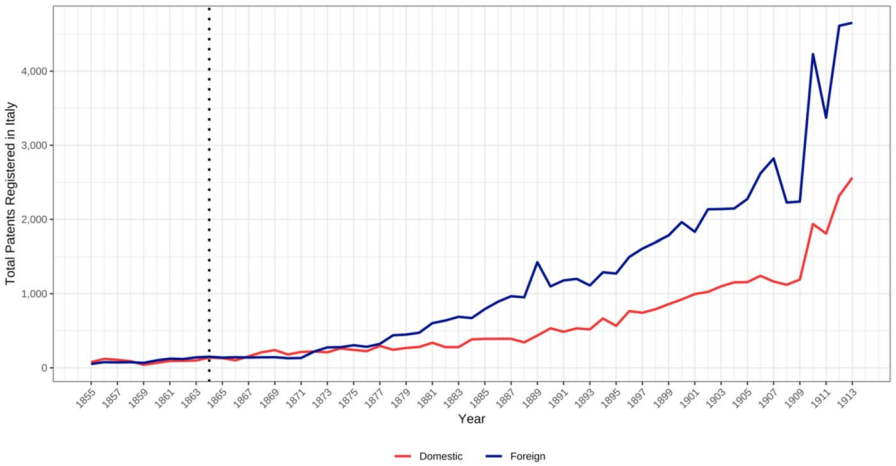

Fig. 1 Number of Italian and foreign patents. *Note:* The patent count for the year 1914 is lower than the rest because many patents of 1914 were recorded in the registers of the following year and are not included in the sample. On top of this, the year 1915 was exceptional as Italy entered in the WWI. For these reasons, the year 1914 is excluded from the figure. *Source*: HIP database (Martinez et al. 2025)

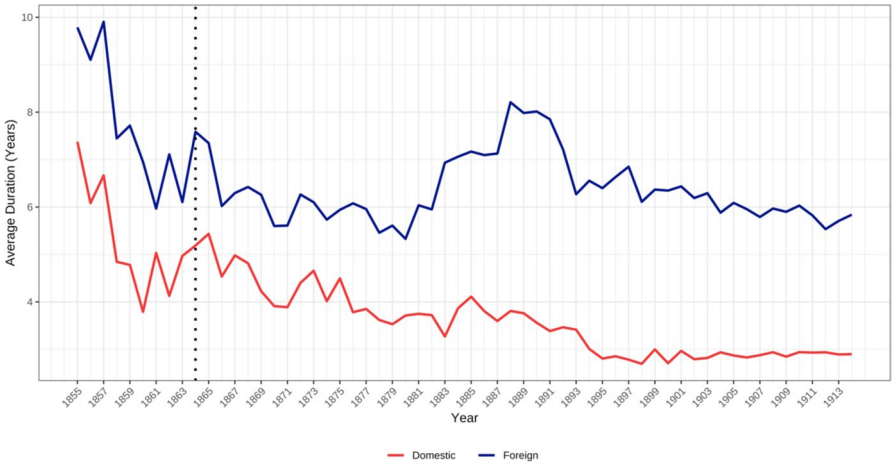

Fig. 2 Average nominal duration of domestic and foreign patents. *Note*: The dashed vertical line indicates the year of introduction of the Italian patent system. Before that, the patents of our dataset derive only from the Kingdom of Sardinia. *Source*: HIP database (Martinez et al. 2025)

eminent Italians gathered from the more than 80,000 pages of the *Treccani Dizionario Biografico degli Italiani.* The *Treccani* Dictionary is a very detailed effort at providing high quality biographies of Italians and is written by renowned specialists. It is not surprising, therefore, that although the first volume of the *Treccani*

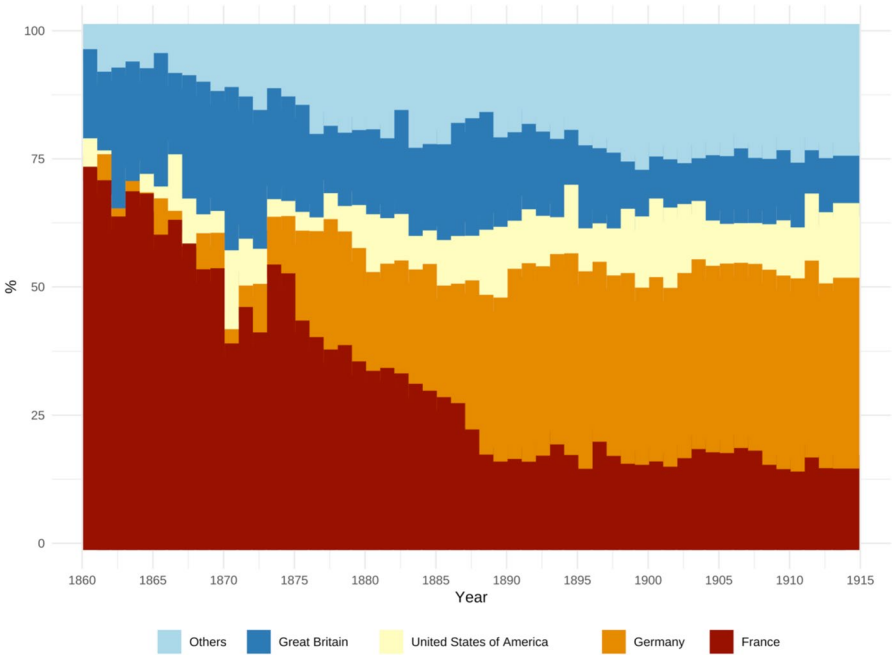

Fig. 3 Share of foreign patents by country of origin, 1861–1914. *Note*: The patent data for Germany before the foundation of the German Empire (1877) include all pre-unitary States of Germany

Dictionary was published in 1960, the last letter of the dictionary was not published until 2021, after more than sixty years of work and a total of 100 volumes.

3.2 The foreign connection indicator

The main explanatory variable is the "foreign connection" (FC) of inventors. The variable considers as inventors with foreign connections those who either: (i) have an Italian name, surname, or both, and have resided abroad at least once while also registering a patent in Italy, (ii) do not have an Italian name, but have registered more patents while residing in Italy than while residing abroad, (iii) are companies residing in Italy more often than abroad while patenting in Italy, or (iv) the inventor patented together with an inventor residing abroad, while s/he instead was residing in Italy. It is important to note that, in order to avoid measuring the foreign connection before having resided abroad, only those patents registered after the person with a FC resided abroad are indicated as having a FC.

Some examples may illustrate how the foreign connection indicator was constructed. Although 'Guglielmo Marconi' had an Italian name, he is not considered to have a foreign connection because he never registered a patent while residing in Italy. 'Enrico Forlanini' is also not considered to have a foreign connection despite having an Italian name, because he always registered patents while residing in Italy. 'Cavalier Giovanni Maria Mure' is marked as having a foreign connection because

Table 1 Extract of the information contained in the patent dataset

Patentee	Mazzoleni Melchiorre fu Gio. Battista	Edison Thomas Alva	F.I.A.T	Chemische Fabrik Goldschmieden Loewig et C
Residenza	Milano	Newark	Torino	Lissa
Provincia	MI		TO	
Country	Italy	United States of America	Italy	Germany
Year	1905	1873	1907	1883
ID	67,882	5,049	77,952	12,949
Inventor ID	35,334	2530	37,458	6674
Register no	216–227		91,022	15,476
Duration	1 year	6 years	3 years	10 years
Typology	Ordinary	Ordinary	Ordinary	Ordinary
Class	VII. Navigazione ed aeronautica	VII. Navigazione ed aeronautica	VII. Carrozzeria e veicoli diversi	XIV. Industrie chimiche diverse ed apparecchi relativi
Title	Nuovo Sistema di rimorchiamento	Instruments telegraphiques á impressions	Giunti a frizione per automobile a dischi metallici	Processo di purificazione delle soluzioni di sali metallici inquinati dal ferro

he obtained two patents while residing abroad and has an Italian name. 'Rignon Joseph Albert' is not marked as having a foreign connection, because even though he only registered four out of ten patents in Italy, and he does not have an Italian first or last name. The same goes for 'Friedmann Alex', who registered a patent while residing in Milan but registered the remaining 34 patents while residing in Vienna, Austria.[11] According to this definition, 1,158 patents had a foreign connection, corresponding to 358 inventors. 377 patents were connected to France, 167 to Germany and 123 to Great Britain. 988 FC patents were filed by independent inventors and 170 were filed by firms (see Table 2).

Figure 4 shows the patterns of FC patenting, and Table 2 describes the number of patents filed by country of connection. Until the 1880s, most FCs were held with France. After the 1880s, French connections started to decline and German connections took over, along with British connections. I consider 1) all foreign connections and 2) focus on French, German and British connections because of their numerical preponderance. The trends in FCs closely mirror the overall trends in foreign patenting in Italy, as highlighted in Fig. 4 and Table 2.

3.3 Patent quality

Patent quality is usually measured by patent renewals and patent citations.[12] For Italy, we lack information on citations. In this context, the duration of patents in years is used as the main proxy for quality. The intuition is that patents with longer durations are increasingly more costly for the patentee, so they should be of higher quality than patents with shorter durations.[13] The possibility to shorten or extend the patent duration granted by Italian law allows me to improve the initial (nominal) duration measure with renewal information.

Patent duration may depend on factors other than quality, such as an inventor's sector-specific knowledge, patenting experience, and income.[14] The decision to register a patent with a long duration could also be influenced by sector-specific technical considerations. For example, duration could also measure the obsolescence of products rather than their quality, and obsolescence is industry-specific and has little to do with the quality of the invention. Although this concern is partially mitigated

[11] It is worth noting that Nuvolari, Tortorici, and Vasta (2023) define an inventor as having a "British origin" if either (1) the inventor resided in Britain, or (2) the inventor was French but co-patented with British inventors. FC is a more restrictive measure than British origin because it focuses only on patentees who were Italian or that were commercially linked but who were nonetheless exposed to foreign technologies. The entire group of foreign inventors would be very positively selected in Italy: If such inventors chose to patent not only in their own country, but also in Italy, this indicates that their invention was successful and thus profitable to patent elsewhere. The foreign connection focuses on domestic inventors who could benefit from technological transfers, excluding those who were themselves transferring technologies to Italy.

[12] See Streb (2023 and 2024) for a survey of this stream of literature. On citations: Trajtenberg (1990); Moser, Ohmstedt, and Rhode (2015). On renewals: Shankerman and Pakes (1985).

[13] In Liberal Age Italy, the nominal duration measure has already been used by Nuvolari and Vasta (2015a, b, 2017).

[14] Merouani and Perrin (2024) use the duration as a measure of resource constraints of French women inventors.

by using technological class fixed effects and a renewal-adjusted duration measure, the limitations described justify the addition of an alternative quality indicator.

The "patent eminence" quality indicator is based on the recognized accomplishments and fame of the patentees, as evidenced by whether an inventor appears in biographical dictionaries at least once. The number of times their names appear in biographical dictionaries. The indicator counts the number of biographical dictionaries in which the name of an inventor who registered a patent in Italy appears (see Table 7 in Appendix for examples and Fig. 5). The patent eminence indicator implicitly assumes that all inventions patented by an eminent inventor are of equal quality.[15]

The duration and biography-based indicators measure two different dimensions of quality. Duration reflects an *ex ante* measure of the perceived quality and technological novelty of the patent. The biography measures the *ex post* importance of the inventor as an individual. Having both measures allow us to capture both *ex ante* (duration) and *ex post* dimensions of quality (eminence).

3.4 Empirical approach

To empirically examine the relationship between foreign technological transfer and the quality of domestic inventions, I estimate the following Poisson regression model:

$$E(y|\boldsymbol{X})_{i,t} = \exp\left(\alpha + \beta\ \text{Foreign Connection}_{i,t} + \delta \boldsymbol{X}_{i,t} + \theta_t\right) + \varepsilon_{i,t} \tag{1}$$

I consider three dependent variables, $y_{i,t}$. The first and main one is the scheduled duration of patents (in years) for patent i at time t. The second is the patent eminence of patent i at time t. The third is the inventor eminence of inventor j at time t—for this third model, the unit of analysis is the inventor j rather than the patent i. The main explanatory variable, $ForeignConnection_i$, is either the connection to any foreign country or the connection to France, Germany, or Great Britain, while the connection to other countries is the omitted category. As control variables, denoted by $\boldsymbol{X}_{i,t}$ in the formula, I consider whether or not the inventor resided abroad at the time of filing the specific patent, whether the invention could be classified as "high-tech," the number of patents filed by inventors during their lifetime, the distance between each municipality and the nearest university active in the nineteenth century, the minimum distance (in km) between the municipality where a patentee resided and the closest of the 147 borders points with foreign countries (France, Austria, and

[15] Other studies using biography data derive other measures of quality or "richness" of the biography, such as the length of the biographies or the number of languages into which a Wikipedia article is translated to (recently, Koch, Stojkoski, and Hidalgo, 2024). The approach to identify alternative quality measures to patent duration in this study is more similar in spirit to Nuvolari, Tartari and Tranchero (2021), as it focuses on the extensive margin (number of different biographical dictionaries an inventor is mentioned in), rather than on the intensive margin (e.g., text length). The two margins can hardly be studied together, as each biographical source differs greatly in format and detail, ranging from Wikipedia to simple lists of inventors. Nevertheless, looking at the intensive margin of biographical quality measures would be a promising addition to this study.

Table 2 Number of patents registered by relevant groups of patentees

	1855–1878	1879–1896	1897–1914	1855–1914 (All)
Domestic patentees in Italy	3858	7858	24,031	35,764
Foreign patentees in Italy	4074	17,207	47,416	68,708
French patentees in Italy	2125	3734	8164	14,023
German patentees in Italy	425	4877	16,458	21,760
British patentees in Italy	756	2817	5958	9531
Patents with foreign connection	160	268	730	1158
Patents with French connection	99	82	198	379
Patents with German connection	14	31	123	168
Patents with British connection	18	32	74	124
Independent patents with foreign connection	150	236	602	988
Firm patents with foreign connection	10	32	128	170

For further descriptive statistics, see Table 3 and Tables 9 and 10 in Appendix

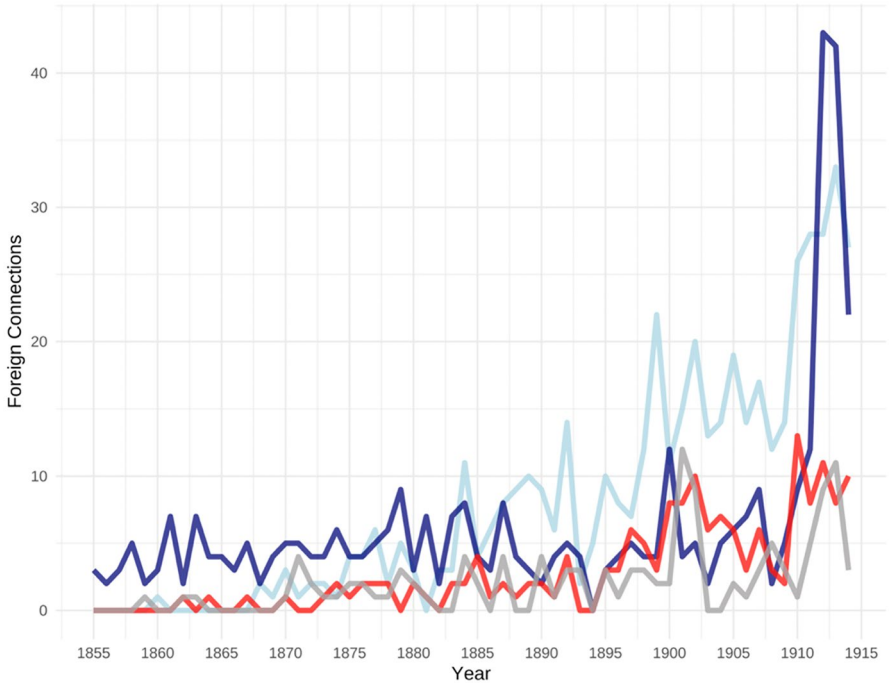

Fig. 4 Patents with foreign connection

Switzerland).[16] $\boldsymbol{X}_{i,t}$ also includes technology and province fixed effects which control for unobservable variation in patenting across technologies and provinces which is constant over time. Finally, year fixed effects (θ_t in the formula) control for unobservable time variation in patenting which is common across patents.[17] The analysis is conducted separately for firms and individual patentees. It is worth noting that when interpreting Poisson regression coefficients, the sign indicates the direction of the association, but the magnitude of the correlations should be calculated as the exponential of the coefficients reported in the regression tables.

The results of the regression analysis cannot be interpreted as causal: Unobservable factors may bias the relationship between foreign connections and invention quality. For example, individual ability may increase the likelihood of both residing abroad and registering a high-quality invention, overestimating the magnitude of the relationship between foreign connections and high-quality inventions. This paper is best understood as a first attempt to gain a better understanding of the factors associated with the increase in patent quality in Italy during the Liberal Age, and the role of foreign connections in this. Nevertheless, to mitigate endogeneity concerns, I use a propensity score matching empirical design with period and technology fixed effects in all the baseline Poisson regression specification and test the robustness to a set of alternative specifications. The propensity score approach allows to find a combination of patents without FC that are as similar as possible in terms of observable characteristics to each patent having a FC. A matching design is particularly well suited to this setting because we have a very large pool of comparison patents from which to draw to find adequate matches for the relatively few patents with a foreign connection. The improvement in terms of similarity between the FC group and the control group of patents after matching is substantial (see Table 3 and Fig. 6 in appendix).

The ideal natural experiment would be one in which inventors with foreign connections were forced to emigrate from Italy for political or military reasons, such as the expulsion of Jewish chemists during Nazism, which had a significant impact on U.S. patenting output in these sectors (Moser et al. 2014). The Italian Liberal Age, like other recent examples of technology transfer empirically analyzed in the economic history literature (e.g., Nuvolari et al. 2023), lacks a similarly clear-cut setting. To lend empirical support to the results of the propensity score matching design, I come as close as possible to such setting as follows. The detailed biographical information of the *Treccani* biographies allows us to obtain an alternative definition of the foreign connections that focuses only on arguably exogenous foreign

[16] It is important to clarify that the dummy for whether the inventor was resident abroad does not exactly move together with the foreign connection variable. Suppose that a patentee with foreign name filed a patent in France and then filed two patents in Italy. Because s/he filed more patents in Italy while residing in Italy than while residing abroad, s/he will appear as having a foreign connection, but s/he will only appear to be residing in Italy for the second and third patent.

[17] Including inventor-level fixed effects besides technology, province and year fixed effects would leave too little variability left to be estimated because most inventors patented just one patent, but we conduct separate analyses at the level of the inventor (see Table 5, columns 5–6). Table 3 describes the mean of covariates for patent groups with and without foreign connections (see also Table 8 in Appendix for further descriptive statistics).

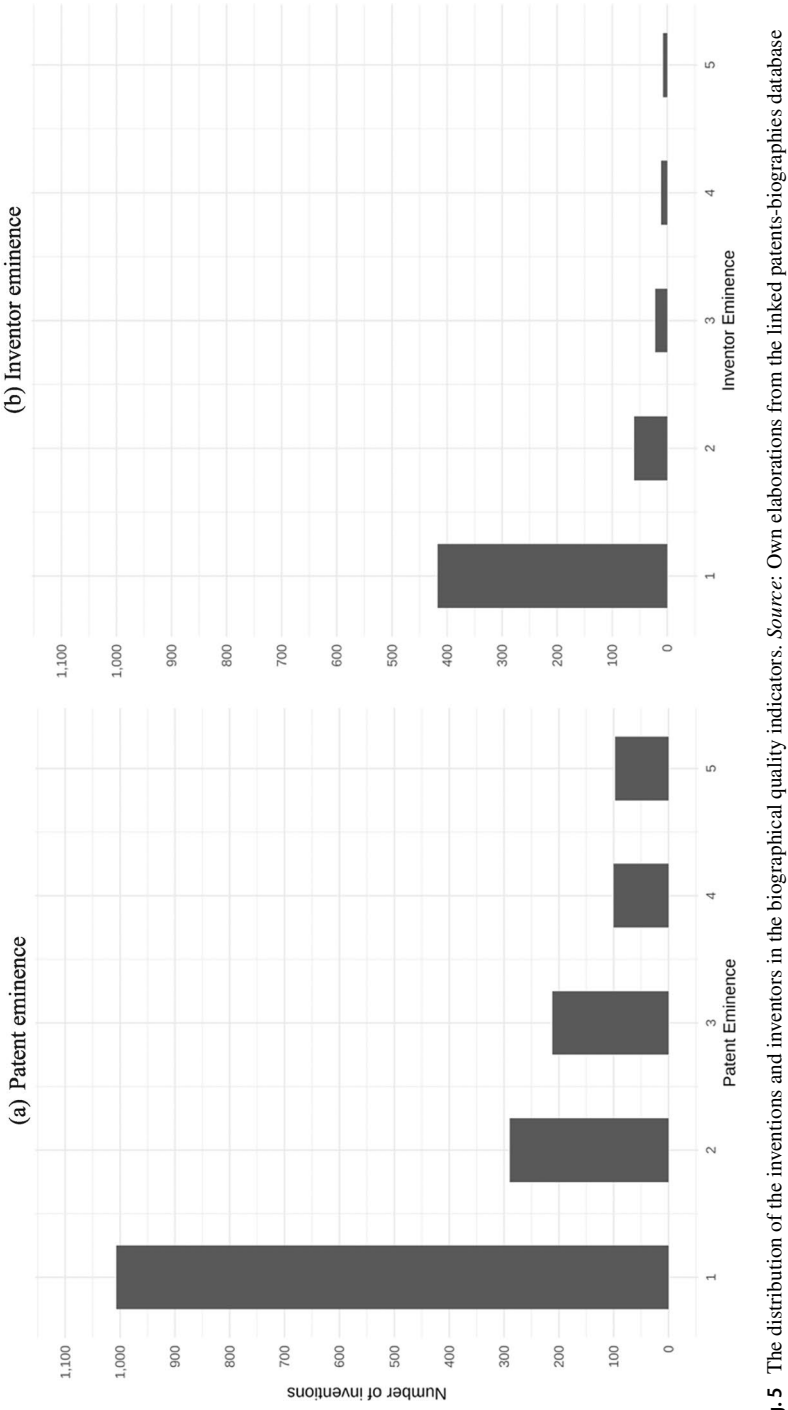

Fig. 5 The distribution of the inventions and inventors in the biographical quality indicators. *Source*: Own elaborations from the linked patents-biographies database

Table 3 Descriptive statistics by subgroup

	Unbalanced				Balanced (PSM)			
	With FC	Without FC	Std. mean diff	Var.ratio	With FC	Without FC	Std. mean diff	Var. ratio
Panel A: patents registered by independent inventors								
Year of patent filing	1896,6	1899,2	−0.17	1.31	1896,6	1894,6	0.13	0.93
Patent duration	4.01	4.81	−0.22	0.86	4.01	4.19	−0.05	0.95
High-tech patent (Y/N)	0.3	0.26	0.08		0.3	0.36	−0.12	
Distance to the Italian border (km)	1.3	1.1	0.0	1.1	1.3	1.7	−0.1	0.7
Distance to the nearest university (km)	0.5	0.5	0.0	1.1	0.5	0.8	0.0	0.7
Patentee residing in Italy (Y/N)	0.57	0.37	0.42		0.57	0.61	−0.06	
Year > 1884 (1/0)	0.77	0.86	−0.2		0.43	0.39	0.06	
Lifetime number of patents	5.44	2.35	0.51	1.13	0.77	0.73	0.1	
Panel B: patents registered by firms								
Year of patent filing	1903,6	1903,4	0.01	1.63	1903,6	1904,3	−0.05	1.18
Patent duration	5.1	6.87	−0.53	0.52	5.1	5.57	−0.14	0.63
High-tech patent (Y/N)	0.17	0.38	−0.55		0.17	0.18	−0.02	
Distance to the Italian border (km)	0.7	0.4	0.3	0.1	0.7	1.2	−0.3	0.0
Distance to the nearest university (km)	0.1	0.2	−0.3	0.0	0.1	0.6	−1.6	0.0
Patentee residing in Italy (Y/N)	0.7	0.22	1.05		0.7	0.7	0	
Year > 1884 (1/0)	0.3	0.78	−1.05		0.3	0.3	0	
Lifetime number of patents	0.92	0.94	−0.08		0.92	0.92	0	

The propensity score matching was performed with an optimal full matching algorithm

connections. In particular, the 'exogenous FC' indicator relies on inventors having foreign connections for reasons related to idiosyncratic, military, and political factors that intervened during their life course, besides the fact that they have moved to Italy after the FC and had most of their patents in Italy following the FC. The most common of these factors was the wave of anti-absolutist revolts in 1848-1849, which led many opponents of the old monarchical systems to leave. Inventors that do not fulfill the additional criteria of the exogenous FC are instead excluded from this analysis.

Some examples can help to clarify how this indicator was constructed. Vincenzo Carbonelli of Palermo was a political fugitive in Paris after the 1848 anti-absolutist insurrections that favored the Bourbons in the Kingdom of Naples and finally returned to Italy (Genoa) in 1854. The mother of Mariano Fortuny was a Spanish noblewoman, and this influenced his Spanish connections. Other inventors are excluded from the exogenous foreign connections category due to their travel motivations. For example, the entrepreneur Alberto Riva, who traveled extensively for industrial supplies, is not considered to have a foreign connection.

4 Foreign technological transfer and the quality of Italian invention

The "foreign connection" variable is significantly correlated with patent quality in most specifications. Without covariates, the estimated correlation for independent patentees is not statistically different from zero (see Table 4, column 2). When all covariates and fixed effects are included, the coefficient is positive and significant for independent inventors with British connections, negative and significant for inventors with German connections, and not significant for French connections. British connections are associated with a longer patent duration of 1.4 years, while German connections have a lower duration of 0.8 years. For firms, German connections are associated with a lower patent duration of 0.6 years, French connections are associated with a higher patent duration of 1.5 years, and British connections are not significant. The effects of the foreign connection variable for firm inventors should be interpreted with caution, as there are few patents filed by firms with a foreign connection (see Table 2). This makes historical sense given the evidence in the literature documenting the prevalence of independent inventors in Italy, as opposed to firm inventors (Nuvolari and Vasta 2015a, b: 869), but should be taken into account when discussing the significance of the results of the firm sample.

The scheduled duration of high-tech patents is 1.1 years longer for both firms and independent inventors, confirming the fact that patents with a long duration are of higher quality and are more technologically sophisticated than innovations with a short duration. Independent inventors residing abroad are more likely to file patents with a longer duration than Italian inventors, including those with a foreign correction, but not to a significantly so. Being located farther from a university does not appear to be associated with the quality of patents produced by independent inventors. This suggests that simply having access to nearby higher education opportunities is not enough to improve patent quality on its own (see Table 4, columns 1–5,

and Table 5). (Table 4, columns 1–5 and Table 5).[18] As in the case of British transmission of technology to France in the early nineteenth century, distance from borders does not explain the quality of patents to any appreciable extent. This suggests that spatial proximity to foreign countries alone cannot explain more technological interaction with the foreign environment than for the rest of Italy.[19] Furthermore, there is a positive relationship between the number of patents an inventor files over their lifetime and their quality.

There are no striking regional disparities in the effects of foreign connections on patent quality, except that the positive impact of French connections is observed only among inventors in Northern Italy. This regional difference likely explains the higher overall foreign connection (FC) coefficient for the North, compared to the Centre and South (see Table 12). These findings suggest that exposure to the technological frontier of foreign countries played a more important role in increasing patent quality than the specific regional characteristics of the location of patentees within Italy. The results of the regressions applied to the unmatched sample regressions are consistent, but appear to be slightly overestimated for independent inventors, and underestimated for firms (see Table 11 in Appendix). The opposite direction of the bias suggests that for individuals, there were positive selection mechanisms such that the most able inventors were also more likely to have foreign connections; for firms, on the other hand, the need to move abroad arguably represented a temporary shock to their creative ability.

The duration indicator of quality may yield overestimated results because the duration of the corresponding patents is the result of a simple sum of the patent duration and of extensions. While extensions are a good indicator of the interest of the inventor in further protecting the invention, the quality may fade out over time, and more strategic considerations may come into play when deciding to extend a patent for a long period. For this reason, Table 15 in Appendix shows the results using the nominal duration rather than the scheduled duration as the outcome variable. The results are generally consistent, although slightly less significant than the ones of Table 4.

The effects are generally consistent, both in statistical and economic significance, when using patent eminence as an alternative proxy for patent quality (see Table 13 in Appendix).[20] Such alternative biographical-based quality indicator is defined as dummy variables rather than as counts. For example, if an inventor appears at least once in a biography, s/he is an eminent inventor. The reason is that counting the number of times an inventor appears in biographies may be problematic because some biographical

[18] It is important to note that in other specifications, patentees who are located farther from the nearest university instead seem to produce patents of lower quality. This pattern is observed at the macro-area level (Table 12), at the inventor level (Table 13, columns 5-6), and when excluding inventors who have filed only a single patent (Table 16).

[19] Burhop and Wolf (2013) adopt a gravity model of trade to the international patent market and show that borders restricted the flow of patents, and especially of lower quality ones.

[20] The effects of the inventor eminence by country should be taken with caution due to the small sample size of inventors with British origin (39 inventors), German origin (57), and French origin (104). The sign reversal of British connections with inventor eminence can be explained with the relatively small sample size of British inventors.

Table 4 Relationship between foreign connections and scheduled duration of patents, matched sample

Dependent variable								
Scheduled duration (years)								
Poisson regression								
	Independent inventors				Firm inventors			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Foreign connection	0.016	−0.049	0.006		0.140***	−0.219**	0.162	
	(0.014)	(0.037)	(0.040)		(0.028)	(0.088)	(0.103)	
German connection				−0.164**				−0.419***
				(0.071)				(0.140)
French connection				0.076				0.396**
				(0.069)				(0.155)
British connection				0.340***				0.199
				(0.070)				(0.289)
High-tech patent	1.909***		0.207***	0.206***	2.048***		0.434***	0.433***
	(0.063)		(0.019)	(0.019)	(0.074)		(0.048)	(0.048)
Residing abroad	0.384***		0.363***	0.380***	0.157		0.171	0.010
	(0.060)		(0.093)	(0.089)	(0.159)		(0.221)	(0.200)
Municipality distance to the nearest university	0.010*		0.010	0.010	0.207***		0.203**	0.210**
	(0.005)		(0.009)	(0.009)	(0.025)		(0.098)	(0.099)
Municipality distance to the border	0.000**		0.000	0.000	−0.002***		−0.002**	−0.002**
	(0.000)		(0.000)	(0.000)	(0.000)		(0.001)	(0.001)
Lifetime number of patents	0.009***		0.010***	0.009***	0.002***		0.002***	0.002***
	(0.000)		(0.001)	(0.001)	(0.000)		(0.000)	(0.000)
Technological class FE	No	No	Yes	Yes	No	No	Yes	Yes

Table 4 (continued)

Dependent variable								
Scheduled duration (years)								
Poisson regression								
	Independent inventors				Firm inventors			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Province FE	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Num. Obs	82,929	82,929	82,929	82,929	20,392	20,392	20,392	20,392
R^2	0.083	0.013	0.093	0.094	0.218	0.013	0.223	0.223
Adj. R^2	0.083	0.013	0.093	0.093	0.217	0.012	0.221	0.222

*The magnitude of the associations in the Poisson Regressions should be calculated as the exponential of the coefficient displayed in the table. For instance, the correlation of "German connection" with "Scheduled duration" (col. 4) is −0.111 in the table, and the corresponding correlation estimated by the regression is—($e^{-0.111}$), or a 0.84 *lower* patent duration (in years)

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 5 The impact of the biography-based foreign connection on patents' duration

Poisson regression				
	Unmatched sample		Matched sample	
	Patent duration			
	Scheduled	Nominal	Scheduled	Nominal
	(1)	(2)	(3)	(4)
Foreign connection	0.244***	0.275***	0.161**	0.268***
	(0.083)	(0.097)	(0.081)	(0.096)
High-tech patent	0.240***	0.210***	0.079*	0.118***
	(0.018)	(0.016)	(0.044)	(0.042)
Residing abroad	−0.429***	−0.604***	−0.775*	−0.923**
	(0.140)	(0.110)	(0.465)	(0.412)
Municipality distance to the nearest university	0.010	0.011	0.009	0.012
	(0.010)	(0.010)	(0.011)	(0.010)
Municipality distance to the border	0.000	0.000	−0.012	−0.013
	(0.000)	(0.000)	(0.011)	(0.010)
Lifetime number of patents	0.009***	0.004***	0.005***	0.001**
	(0.001)	(0.001)	(0.001)	(0.000)
Technological class FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Num.Obs	81,677	81,677	81,677	81,677
R^2	0.095	0.092	0.413	0.518
Adj. R^2	0.094	0.092	0.413	0.518

*The nominal duration is the initial stated duration of original patents, while the scheduled duration incorporates extensions or reductions which were later incorporated on the patent

**The total number of patents with foreign connection according to this indicator is 182, corresponding to 72 inventors

*$p<0.1$; **$p<0.05$; ***$p<0.01$

sources are more reliable or indicative of eminent inventors than others. Keeping this caveat in mind, as a robustness check Table 14 in Appendix uses the quality indicators as counts. The results are unchanged according to this measure, although slightly less significant. Another concern about the measurement is that by construction, the only individuals who can have a foreign exposure must have at least two patents, because an inventor with FC must have a patent while residing in another country and patents while residing in Italy. It is not possible to know whether the 77% of inventors who filed only one patent had a FC. Although using the number of patents filed in Italy over the lifetime as control and the stock of patents filed up to a given patent was filed as a matching variable mitigates this problem, comparing the FC patentees with the entire set of patents can bias the results if their foreign connections have different effects for inventors with more than one patent than for inventors with only one patent. Appendix Table 16 shows the effects on the patent duration when the sample is restricted to inventors who file more

than one patent. The results are consistent with those in Table 4, although the positive coefficient for French connections among firms now becomes statistically significant.

Table 17 in Appendix interacts French and German connections with specific time periods. German connections were positively related to patent quality only up to 1875, while French connections are negatively related to patent quality up to 1875 and positively related to patent quality starting from 1885.[21] This provides some initial support for the intuition that Italian inventors may have benefited more from the low-tech connections than from the high-tech connections, which were predominantly French until the 1880s, and then predominantly German—a leader in the technologies associated with the second industrial revolution of the 1880s.

So far, propensity score matching and fixed effects econometric methods have been used in the paper to address major endogeneity concerns. What follows goes a step further and combines such methods with the analysis of *Treccani* biographies to focus on 'exogenous' FCs, as described in the previous Sect. 3.4.[22] Table 5 shows the effects of the foreign connection measure assessed through biographies, on the duration of patents. The effects of a foreign connection are consistently positive and statistically significant, suggesting that the effect of foreign connections was underestimated when including all foreign connections (compare Tables 4 with 5).[23] The effect size ranges from an additional duration of 1.3 years when comparing inventors with FC to the universe of patentees (columns 1–2), to an additional duration of 1.2 to 1.3 years when comparing inventors with FC to the propensity-score matched sample of patentees (columns 3–4).

5 Discussion

This section provides an in-depth interpretation of the empirical results to better understand, first, how inventors benefited from foreign technology and how this exposure influenced the quality of Italian patents, and second, why the effects differed between French, German, and British connections. To better understand the mechanisms, it may be useful to analyze a selected set of cases of inventors for whom we have more detailed documentation which I summarized from the biographies of the Treccani's Dizionario *Biografico degli Italiani.*

Quintino Sella was born in 1827 in Sella di Mosso (Piedmont). He graduated in hydraulic engineering at the age of 20. He did not fulfill his father's expectations of working in his wool spinning business, as one of his professors proposed

[21] The interactions of specific time periods with all foreign connections and British connections are not significant but are available upon request.

[22] A limitation of this approach is that only 182 patents, corresponding to 72 inventors, satisfy such criteria, making it challenging to safely disaggregate the empirical analysis by country of foreign connection.

[23] Even in an ideal natural experiment, where several inventors were forced to move abroad for political reasons, it would be difficult to generalize the results to the entire sample of inventors with foreign connections if this event isolated the inventors from their local social networks and biased the estimates of foreign exposure on the quality of the invention downwards. The evidence suggests that for independent inventors, the direction of the bias is positive in Tables 4 and 5.

to the Piedmontese government that he be sent to Paris, at state expense, to attend a three-year postgraduate course at the *École des mines*. After completing his studies in Paris in 1851, he spent two years of apprenticeship as a mining technician in the Harz region of Hannover (Germany) and then in the mines of Wales and Cornwall (Great Britain). Besides his political activity, he also worked as an inventor of various mineral processing instruments, and in 1855, he patented a system for the mechanical processing of ores with magnetite (patent no. 128).

Edwin Cerio was born on the island of Capri in 1875. He studied at the nautical high school of Naples and graduated in nautical engineering in Genoa. He then moved to Kiel (Germany) to work for Krupp in 1900. After other travels, in 1912, as soon as he returned to Italy, he patented a multiple shot swivel torpedo launcher for submarines (patent no. 388–361, 1912) and a removable armor for submarines (patent no. 398–114, 1913).

Mario Carlo Levi was born in Padua (Venetia) in 1878. He graduated in chemistry in 1900. In 1902, he won a national scholarship to study abroad and moved to the Technische Hochschule of Karlsruhe. He then filed three chemical patents which were strictly related to his academic research (patents no. 238–186 of 1906, 223–20 of 1906, 94,587 of 1910). The patents had an initial duration of three years, and two of them were renewed for additional three years.

Such case studies suggest that more than the length of time spent abroad, a decisive factor was working in fields in which the inventors had already gained some experience in Italy, especially through higher education. This basic knowledge was then refined abroad, often through visits to many countries and contact with highly specialized university laboratories and high-tech companies, enabling the inventors to register high-quality, high-tech patents soon after their return to Italy.

The observation that German connections lead to lower quality domestic patents in Italy, while French and British connections lead to higher quality patents, is intriguing given the position of Germany as a technological leader for the technologies of the second industrial revolution. In contrast, France and Britain maintained leadership in industries linked to the first industrial revolution. This difference may be due to significant differences in factor endowments between Italy and these countries, making it easier for Italian inventors to adapt older technologies from France and Britain than newer ones from Germany.

To analyze the differences in the effects between the exposure to different foreign countries, I rely on the indicator of technological distance of Bar and Leiponen (2012). The indicator measures the distance between two patent "portfolios" distributed over the 26 industries available for Italian patents. It is computed as follows:

$$TD_{ij} = 1 - \sum_{K=1}^{K} \min\left(\mathrm{p_{i,\,k}},\ \mathrm{p_{j,k}}\right)$$

where TD_{ij} denotes the technological distance between the patent portfolios i and j, while $p_{i,k}$ and $p_{j,k}$ indicate the share of patents in industry k in portfolios i and j, respectively. The indicator takes value 0 when the sectoral distribution of the patent portfolios is equal (no distance) and takes value 1 when the sectoral distribution of the two patent portfolios has a maximum distance. Table 6, panel A shows that

the technological distance between Italian and French patentees is small, suggesting lower barriers to adopting high-quality French technology, while the distance is much greater for German connection patents, and especially so for high-quality patents. This supports the idea that the German technology was too distant from the Italian technological structure. The limited diffusion of higher education in Liberal Age Italy, and the consequent limited absorptive capacity, may explain why this technological distance has not instead been used by Italian inventors as an opportunity for successful high-tech technology transfer.[24]

Despite this challenge, Italian inventors with German connections still pursued advanced technology from Germany, as shown in Table 6, panel B: French and British connections contribute a higher share of patents in first industrial revolution machinery sectors compared to domestic patents, while German connections yield a larger share in second industrial revolution sectors like chemistry and electrical engineering. This suggests that French and British patents provided an advanced version of the Italy's own technological frontier, while German connections introduced a new frontier that was more difficult to adapt to. Historical examples, such as those of Quintino Sella and Edwin Cerio, illustrate that technology transfer from Germany required years of practice and adaptation before it could lead to successful inventions.

6 Conclusion

This paper studied the association between patent quality and exposure to foreign technologies by introducing a third intermediate category between domestic and foreign patentees, looking specifically at German, French and British connections. The main finding is that Italian inventors exposed to foreign technologies were more likely to patent higher-quality inventions themselves, but only to a limited extent. They were also more likely to be eminent, i.e., to be mentioned in biographical dictionaries, but again only marginally. The relationship appears to be positive for inventors connected with Great Britain and France and negative or not significant for inventors connected with Germany.

This suggests that the institutional and human capital deficiencies of Italy at the time were too high to facilitate the improvement in the quality of inventions through direct exposure to the technological frontier of the Second Industrial Revolution, while inventors exposed to technologies related to the First Industrial Revolution were more successful in absorbing them. In addition to institutional reasons, differences in factor endowments may also have played a role: The fact that Italian inventors struggled to adopt more advanced technologies is also consistent with Allen's (2009) theory that high wages and low energy costs increased the adoption

[24] The complementary role of higher education and successful technology transfer with countries at the technological frontier supported by the high percentage of individuals with a university degree attested among the biographies of individuals with 'exogenous FCs' with Germany. In particular, inventors with exogenous FCs with Germany appear to be more likely to be university graduates than patentees with foreign connections to France (76% vs. 58%) and significantly more than for Great Britain, for which the correlation between having a British connection and being a university graduate is not significant.

Table 6 Measures of technological distance

Technology distance (26 technological classes)	Bar-Leiponen index (All patents)		
	All patents	Lower quality (Duration ≤ 10 yrs.)	Higher quality (Duration > 10 yrs.)
Panel A. Bar-Leiponen index of technological distance			
Domestic patents in Italy—foreign patentees in Italy	0.135	0.150	0.212
Domestic patents in Italy—French patentees in Italy	0.138	0.183	0.222
Domestic patents in Italy—German patentees in Italy	0.162	0.166	0.176
Domestic patents in Italy—British patentees in Italy	0.190	0.218	0.283
Domestic patents in Italy—foreign connection	0.119	0.162	0.219
Domestic patents in Italy—French connection	0.212	0.283	0.312
Domestic patents in Italy—German connection	0.254	0.495	0.717
Domestic patents in Italy—British connection	0.438	0.438	0.534
	High-tech patents (%)		
	Chemistry & electrical engineering	Machinery, steam engines and weapons	All high-tech
Panel B. share of high-tech patents			
Domestic patents	8.5	14.9	23.4
Foreign connection	9.5	18.5	28.1
French connection	5	19.6	24.7
German connection	18.6	10.8	29.3
British connection	8.1	41.5	49.6
Other connection	8.3	18	26.4

Following Nuvolari and Vasta (2015a, b), the patents belonging to the following sectors are considered as high-tech patents: chemicals; electricity; machine tools, machinery, components, and metalworking, steam engines; and weapons

of new technologies that led to the British Industrial Revolution. Coal prices in Italy were four times higher than in the United Kingdom between 1883 and 1912 (Bardini 1998, p. 52, 63; Licio 2023) and real wages were very low compared to more developed countries (Federico et al. 2019, p. 74), making it particularly challenging for Italy to adopt new frontier technologies.

This paper raises the question of whether Italian inventors were at least able to benefit from the overwhelming presence of foreign patenting in Italy, despite low institutional arrangements and comparably low levels of technical education (see Nuvolari and Vasta 2017). Italy started to industrialize during the Liberal Age, but it did

so while relying predominantly on inventions coming from abroad. This fact raises the question of the role of this exposure to foreign technologies on quality of the domestic inventions. The findings of this paper align with Vasta (1999), Nuvolari and Vasta (2015b) and Di Martino and Vasta (2017) who highlighted a lack of absorptive capacity among Italian inventors. The paper also fuels further the debate about the impact of higher education, particularly technical education, in driving the Italian innovation rate. Indeed, when interpreting the results, we should consider the fact that most French technological transfers in Italy occurred up until the 1880s, while German transfers occurred later. As more human capital accumulated in Italy, inventors should have been more receptive to the inventive activities of Germans. The preliminary evidence in this paper suggests that this is not the case. The evidence provided in this paper suggests that the large technological distance between Italian and German patents could have hindered the ability of Italian inventors to absorb and apply such frontier technologies. This difficulty in absorbing high-tech innovations was arguably compounded by the fact that, despite the general diffusion of education in late nineteenth-century Italy, it did not lead to a notable increase in the number of educated Italian inventors which could successfully bridge the technological gap. Although this hypothesis is supported by the analysis of this paper, future research is needed to further disentangle the role of the distance from the technological endowment of Germany from the role of the development of technical human capital in the transition of Italy from relying on French to relying on German technologies.

Appendices

Appendix 1: The construction of the database

Patent database

To disambiguate inventors across the patent database, inventors were linked by name and manually verified the disambiguation across the 64,440 uniquely identifiable inventors. The procedure followed to maximize the quality and scope of the linking process included several steps and methods, which are outlined here. For further details on the procedure, see Martinez et al. (2025)

1. *Patentee name cleaning*: Excess whitespace was removed, the patentee information that was entered in the wrong cells was added into the correct ones, and similar tasks were performed. Next, we developed an online platform with the help of software engineers to display all the different words of patentee names separately, then sorted alphabetically and by frequency (for example, Bayer AG with frequency 52, Bayern Aktiengesellschaft with frequency 2). We then merged names referring to the same patentee based on the most commonly used dictionary. This platform allowed us to manually check and correct each word or series of words, either individually or by matching them to the most phonetically and string-similar words in the dataset.

2. *Uniforming patent names*: Inventors always included the full name (first name and second name). However, many inventors included not just their family name, but also their second names and the patronymic (e.g., Giovanni 'fu Vittorio'). Others included titles such as 'ing.' for engineer or 'vedova' for a widow. We first double-checked to see if the identified cases were for the same person by looking at the place of residence and, if different, in the patent industry. We then removed the additional information and just retained the name values. For instance, 'Ing. Giovanni fu Vittorio Rossi' becomes Giovanni Rossi.
3. *Linking patentee names*: Disambiguating means to identify unique inventors among patents. For instance, a patent of F.I.A.T. in 1896 is associated with another patent of F.I.A.T. in 1906. To link patentee names, we employ a strict criterion requiring exact name matches, while allowing variation in residence and patent type over time. While this approach may miss some linkages, it eliminates the risk of falsely linking two distinct individuals, which could distort an inventor's career by incorrectly attributing inventions across different industries. Although more advanced methods, such as considering the places of residence or hierarchical tree structures, were explored, name-based linkage is preferred due to its conservative nature. The potential cost of missing some linkages is considered less problematic than the risk of incorrect linkages. The disadvantage of this approach is that, especially for Italian independent inventors, common names may relate to multiple inventors (e.g., "Mario Rossi"). This risk has been mitigated by manually checking all the matches, but it was not a major issue before because most of the inventors' surnames were rare.

Some examples may better illustrate how the disambiguation was performed. The patentee "Abate Epaminonda" filed a patent 1874 and a patent in 1886. As a result, both patents were assigned to the inventor ID of Abate Epaminonda (number 4313). "Appiani Graziano" filed 10 patents, and the patents were assigned to the inventor ID of Appiani Graziano (number 3744). The firm named "Boltri Lodovico Ditta" filed 20 patents, so they were all assigned to the inventor ID number 162.

To compute the "scheduled" duration indicator, i.e., patent durations that take into account the fact that a patent's duration was later extended or reduced, the *completivi* patents were first removed from the sample, leaving only patents with a duration (see the sources section). The ordinary patents were then linked to their corresponding *prolungamento* or *riduzione* patent. To link the patents, the duration of an ordinary patent was summed to the duration of the next prolungamento or riduzione patent filed by the same inventor.

For example, the firm Krupp Fried. Aktiengesellschaft filed an ordinary patent entitled "*Une cartouche destinée à enflammer la charge des bouches à feu*" in 1880 (no. 23/285) with nominal duration of 3 years. The next patent of the same firm had the same title, but was of *prolungamento* type, and had a duration of 3 years. The scheduled duration of the patent no. 23/285 is therefore six years. In 1878, the independent inventor Siddley John filed an ordinary patent entitled "*Perfezionamenti nella fabbricazione del ghiaccio negli apparecchi o mezzi impiegati nella medesima*" (no. 33–349) with nominal duration of 8 years and another patent with the

Table 7 Quality indicators for an extract of inventors

Year	Patent ID	Description of the invention	Inventor name	Patent eminence	Sched. duration
1885	15,962	Gas and fuel engine	Daimler Gottlieb	5	6 + 5 extension
1867	2,693	New method to produce inox	Hargreaves James	4	3 + 3 extension
1887	18,756	New food for animals based on blood	Forlanini Carlo	3	3 + 3 extension
1896	36,063	System of electric traction with monophase alternate current	Ferraris Galileo	2	2
1912	111,060	Parachute with rigid system	Valle Giuseppe	1	1
1890	24,752	Metallurgic concrete	Giorelli Maggiorino	0	8

Table 8 Number of patent-eminent inventor linkages by biographical source

Source	N in source	With homonymies		Correcting homonymies	
		Patents	Inventors	Patents	Inventors
Dizionario Biografico Treccani	29,551	1599	556	718	209
Yu et al. (2016)	11,044	892	132	704	130
Gergaud, Laouenan and Wasmer (2017)	110,316	40	17	26	10
Day and McNeil (1996)	1896	1064	122	1064	122
Murray (2006)	3840	410	86	299	61
Benson (2009)	654	448	41	440	39
De Galiana and Rival (1996)	2380	1237	144	1714	144
1 + sources matched (excluding overlaps)		4941	1720	1714	353
Observations		131,447	68,257	131,447	68,257

*The numbers are based on the full count of patents, including the extensions of previously registered patents ('*prolungamenti*')

**Gergaud, Laouenan and Wasmer contain only 3,006 individuals in the class of "Explorer/Inventor/Developer" born between 1800 and 1900, and most of them originate from the United States of America

same title and duration but of *prolungamento* type. The scheduled duration of patent no. 33–349 is therefore of 16 years. Table 7 shows other examples of nominal and scheduled duration for a set of inventions. For further details on the construction of the patent dataset, I refer to the detailed data construction appendix of Martinez et al. (2025).

Biographical databases and their linkage with patent data

Regarding the data collection from databases of notable people, the *Treccani* biographical database is a completely novel dataset created for this paper in order to better represent the population of eminent Italian individuals than international compilations available in the literature. The database is available both in printed volumes and online. The online format contains an index of the names of eminent

Table 9 Further descriptive statistics of the key variables used in this study

Variable	Obs	Mean	Std. dev	Min	25% pc	75% pc	Max
Nominal duration	104,453	5.205	4.215	1	2	6	15
Scheduled duration	104,453	6.627	5.739	1	3	7	30
Foreign connection	1158 (=1)	0.011	0.104	0	0	0	5
German connection	168 (=1)	0.001	0.040	0	0	0	1
French connection	104,453	0.003	0.060	0	0	0	1
British connection	124 (=1)	0.001	0.034	0	0	0	1
Patent eminence	1734 (>0)	0.029	0.277	0	0	0	5

Independent or company		
Company	20,589	19.7%
Independent	83,864	80.3%
Domestic Foreign		
Domestic	35,764	34.2%
Foreign	68,708	65.8%
Technological level		
High-tech	29,352	28.1%
Low-tech	73,994	70.8%
Country of Residence		
Italy	35,860	34.3%
France	14,333	13.7%
Germany	21,458	20.5%
Great Britain	9633	9.2%
U.S.A	8334	8.0%
Other	14,702	14.1%

Italians displayed on 603 web pages. I use web scraping to extract each individual name from the index of names on the website, taking care to exclude the irrelevant information, such as the initial of each new letter in the index and the date on which a new biography was entered into the system. The names that could refer to different individuals were also excluded. This procedure was repeated for the entire set of 603 web pages. The remaining datasets were either manually transcribed for Galiana and Rival (1996), scanned with OCR for Day and McNeil (1996), Benson (2009), and Murray (2003), or collected from the publisher's pages for Yu et al. (2016) and for Gergaud, Laouenan, and Wasmer (2016).

To correct for homonyms when linking the biographies to the patent database, I examined the consistency of the invention's data with the biographical history of the inventor using the following criteria. First, the inventor had to be active before the death of the linked individual. Second, the individual in the biography must have been living during his or her lifetime. Third, the field of activity of the invention, as derived from the industrial category of the invention, should be coherent with the activity described in the biography. Fourth, special care was paid with linked common names (e.g., "Rossi Carlo," "Ferrari Giuseppe" or "Joseph Smith") and

with names of renewed people or noblemen (e.g., "Grimaldi Carlo," "Caracciolo Giuseppe," or "John Keats").

For an overview of the number of successful linkages derived from each database before and after correcting for homonyms, see Table 8. For example, out of 1,599 linkages of inventions with *Treccani* biographies, corresponding to 556 inventors, only 718 were not driven by homonyms, corresponding to 209 uniquely linked inventors out of the 22,429 Italian residents who patented a total of 45,768 inventions (Table 9).

Appendix 2: Additional results and robustness checks

See Fig. 6, Tables 10, 11, 12, 13, 14, 15, 16, 17.

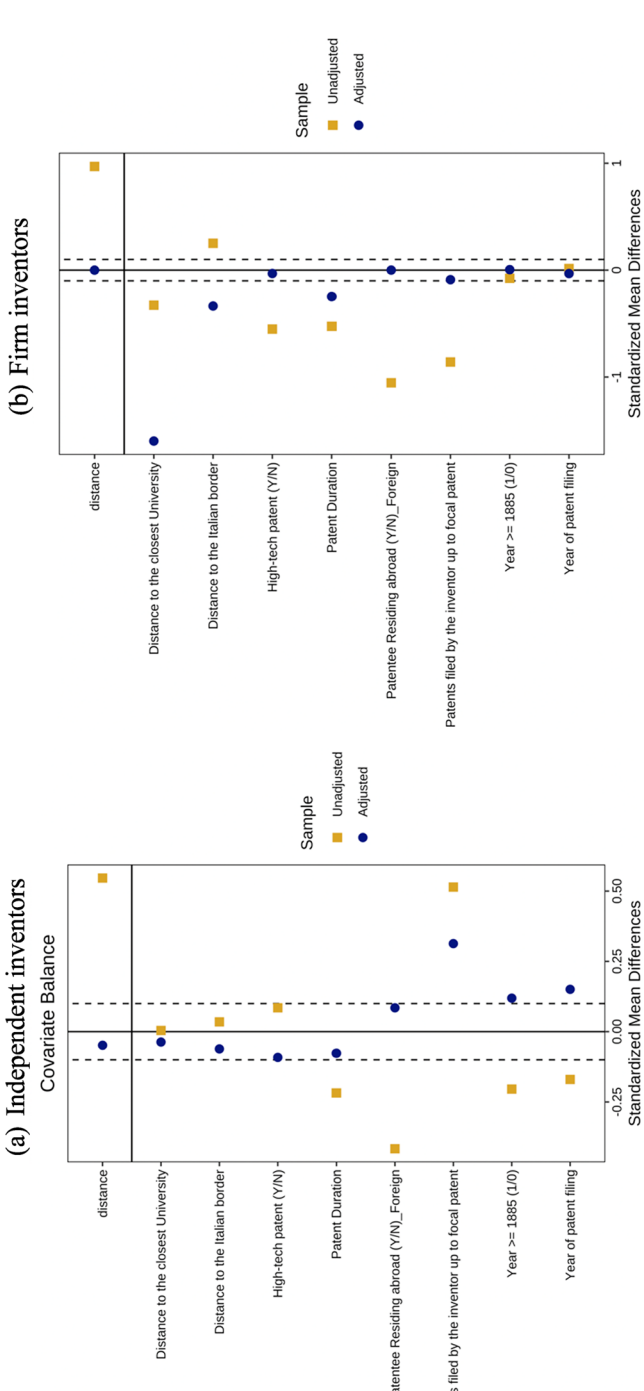

Fig. 6 Difference in means in the characteristics of patentees belonging to the foreign connection (FC) group and remaining firms/independent inventors. *Note*: The matching is conducted using the generalized full matching algorithm

Table 10 Number of patents registered in Italy by Italian and foreign residents

Period	Italy	France	Germany	Great Britain	U.S.A	Other
1861–1879	4,132	2,310	501	820	283	580
Panel A: patent counts						
1880–1896	7,609	3,749	4,898	2,858	2,052	3,179
1897–1914	24,101	8,273	16,059	5,951	5,998	10,939
Tech class	Italy	France	Germany	Great Britain	U.S.A	Other
High-tech	8,299	4,228	6,929	3,160	2,573	4,133
Low-tech	27,142	9,960	14,287	6,369	5,697	10,436
Panel B: % over total by country						
1861–1879	11.5	16.1	2.3	8.5	3.4	3.9
1880–1896	21.2	26.1	22.8	29.7	24.6	21.6
1897–1914	67.2	57.7	74.8	61.8	72.0	74.4
Observations	35,860	14,333	21,458	9,633	8,334	14,702
Tech class	Italy	France	Germany	Great Britain	U.S.A	Other
High-tech	23.4	29.8	32.7	33.2	31.1	28.4
Low-tech	76.6	70.2	66.7	66.8	68.9	71.6
Observations	35,441	14,188	21,216	9,529	8,270	14,529

*High-tech patents include patents in the sector of chemicals, electricity, machineries and weapons

**Extension (*prolungamento*) patents are excluded because their duration is added to the duration of the prolonged patent

***The data for Germany include all predecessor states (e.g., Prussia and Bavaria) prior to the foundation of the German Empire of 1877

Table 11 Relationship between foreign connections and patent's scheduled duration, unmatched sample (see also Table 4)

Dependent variable								
Scheduled duration (years)								
Poisson regression								
	Independent inventors				Firm inventors			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Foreign connection	−0.030**	0.007	−0.019		0.002	−0.032	0.028	
	(0.014)	(0.030)	(0.036)		(0.028)	(0.104)	(0.120)	
German connection				−0.188***				−0.446***
				(0.070)				(0.150)
French connection				0.040				0.183
				(0.064)				(0.178)
British connection				0.323***				0.223
				(0.064)				(0.280)
High-tech patent	1.532***		0.161***	0.160***	2.854***		0.434***	0.433***
	(0.043)		(0.036)	(0.036)	(0.023)		(0.094)	(0.094)
Residing abroad	0.364***		0.380*	0.389*	−0.059		0.025	−0.078
	(0.047)		(0.212)	(0.211)	(0.176)		(0.311)	(0.217)
Municipality distance to the nearest university	0.000		−0.001	−0.001	−0.275***		−0.256**	−0.258**
	(0.003)		(0.009)	(0.009)	(0.016)		(0.102)	(0.103)
Municipality distance to the border	−0.002		0.000	0.000	0.264***		0.245**	0.247**
	(0.003)		(0.009)	(0.009)	(0.016)		(0.099)	(0.100)
Lifetime number of patents	0.008***		0.009***	0.009***	0.002***		0.002***	0.002***
	(0.000)		(0.001)	(0.001)	(0.000)		(0.000)	(0.000)
Technological Class FE	No	No	Yes	Yes	No	No	Yes	Yes

Table 11 (continued)

Dependent variable								
Scheduled duration (years)								
Poisson regression								
	Independent inventors				Firm inventors			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Province FE	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Num.Obs	82,929	82,929	82,929	82,929	20,392	20,392	20,392	20,392
R^2	0.192	0.101	0.200	0.200	0.641	0.603	0.655	0.655
Adj. R^2	0.191	0.101	0.199	0.200	0.640	0.602	0.654	0.654

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 12 Relationship between foreign connections and patent's scheduled duration by Italian macro-area

Scheduled duration (days)						
Poisson regression						
	North		Centre		South	
	(1)	(2)	(3)	(4)	(5)	(6)
Foreign connection	0.051		−0.097**		−0.114***	
	(0.035)		(0.038)		(0.038)	
German connection		−0.136**		−0.223***		−0.220***
		(0.061)		(0.068)		(0.063)
French connection		0.181**		0.004		−0.013
		(0.076)		(0.069)		(0.066)
British connection		0.260***		0.235**		0.171**
		(0.060)		(0.100)		(0.075)
High-tech patent	0.282***	0.281***	0.299***	0.299***	0.320***	0.320***
	(0.050)	(0.050)	(0.059)	(0.059)	(0.057)	(0.057)
Residing abroad	0.091***	0.091***	0.034	0.033	0.019***	0.019***
	(0.031)	(0.031)	(0.044)	(0.045)	(0.007)	(0.007)
Municipality distance to the nearest university	−0.090***	−0.090***	−0.032	−0.031	−0.018***	−0.018***
	(0.030)	(0.030)	(0.043)	(0.043)	(0.007)	(0.007)
Municipality distance to the border	0.411***	0.425***	0.291**	0.322**	0.288**	0.322**
	(0.135)	(0.133)	(0.143)	(0.143)	(0.135)	(0.134)
Lifetime number of patents	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Technological class FE	No	No	Yes	Yes	No	No
Province FE	No	No	Yes	Yes	No	No
Year FE	No	YES	Yes	Yes	No	Yes

Table 12 (continued)

Scheduled duration (days)						
Poisson regression						
	North		Centre		South	
	(1)	(2)	(3)	(4)	(5)	(6)
Num.Obs	92,604	92,604	75,011	75,011	71,790	71,790
R^2	0.487	0.488	0.632	0.632	0.656	0.656
Adj. R^2	0.487	0.487	0.632	0.632	0.656	0.656

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 13 Extensive margin of the association between foreign connections and patent's quality

Dependent variable						
	Duration dummy (1–2)		Patent eminence dummy (3–4)		Inventor eminence dummy (5–6)	
	Poisson regression					
	(1)	(2)	(3)	(4)	(5)	(6)
Foreign connection	−0.199		0.053		−0.819	
	(0.123)		(0.259)		(0.758)	
French connection		0.081		0.725***		−0.087
		(0.173)		(0.254)		(0.997)
German connection		−0.288		−15.731***		−15.883***
		(0.298)		(0.078)		(0.156)
British connection		0.544*		1.103***		-16.860***
		(0.280)		(0.299)		(0.415)
High-tech patent	0.735***	0.736***	0.643**	0.646**	1.408***	1.418***
	(0.132)	(0.132)	(0.252)	(0.253)	(0.512)	(0.511)
Residing abroad	−0.479	−0.537	−3.045***	−3.046***	−2.310***	−2.325***
	(0.544)	(0.542)	(0.223)	(0.222)	(0.229)	(0.229)
Municipality distance to nearest university	−0.018	−0.019	0.030**	0.030**	−0.384***	−0.387***
	(0.061)	(0.062)	(0.013)	(0.013)	(0.114)	(0.114)
Municipality distance to the border	0.007	0.008	−0.024	−0.025	0.397***	0.400***
	(0.065)	(0.065)	(0.015)	(0.015)	(0.116)	(0.116)
Lifetime number of patents	0.008***	0.008***	0.018***	0.018***	0.059*	0.059*
	(0.001)	(0.001)	(0.003)	(0.003)	(0.033)	(0.033)
Technological class FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs	82,905	82,905	82,654	82,654	51,238	51,238
R^2	0.130	0.130	0.115	0.116	0.327	0.327
Adj. R^2	0.124	0.124	0.101	0.102	0.263	0.263

The duration dummy takes value 1 if the nominal duration is above 10 years and 0 otherwise. The eminence dummies take value 1 if the eminence score has a value of at least one and 0 otherwise

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 14 Relationship between foreign connections and biographical-based quality indicators, matched sample

Dependent variable						
	Patent eminence (1–3)			Inventor eminence (4–6)		
	Poisson regression					
	(1)	(2)	(3)	(4)	(5)	(6)
Foreign connection	−0.566***	−0.485*		−0.562	−0.860	
	(0.190)	(0.248)		(0.501)	(0.738)	
German connection			0.240			−0.217
			(0.293)			(1.021)
French connection			−15.108***			−16.019***
			(0.080)			(0.163)
British connection			0.802**			−16.597***
			(0.333)			(0.457)
High-tech patent	−18.082	0.017	0.014	−21.377	1.307*	1.318*
	(458.138)	(0.518)	(0.518)	(1151.257)	(0.774)	(0.774)
Residing abroad	0.031	0.018	0.018	−0.349***	−0.438***	−0.440***
	(0.091)	(0.139)	(0.138)	(0.094)	(0.109)	(0.108)
Municipality distance to the border	−0.035	−0.022	−0.022	0.358***	0.453***	0.454***
	(0.094)	(0.143)	(0.143)	(0.096)	(0.110)	(0.110)
Municipality distance to nearest university	4.512***	4.082***	4.084***	5.073***	3.561***	3.566***
	(0.317)	(0.358)	(0.357)	(0.314)	(0.217)	(0.216)
Lifetime number of patents	0.020***	0.022***	0.022***	0.048***	0.086**	0.086**
	(0.000)	(0.002)	(0.002)	(0.001)	(0.040)	(0.040)
Technological class FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	No	Yes	No

Table 14 (continued)

Dependent variable						
	Patent eminence (1–3)			Inventor eminence (4–6)		
	Poisson regression					
	(1)	(2)	(3)	(4)	(5)	(6)
Num.Obs	82,923	82,648	82,648	55,009	51,235	51,235
R^2	0.157	0.184	0.184	0.176	0.442	0.442
Adj. R^2	0.152	0.176	0.176	0.161	0.398	0.398

*Patents are aggregated at the inventor level using the uniquely identifiers of inventors. In doing so, the years of patents are averaged over the years when each inventor registers a patent over time. Categorical variables such as the technological class of the inventions are instead selected to be the first of the categories that appears as a patent registered by that inventor. This is preferred to using intermediate or last values because it underestimates the coefficients

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 15 Relationship between patents issued by Italian residents with foreign connections and nominal duration, matched sample

Dependent variable						
	Independent inventors			Firm inventors		
	Poisson regression					
	(1)	(2)	(3)	(4)	(5)	(6)
Foreign connection	−0.047	−0.080**		−0.139*	−0.073	
	(0.033)	(0.037)		(0.081)	(0.081)	
German connection			−0.138			−0.311*
			(0.086)			(0.172)
French connection			0.010			−0.041
			(0.062)			(0.118)
British connection			0.280***			0.103
			(0.096)			(0.410)
High-tech patent		0.151***	0.150***		0.387***	0.386***
		(0.033)	(0.033)		(0.118)	(0.118)
Residing abroad		−0.001	−0.001		0.346***	0.347***
		(0.007)	(0.007)		(0.103)	(0.103)
Municipality distance to the nearest university		−0.001	−0.001		−0.361***	−0.362***
		(0.008)	(0.008)		(0.106)	(0.106)
Municipality distance to the border		0.410**	0.434**		0.303*	0.262
		(0.181)	(0.179)		(0.157)	(0.173)
Lifetime number of patents		0.005***	0.005***		0.001***	0.001***
		(0.001)	(0.001)		(0.000)	(0.000)
Technological class FE	No	Yes	Yes	No	Yes	Yes
Province FE	No	Yes	Yes	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	No
Num.Obs	82,929	82,929	82,929	20,392	20,392	20,392
R^2	0.250	0.317	0.317	0.419	0.471	0.471
Adj. R^2	0.250	0.316	0.316	0.419	0.470	0.470

*The magnitude of the associations in the Poisson regressions should be calculated as the exponential of the coefficient displayed in the table

**The nominal duration is the initial stated duration of original patents

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table 16 Association between foreign connections and patent's quality, restricting the sample to inventors with at least two patents

Dependent variable								
Scheduled duration (years)								
Poisson regression								
	Independent inventors				Firm inventors			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Foreign connection	−0.040***	−0.059*	−0.034		0.070**	0.054	0.048	
	(0.014)	(0.034)	(0.038)		(0.028)	(0.130)	(0.137)	
German connection				−0.222***				−0.410***
				(0.076)				(0.158)
French connection				0.055				0.158
				(0.072)				(0.213)
British connection				0.304***				0.198
				(0.060)				(0.297)
High-tech patent	1.619***		0.206**	0.204**	2.175***		0.464***	0.464***
	(0.077)		(0.091)	(0.091)	(0.048)		(0.097)	(0.097)
Residing abroad	0.761***		0.756*	0.777**	0.011		0.032	-0.083
	(0.093)		(0.397)	(0.383)	(0.174)		(0.301)	(0.192)
Municipality distance to the nearest university	−0.016***		−0.016***	−0.016***	0.240***		0.248**	0.250**
	(0.004)		(0.005)	(0.005)	(0.015)		(0.118)	(0.118)
Municipality distance to the border	0.012***		0.012**	0.012**	−0.250***		−0.259**	−0.261**
	(0.004)		(0.006)	(0.006)	(0.016)		(0.121)	(0.122)
Lifetime number of patents	0.008***		0.008***	0.008***	0.002***		0.002***	0.002***
	(0.000)		(0.000)	(0.000)	(0.000)		(0.000)	(0.000)
Technological Class FE	No	No	Yes	Yes	No	No	Yes	Yes

Table 16 (continued)

Dependent variable								
Scheduled duration (years)								
Poisson regression								
	Independent inventors				Firm inventors			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Province FE	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Num.Obs	40,245	40,245	40,245	40,245	40,245	40,245	40,245	40,245
R^2	0.375	0.309	0.379	0.379	0.709	0.666	0.721	0.721
Adj. R^2	0.374	0.309	0.378	0.379	0.709	0.666	0.720	0.720

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 17 Interaction of French and German connection with dummies for specific periods

Panel A: French connections						
Dependent variable						
Scheduled duration (years)						
Poisson regression						
	(1)	(2)	(3)	(4)	(5)	(6)
French connection	0.136*	−0.064	−0.074	−0.098	−0.109*	−0.109*
	(0.076)	(0.082)	(0.070)	(0.067)	(0.065)	(0.062)
High-tech patent	0.161***	0.161***	0.161***	0.161***	0.161***	0.161***
	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)
Municipality distance to nearest university	0.000	0.000	0.000	0.000	0.000	0.000
	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.009)
Municipality distance to the border	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Resident abroad	0.392*	0.391*	0.391*	0.385*	0.385*	0.383*
	(0.212)	(0.212)	(0.212)	(0.212)	(0.211)	(0.212)
Lifetime number of patents	0.009***	0.009***	0.009***	0.009***	0.009***	0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
French connection * Year ≤ 1875	−0.281**					
	(0.120)					
French connection * Year ≥ 1880		0.188				
		(0.116)				
French connection * Year ≥ 1885			0.239**			
			(0.112)			
French connection * Year ≥ 1890				0.309***		
				(0.109)		
French connection * Year ≥ 1895					0.361***	
					(0.104)	
French connection* Year ≥ 1900						0.405***
						(0.102)
Technological class FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs	82,929	82,929	82,929	82,929	82,929	82,929
R^2	0.200	0.200	0.200	0.200	0.200	0.200
Adj. R^2	0.199	0.199	0.199	0.199	0.199	0.200

Panel B: German connections						
	(1)	(2)	(3)	(4)	(5)	(6)
German connection	−0.220***	0.117	−0.055	−0.182	−0.125	−0.124
	(0.062)	(0.327)	(0.275)	(0.231)	(0.195)	(0.132)
High-tech patent	0.161***	0.161***	0.161***	0.161***	0.161***	0.161***
	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)

Table 17 (continued)

Panel B: German connections

	(1)	(2)	(3)	(4)	(5)	(6)
Municipality distance to nearest university	0.000	0.000	0.000	0.000	0.000	0.000
	(0.009)	(0.009)	(0.009)	(0.008)	(0.009)	(0.009)
Municipality distance to the border	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Resident abroad	0.371*	0.379*	0.377*	0.374*	0.375*	0.374*
	(0.209)	(0.212)	(0.211)	(0.210)	(0.210)	(0.209)
Lifetime number of patents	0.009***	0.009***	0.009***	0.009***	0.009***	0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
German connection * Year ≤ 1875	0.541					
	(0.387)					
German connection * Year ≥ 1880		−0.332				
		(0.331)				
German connection * Year ≥ 1885			−0.148			
			(0.280)			
German connection * Year ≥ 1890				0.003		
				(0.238)		
German connection * Year ≥ 1895					−0.072	
					(0.203)	
German connection* Year ≥ 1900						−0.088
						(0.149)
Technological class FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs	82,929	82,929	82,929	82,929	82,929	82,929
Adj. R^2	0.200	0.200	0.200	0.200	0.200	0.200
Adj. R^2	0.199	0.199	0.199	0.199	0.199	0.199

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

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