UNCERTAINTY AND INNOVATION: NEW PERSPECTIVES FROM THE VALUE OF PATENTS IN ITALY, 1861-1913

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ABSTRACT: This paper uses renewal data to estimate the value of Italian patents during the so-called Liberal Age (1861-1913) controlling for inventor and patent characteristics. We make use of a new dataset comprising all patents granted in Italy in five benchmark years. Using renewal data, we estimate both the value of patents "ex-ante" (that is in the moment in which the patent was granted) and "ex-post" (that is in the moment in which the patent expires). We use the differences between "ex-ante" and "ex-post" values of patents to study the attitudes of different type of inventors concerning the uncertainty surrounding the innovation process. Furthermore, we find that patents issued to firms and to foreign inventors and patents covering high-tech inventions are more "valuable" than those issued to independent inventors and domestic inventors or in low-tech sectors.

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1. Introduction

The search for innovations is an economic activity characterized by a strong degree of uncertainty. This uncertainty is the outcome of a complex interaction between technical and market forces. Successful innovations should represent both a feasible solution to technical problems and be able to cater the needs of users and consumers in a cost effective way. Freeman and Soete (1997) have argued that the degree of uncertainty which characterizes innovation activities is such that they do not lend themselves even to sophisticated methods of risk assessment. Accordingly, Freeman and Soete (1997) suggest that the Keynesian notion of “animal spirits” is relevant not only for financial and speculative investment, but also for innovative activities. Freeman and Soete also notice that the different type of innovators (small firms, large firms, government sponsored firms, independent inventors) will be characterized by different expectations concerning the economic prospect of an innovation.

So far, most of the research on the role of animal spirits and expectations in the innovation project has been focusing on case studies or on small sample of innovations. This is due to the fact that expectations and animal spirits are inherently elusive concepts and difficult to assess using large scale samples.

In this paper we take advantage of a peculiar characteristic of the Italian patent system between the end of the XIX century and the beginning of the XX century which allows us to carry out a systematic assessment of the profits expectations of innovators at different moment in time.

Since the seminal contribution of Schmookler (1966), patents have become one of the favorite “laboratory mice” of innovation scholars. They have allowed to gather important insights on patterns of innovation at multiple levels of analysis ranging from individual inventors to firms, all the way to industries and countries. This research tradition has gained further momentum since the early 2000s with the availability of large and easily accessible datasets such as the NBER-USPTO (Jaffe and Trajtenberg 2002) or the PATSTAT dataset issued by the European Patent Office (https://data.epo.org/expert-services/index-2-3-6.html).

Following the pioneering contributions of Dutton (1984) and Macleod (1988) for England and Sokoloff (1988) and Sokoloff and Khan (1990) for the United States, the use of patents as innovation indicators has developed into a consolidated tradition also in economic history. Since then, historical patent data have been insightfully employed to reconstruct profiles of inventive activities for other countries such as Germany (Streb, Baten and Yin 2006), Italy (Vasta 1999, Nuvolari and Vasta 2015, 2017), Japan (Nicholas 2011a), Spain (Saiz 1999 and Saiz 2012), Norway (Basberg 2006), Sweden (Andersson and Tell 2016), and also in international comparative perspective (Nicholas 2011b).

Notwithstanding this success, it has been also frequently acknowledged that the use of patent data as innovation indicators suffers from some significant limitations. In the words of Griliches (1990: 1669): "….not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in "quality," in the magnitude of inventive output associated with them". Concerning the first two issues raised by Griliches, some recent contributions have resorted to the use of historical sources such as exhibition catalogues or engineering reports that can capture the dynamics of inventive activities not covered by patents (Nuvolari 2004, Moser 2005). The main lesson from these latter studies is that, whenever possible, one should try to integrate patent data with other indicators that may provide some outlook on inventive activities taking place outside the coverage of the patent system.

In the modern innovation studies literature, the issue of the differential quality of patents inventions ranging from minor improvements to genuine technical breakthroughs has been addressed, by exploiting patent information such as citations, renewals, claims or family size (van Zeebroeck 2011).[1] By contrast, in economic history, the construction of patent quality indicators is still in a somewhat infant phase. So far, it is possible to distinguish three main research strategies (also constrained by the very nature of the sources).

The first approach is the use of patent citations. The intuition underlying this approach, as already mentioned, is that patents that received more citations have exerted a major

[1] In modern innovation studies, patent citations are probably the most popular indicator of patent quality. The intuition is analogous to the use of citations to assess the relative impact of scientific papers. The use of patent citations has been corroborated by a number of studies which have shown the existence of a correlation between the number of citations and the independent measures of patent quality in various technical fields (Carpenter, Narin and Woolf 1981, Trajtenberg 1990, Moser, Ohmstedt and Rhode 2017). Renewal indicators, as we explain later, are based on the amount of fees that an inventor is willing to pay to keep his patent in force. Claims is the number of original features for which the patent provides protection, hence patents with more claims ought to be intuitively more valuable. Finally, family size is the number of countries in which the patent has been granted. The intuition is that inventors will patent their more valuable inventions in more countries. There are also "composite" patent value indicators constructed by aggregating multiple indicators (Lanjouw and Schankerman 2004).

impact on subsequent technological developments. Nicholas (2010, 2011b) has exploited the systematic availability of citations in US patents since 1947 to construct suitable indicators of patent quality both for US and British patents. A similar approach has been adopted by Nuvolari and Tartari (2011) to estimate the quality of English patents in the period 1617-1841. They have considered as quality indicator the number of times each patent is referenced in the coeval engineering and legal literature. Again, the intuition is that patents covering major inventions or more contested because of their ultimate economic significance will attract more mentions. However, even if it has provided insightful results, this first approach has resulted of limited applicability in economic history, since patent citations or literature references are not systematically available or, in some cases, are not even required by the prevailing patent laws.

The second approach considers the duration or lifetime of the patent as a possible measure of its underlying quality. In this case, the intuition is that inventors will prolong a patent by paying the required legal fees, only for patents that are capable of generating profitable revenue streams (ie, only for those of relatively highest quality). On the other hand, patents covering minor or unprofitable inventions will be discontinued. This approach has been employed by Streb, Baten and Yin (2006) who have considered German patents renewed for 10 years or more as covering the most significant innovations. Saiz (2012) has looked at the duration of Spanish patents in the period 1820-1939. Finally Nuvolari and Vasta (2015) have also constructed quality indicators for Italian patents using duration data. Interestingly enough, in the case of Italian patents it was possible to exploit a peculiar feature of the Italian patent law, which allowed to distinguish between an "ex-ante" and "ex-post" assessment of the value of the patent by the inventors.[2] As noted by MacLeod et al (2003), information on patent duration is noisy and should be handled with care: inventors suffering from credit constraints may have been prevented from extending the lifetime of valuable patents up to their optimal duration. On the other hand, it is also possible that overoptimistic inventors will be inclined to prolong the duration of patents well beyond the duration required by their sensible economic exploitation. Notwithstanding

[2] The Italian patent law prescribed the initial payment of an increasing fee for establishing the duration of the patent from 1 to 15 years. This information is used for assessing the "ex-ante" value of the patent. Subsequently, patentees were required to pay an increasing renewal fee to maintain the patent in force. This information on the actual payment of these yearly fees can be retrieved, by painstaking archival work, on the regular instalments of the *Gazzetta Ufficiale del Regno d'Italia* and it can be used as indicator of the "ex-post" value of the patent. See Nuvolari and Vasta (2015) for more details.

these limitations, patent duration, when carefully used seems to provide a suitable measure of patent quality.[3]

The third approach to assess the quality of patents is the use of renewal data (Shankerman and Pakes 1986). To the best of our knowledge, so far, the only implementation of the renewal approach in economic history is offered by Sullivan (1994). He has used the method to estimate the value of British patents in the period 1852-1876. This approach is closely linked to the duration method described above, but it takes explicit consideration of the structure of the renewal fees. In particular, the approach assumes: *i*) a rational behavior of the patentee who will keep on paying the patent renewals only as long as this is economically justified by the revenue streams generated by the patent; *ii*) a log normal distribution of the revenues streams generated by the patent. Thus, the main limitation of the approach is that it requires to accept a strict set of assumptions concerning both the behavior of the patentees and the distribution of innovation returns. On the other hand, the main advantage of the method is that it provides an assessment of the value of patents in straightforward monetary terms. This is a significant advantage, since there is ample evidence that the size distribution of inventions is characterized by a "fat-tailed" behavior (Silverberg and Verspagen 2007). Indeed, the renewal approach has the merit of offering a more precise description of the value distribution than the duration approach, being the latter characterized by a more crude scale of values corresponding to the specific time structure of patent fees.

In order to assess the changing expectations of innovators about the economic prospects of their inventions, this paper expands on this line of research by providing new estimates of the value of Italian patents in the Liberal age using the renewal method. In particular, we will follow the approach by Bessen (2008). We find that introducing a characterization in terms of patent values provides a significant qualification to patterns of innovation reconstructed using simple patent counts, assigning a larger role in the overall dynamics of technical change to patents granted to firms, to foreign inventors and in high-tech sectors. Overall, we find that the profile of technical change reconstructed using the patent value approach provides a more historically plausible narrative of Italian innovation in

[3] For example, the use of duration as indicator of patent quality was corroborated by Nuvolari and Vasta (2015) by showing that Italian patents granted also in the United States (hence patents whose inventors considered them as to be suitable of exploitation in a foreign and fiercely competitive market) were characterized by longer durations.

that period. This indeed suggests that the renewal method is an insightful tool that can complement patent counts in quantitative studies of technical change. Finally by looking at the expectations on innovation returns at different point in time, we also explore the different attitudes of innovators concerning the radical uncertainty surrounding the innovation process.

The paper is structured as follows. In Section 2 we introduce the salient institutional features of the Italian patent system in this period. Section 3 discusses the sources and outlines the main patterns of innovation as captured by patent data. In Section 4 we present the patent renewal model that we adopt to describe the distribution of patent values and we carry out its econometric estimation. In section 5 we use ex-ante and ex-post patent value to study innovators' attitudes towards uncertainty. In Section 6 we present our appraisal of the distribution values and we study the differences in the characterization of inventive activities carried out using patent counts vis-a-vis to that using patent values. Section 7 draws conclusions.

2. Italy and its patent system in the Liberal Age

The Italian patent law was enacted in 1864 (Law n. 1657, 31st January 1864), three years after the political unification of the country. The original version of this law (inspired by the French and Belgian examples of 1844 and 1854) had been introduced in Piedmont in 1855. In a nutshell, the main features of the Italian patent system were the following. It was a registration system and, accordingly, there was no examination of the actual novelty of the invention patented. This meant that controversies on the novelty of patents were to be settled by means of court cases. In the Italian system, in contrast with the practice prevailing in other countries, such as the US, where patents could be registered only in the name of inventors, could also be registered in the name of firms.[4] This peculiarity of the Italian patent Law allows us to have an immediate direct assessment of whether a patent is to be ascribed to an independent inventor or to a firm.

For our aims, the crucial feature of the patent system that we have to consider are the rules determining the cost of taking and keeping a patent "alive". These costs affected the choice of an inventor on whether and how long protect his invention. In Italy the system was

[4] The article 27 of *Regolamento* of the 1864 Law stated explicitly that the application for a patent could be submitted both by individuals and by corporations or other organizations.

extremely flexible: an inventor could register a patent for any duration ranging from 1 to 15 years according to his own choice. There was an initial payment that was proportional to the number of years for which the patent was requested (10 Italian lire for one year, 20 lire for two years…150 lire for 15 years). In addition, it was necessary to pay an annual renewal fee for keeping the patent in force. This renewal fee was increasing 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. The *Gazzetta Ufficiale del Regno d'Italia* kept regular track of the lifetime of patents by publishing the list of patents expired due to non-payment of the renewal fees. Furthermore, the Law gave also the possibility of "extending" the duration of a patent initially taken for a shorter period. For doing this, the inventor had to apply for an *attestato di prolungamento*. This cost 40 lire plus all the other fees required for a normal patent of the same duration. Hence, since *prolungamento* involved an extra cost of 40 lire, when the inventor was sure about the prospects of his invention, it was more convenient to take immediately the patent for the desired duration. However, when the prospects of the invention were uncertain, the possibility of taking *prolungamento* gave to the system a further degree of flexibility. Unfortunately, because of subtle differences in the structure of patent fees and in the actual enforcement of patent protection in different legislations, it is not straightforward to compare precisely the costs of patenting in different countries. However, the renewal fee structure for Britain and Germany have been recently discussed respectively by Nicholas (2011c) and by Streb, Baten and Yin (2006). Thus, Figure 1 compares the structure of renewal fees in Italy, UK and Germany.[5] The yearly fees have been measured in relation with the average weekly wages of workers in the engineering sector. Overall, this normalized measure confirms that, except for the initial year, the costs for keeping a patent alive was systematically lower in Italy than in Germany and UK. The last histogram on the right hand side reports the total amount of the fees paid throughout the patent life. Again, Italy appears to offer considerably cheaper fees in comparative perspective. Interestingly enough, in Italy, the most expensive annual renewal fees (those for years 13, 14 and 15) are lower than the cost in year 1. For this reason, it seems very unlikely that an inventor who had been able to enter in the Italian system (paying the costs in year 1) was later on unpaired in his

[5] The maximum patent duration of the German system was of 15 years, whereas in the British system the maximum patent duration was of 14 years.

renewal behavior by credit constraints. This particularity of the Italian fee structure supports the use of renewal data as indicator of the quality of patents (Nuvolari and Vasta 2015). Of course, this argument does not exclude that some independent inventors may not have been able to access the patent system because of credit constraints. Nevertheless these inventors are not included in our sample and consequently they do not affect the results of our analysis. In our interpretation, the flexibility of the Italian patent system can account both for the significant growth of patenting activity in Italy in the period in question and for the attractiveness of the system for foreign inventors.

[Figure 1 about here]

Figure 2 shows the number of patents per capita in some of the most industrialized countries in the period 1861-1913. The Figure shows that patenting activity in Italy increased substantially during this historical phase. Even if Italy at the time was a latecomer country, its volume of patenting activity, at the end of period, was not distant from that of a leading country of the Second Industrial Revolution such as Germany. This dynamism was coupled by the activities of some Italian inventors that were able to successfully develop "macroinventions" à la Mokyr (1990). Just to mention a few prominent examples, we can recall Ascanio Sobrero (1812-1888), an academic chemist working in Torino, who, in 1847, discovered nitroglycerine; Alessandro Cruto (1847-1908) who invented during the 1880s an extremely efficient electric light bulb that in a systematic series of experiments clearly outperformed Edison's bulb; Eugenio Cantono who developed in 1905 an electric areal power supply system for trams and buses which had an international success and Giuseppe Restucci who, in 1905, developed an innovative diving suit with artificial arms. Last but not least, it is worth mentioning Guglielmo Marconi (1874-1937) who pioneered the first successful long-distance radio-transmission equipment, for which he was awarded with the Nobel prize in Physics in 1909.

[Figure 2 about here]

Figure 3 provides a comprehensive comparative perspective on the "openness" of different patent systems, measured as the share of patents granted to foreign residents. Figure 3 suggests that the Italian patent system was extremely "open" relative to other major countries such as the United States, Germany, the UK and France. Overall the degree of “openness” of Italy resembles that of other small “open” economies such as Belgium, Netherlands, Sweden and Switzerland.

[Figure 3 about here]

3. Inventive activities and patents in Italy: a preliminary outlook

In this paper we make use of an updated version of the data-set on Italian patents constructed by Nuvolari and Vasta (2015). The data-set contains detailed information on all the Italian patents granted in five benchmark years: 1864-65, 1881, 1891, 1902 and 1911. In particular, for each patent we have collected information on the patentee, the invention, the technology class, the residence of the patentee and the duration of the patent (for more details on the salient features of the data-set, see Nuvolari and Vasta (2015)). This updated version of the data-set contains not only the patents registered in Italy, but also patents granted in other countries and registered in the Italian system on the basis of the Paris Convention of 1883.[6]

Table 1 shows the distribution of different type of patentees, that is firm versus independent inventors. The Table also shows the distribution of patents in the data-set according to the nationality of the patentee. Two broad trends stand out: the first is the increase in the share of company patents or, put the other way around, a decline in the share of independent inventors. Interestingly enough, this decline of independent invention in Italy in this historical period is common to the patterns of other major countries, as shown in Figure 4. This picture is consistent with the notion of the “industrialization of invention” proposed by Bernal (1953). The notion indicates the shift of inventive activities from independent inventors to the formalized R&D laboratories of firms, concomitantly with the unfolding of the Second Industrial Revolution. The second trend is that the share of company patents on foreign patents is significantly larger than the share of company patents on domestic patents (in particular in the last two benchmarks).

[Table 1 and Figure 4 about here]

Table 2 shows the distribution of domestic and “imported” foreign patent for the last three benchmark years. By “imported” foreign patents, we mean patents that were

[6] For an historical account of the Paris Convention, see the classic work by Penrose (1951).

originally registered in a foreign country, and for which the patentee applied for the Italian registration according to the protocol of the Paris Convention of 1883. In other words, in our dataset, for the last three benchmarks years, there are two types of foreign patents. The first is the case of a foreign inventor applying for an Italian patent through the normal procedure. The second is the case of a foreign inventor, holding a valid patent in a country member of the Paris Convention, who applies for the registration of that patent in Italy. It is interesting to note that this second types of patents is particularly significant only in the last benchmark. Speculatively, this suggests that the Convention (at least for Italy) was becoming effective only from the 1910s.

[Table 2 about here]

Table 3 shows the average duration (in years) of patents of different types. We consider, as mentioned, two kinds of duration. The first is what we call "ex-ante" duration, that is the number of years for which the patent was taken initially. The second is what we call "ex post" duration, that is the number of years for which the patent was actually kept in force by the patentee through the regular payment of the annual fees. In general, Table 3 shows that firm patents are characterized by longer durations than patents of independent inventors and foreign patents are characterized by longer durations than Italian ones. Interestingly enough, the patents with the longer duration are those registered by means of the Paris Convention. These patterns hold both for "ex ante" and "ex post" durations and for each benchmark.

[Table 3 about here]

In Figure 5a-b, we plot the planned and realized duration of our sample of patents, by benchmark year, in terms of percentage share. The realized (ex post) duration (Figure 5a) confirms the general idea of a skewed distribution of the value of patents, with a large fraction of patents with limited duration and a small number of patents extended through the maximum patent duration. On the contrary, the distribution of planned (ex ante) duration (Figure 5b) shows a modal outcome at 6 years. Duration of 1 year, 3 years, and 15 years also appears to be chosen ex ante by the inventors, with very few applications that extends to intermediate durations. The planned duration is confirmed in 24.4% of cases, whereas more often the patent is abandoned earlier than planned duration (57.3% of patents). In 18.3% of cases, the patent is extended beyond originally planned duration.

[Figure 5 about here]

4. A patent renewal model

The renewal behavior of patentees, that is the choice of keeping a patent "alive" or "aborting" it by not paying the renewal fees, is depicted in Figures 6a-d, that compares observed *ex post* renewal rates with the initial *ex ante* decision of patent coverage. The Figures are constructed by showing on the horizontal axis patent duration in years and on the vertical axis the share of patents that are kept alive for any given duration. The renewal behavior of patentees seems in line with the notion that patentees are acting as somewhat "rational/profit motivated" agents. In other words, at each moment in time, patentees make an assessment of the revenues arising from the patent and they compare them with costs of the renewal fee. This means that, as time goes by, only the most valuable patents are kept in force. *Ex post* duration is on average lower than *ex ante* duration, with a non-negligible share of inventors initially overstating the duration of the patent.

[Figure 6 about here]

Remarkably, in terms of *ex-post* duration, Figure 6a shows that patentees using the Italian system exhibited a renewal behavior very similar to that of German patentees in 1878-1914 period studied by Streb, Baten and Yin (2006). For example, they found that in the period 1887-1907 the share of patents renewed for 10 years or more ranged from 8 per cent to 11 per cent of the total. In the Italian case, we have a corresponding share of 8.4 per cent. Also the renewal behavior of British patentees in the second half of the nineteenth century seems characterized by a similar pattern, with about 10 per cent of patents kept in force for a duration of 10 years or more (Nicholas 2011c: 327). Fascinatingly, these results suggest the notion that XIX century patentees adopted homogeneous rules of thumb for assessing the value of patents.

A larger share of patents is abandoned in the first years after original applications as compared to planned (ex ante) duration (Figure 5a). Figures 5b-d show other plausible patterns in terms of a rational behavior of patentees. If we assume that "high-tech", “corporate” and “foreign” patents will typically be more “valuable”, we find that, at any given duration, a higher share of high tech patents than low tech patents is kept in force (Figure 5b), and that, at any given duration, a higher share of corporate patents than independent inventors’ patents is kept in force (Figure 5c) and, finally, that, at any given duration, a higher share of foreign patents than of domestic patents is kept in force (Figure 5d). Again, the main differences between planned (*ex ante*) and observed (*ex post*) renewal rates are observed in the early years after application.

Following the existing literature, we estimate the value of patents by considering the cost structure of the patent system and the renewal behavior of the patentees (Shankerman and Pakes 1986). The value of the patents will be estimated on the basis of *ex post* (realized) behavior (renewal rates of the patent), taking into account the behavior of the patentees during the entire lifespan of the patent. Then, the estimated model will be also employed to compute *ex ante* values, imputed on the basis of *ex ante* planned durations based on the decision of the patentees at the moment of the registration of the patent, focusing on the initial duration for which the patent was applied for.

Let L be the patent length, $L = 1,\ldots,15$ years. The initial fee to be paid at the moment of the application was equal to 10*L Lire. Then, for each year of patent duration, the patentee will be requested to pay a fee in order to keep the patent in force, as illustrated in the second row of Table 4.

[Table 4 about here]

For example, if a patentee decides to take a patent for 6 years, he will have to pay initially a registration fee of 60 lire, and, in the first year, 40 lire, the second year 40 lire, the third year 40 lire, the fourth year 65 lire, the fifth year 65 lire and the sixth year 65 lire. Hence the total cost expected to keep this patent in force for six years would be 375 lire, that is 315 plus the initial payment of 60 lire. We indicate with C_t the yearly fee at time t (for example if $t = 6$, $C_t = 65$ lire).

Our estimate of patent value considering ex post durations is based on the approach developed by Bessen (2008).

Let $r_i(t)$ be the annual flow of rents for the patent i in year t. We assume that the profit stream depreciates at a constant rate d: $r_i(t) = r_i(0)\, e^{-dt}$. We still assume a lognormal distribution for $r_i(0)$, so that the profit flow may be written again as a function of observable characteristics of the patent:

$$\ln r_i(0) = x_i' \beta + u_i$$

with u_i normally distributed with means zero and standard deviation σ. In each time period, the patent owner has to decide whether to pay the patent fee to keep the patent in force for one more year or quitting. The patentee will renew the patent at time t if the present value of profit in the additional year exceeds the renewal fee, C_t.

The present value of profits from t to t+1, is:

$$\int_t^{t+1} r_i(\tau)e^{-s\tau}d\tau = r_i(0)z_t$$

with $z_t = e^{-(d+s)t}\frac{1-e^{-(d+s)}}{d+s}$ and s is the discount rate. We set s = 5%.[7] In other words, the patent fee will be paid to keep the patent in force for an additional year if:

$$\ln r_i(0) \geq \ln (C_t / z_t)$$

The likelihood function is built accordingly as:

$$\Pr(\text{patent expires in 1}) = \Phi\left(\frac{\ln(C_1/z_1) - x_i'\beta}{\sigma}\right)$$

$$\Pr(\text{patent expires in } t) = \Phi\left(\frac{\ln(C_t/z_t)-x_i'\beta}{\sigma}\right) - \Phi\left(\frac{\ln(C_{t-1}/z_{t-1})-x_i'\beta}{\sigma}\right) \text{ with } t = 2,\ldots,14$$

$$\Pr(\text{patent expires in 15}) = 1\text{-}\Phi\left(\frac{\ln(C_{15}/z_{15}) - x_i'\beta}{\sigma}\right)$$

The results of the estimated model are reported in Table 5. In Model 1 a dummy for hi-tech industry is included among the regressors,[8] whereas in Model 2 the dummy variable that identifies hi-tech industries is replaced by industry-specific dummy variables. Results are broadly consistent across the two model specifications and confirm the qualitative evidence provided above (Table 3 and Figure 6). The value of foreign patents is

[7] Bessen (2008) sets s=10%. However, given the time period and the country in the analysis, a 5% discount rate seems more appropriate. Note that, by changing the value of the discount rate s, estimates do not change, with the unique exception of the constant term. This is due to the structure of the log likelihood, in which the discount rate s only affects the value of z_0. Note that $\ln(z_0)$ combines linearly with the constant term, β_0, so that values of s, d, and β_0 that would produce the same value for ln(z0) + β_0 would not change the value of the log likelihood. The value distribution is also broadly consistenti if s = 10% is chosen for the analysis.

[8] The sectors classified as hi-tech are: Chemicals, Electricity, Machine tools, machinery, components and metalworking, Steam engines, Weapons. The low-tech sectors in our database are: Agriculture, Construction and construction materials, Food and beverages, Mining, Paper and printing, various instruments, Textiles, apparel & leather, Transport, and Other manufactures.

higher with respect to Italian patent, as well as patents in the high tech sector (as opposed to low tech patents), patents issued to firms (as opposed to patents by independent inventors), and the patents applied under the Paris Convention (as opposed to domestic patents). As for the dynamics of value over time, patents granted in the year 1891 to have lower value with respect to patents granted in the year 1902 (no difference emerges with respect to patents granted in the year 1881).

[Table 5 about here]

On the basis of the estimates in Table 5 (column 1), we are able to estimate the net present value of patents, using Monte Carlo simulation methods as done by Bessen (2008). On the basis of the estimated values of β, σ e d we first determined the bounds on the error term u_i for each observation, conditional on the renewal decision made for the patent. Then, a random draw for u_i is considered from the appropriate lognormal distribution, and the corresponding $\log(r_{i0})$ is calculated. Ten Monte Carlo iterations are considered for each patent.

Values are simulated both on the basis of the realized (*ex post*) decision on the renewal of the patent as well as of the planned (*ex ante*) decision.[9] In the latter case, we simulate the value of the patent that would be observed if the initial decision on the patent duration would be confirmed in each time period. The distribution of simulated values is analysed in the next Section. The analysis of the distribution of the patent value consider the full set of simulated values.

5. Uncertainty, expectations and patent values

Table 6 provides a comprehensive estimate of the distribution of the *ex-ante* and *ex-post* patent values as a function of both realized and planned duration using the coefficients of Table 5 (Model 1). On the basis of the estimated model, patents with longer durations have higher values, both in terms of planned duration and realized duration. We also report the mean and median values of the realized value (computed on the basis of ex post duration) as a function of planned duration. While it is true that the realized value seems to

[9] The same seed is employed for the two sets of simulations, so that when ex post and ex ante duration are the same also the estimated value does not change.

increase with planned duration, standard deviations are very large, confirming that at application inventors “only have a rough idea of the value of the patent” (Sullivan 1994).

To provide a feeling of the estimated values, it is worth noting that the median ex post value of patents with realized duration of 15 years (about 9 million lire of 1902) would correspond to 48,600,000 of current (2014) US $.[10] Considering the historical context, it is worth noticing that the total value of the shared capital of company such as FIAT, one of the most important Italian firms of the time, in 1906 was 9 million lire.[11] For sake of comparison, Sullivan (1994) estimated the value of the top British patent around 1870 at £ 3,624, which corresponds to US$ 414,000 in 2014 prices using CPI. Unfortunately, it is difficult to provide a fully satisficing interpretation of the different estimates in the two countries since they refer to different periods, possibly characterized by substantially different technological opportunities. In addition, several other factors, such as the effectiveness and the cost of the patent legal system, the degree of competition in the relevant market and the technological development of the country, are likely to affect the value of the top patents.

[Table 6 about here]

In Table 7 we compare the distribution of ex ante and ex post value for different groups of patents. Results show that foreign, high-tech and “imported” patents are characterized by higher values, whereas patents of independent inventors are characterized by lower values, both *ex ante* and *ex post*. Interestingly enough, we show that the most valuable profile, considering ex post value, is the one of “imported” patents. This seems plausible since it may reflect the fact that these patents had been probably already begun to be successfully exploited in some other countries. The mean value is higher than the median which indicates the presence of skewness in the distribution of patent value.

[Table 7 about here]

For each patent, we also considered the difference among the two estimated values (*ex ante* and *ex post*). Mean and median values of the difference are reported at the bottom of Table 7. At the bottom of the Table 7, we report the mean and median differences

[10] This amount has been computed, by means of Officer and Williamson (2017), converting lire into dollars using the exchange rate and then finding the current amount adopting the CPI converter (last access July 2017).
[11] Source: http://Imitadb.unisi.it (last access June 2017). Unfortunately, so far we do not have precise information on the market value of the Italian firms at the time.

between *ex ante* and *ex post* simulated values. The difference tends to be positive (as expected as more than 50 percent of patents are abandoned earlier than planned duration) with differences across the different groups. Larger differences emerge for foreign patents, both in the average and median values. Hi-tech patents exhibit the larger mean difference, whereas imported and priority patents are characterized by a large difference in the median value, but smaller than the overall sample in terms of the mean value. Information on the value of the innovation covered by imported and priority patents may already be acquired in the originator country, leading to a more reliable estimate of the value of the innovation at patent application.

Figure 7 shows the boxplots of the difference between ex ante and ex post values (log) for all patents, foreign patents as compared to Italian patents, independent patents as compared to firm patents, hi-tech patents as compared to low-tech patents and imported and priority patents as compared to all other patents (outside values are not shown).[12]

[Figure 7 about here]

Differences for foreign patents seem to be larger with respect to differences in value that characterize Italian patents, and this is also true, even if to a lesser extent, for independent patents as compared to patents by firms. Little differences emerge in the distribution of hi-tech patents and imported and priority patents.

Next we estimate a multinomial probit model to understand whether the differences are related to patent's and inventors' characteristics. The analysis is interesting as it reveals the attitude of the different types of inventors in the assessment of their patents.

We consider a categorical model that takes into account the probability of observing large negative / negative / zero / positive / large positive differences. The latter model is better suited to take into account non-linearity in the distribution of the estimated differences. In order to define large positive and large negative differences we take into account the distribution of the difference between ex ante and ex post values. As the median negative difference and the median positive difference is about 4,000 lire, large

[12] The boxplot provides a graphical representation of the full distribution of the value. The box extends from the 25th percentile to the 75th percentile; the horizontal line represents the value of the median. The "whiskers" extend up to the minimum and maximum of the distribution, or up to 1,5 times the value of the interquartile range. Values larger or smaller than this threshold are considered as "outliers" (not shown in our Figure).

differences are defined as those differences exceeding 4,000 lire (in absolute value for negative differences). A multinomial probit model is considered in which the dependent variable is defined as: (1) large negative difference, i.e. the value of the innovation is largely understated at application: D < -4,000; (2) negative difference, i.e. the value of the innovation is understated at application: -4,000 <= D < 0; (3) no difference, i.e. the value of the innovation is well assessed at application: D = 0 (taken as the base category for estimation of the model); (4) positive difference, i.e. the value of the innovation is overstated at application: 0 < D < 4,000; (5) large positive difference, i.e. the value of the innovation is largely overstated at application: D >= 4,000.

For the multinomial probit analysis, one observation for each patent is considered, where again, in order to aggregate the value of the variable from the multiple (ten) Monte Carlo iterations, we considered, for each patent, the minimum category, the maximum category and the category which is more often observed.[13] Table 8 reports the distribution across the five category of the dependent variable for each of the chosen aggregation criteria.

[Table 8 about here]

Marginal effects from the estimated multinomial probit model are reported in Table 9.[14] Foreign patents are more likely to report large positive differences as compared to Italian patents, and less likely to exhibit no difference between positive and negative values. Independent patents are more likely to report no difference or positive difference, but less likely to score large negative difference as compared to patents by firms. Hi-tech patents are more likely to experience large differences, both positive and negative, whereas imported and priority patents are more likely to record no difference between *ex ante* and *ex post* values.

[Table 9 about here]

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[13] For those patents with no difference (category 3), the minimum, maximum and modal selection criteria produce the same results. Difference may emerge when considering negative and positive differences. In the few cases (5%) in which the category 1-2 and 4-5 is evenly distributed for a single patent, categories 1 and 5 are, respectively, considered.

[14] Full results are available from the authors upon request. As multinomial probit coefficients provide little information on the sign and magnitude of the effect of the variables on the probability of each outcome, we prefer to report estimated marginal effects directly. The full set of coefficients is not reported to save space.

6. Counting or weighting patents

The significance of our estimates of patent value is well illustrated in Figures 8a and 8b which show the difference in the distribution of various types of patents when measured, on the one hand, using simple patent counts (Figure 8a) and, on the other hand, using patents weighted by their estimated values (Figure 8b). Figure 8a shows a rather stable pattern of technical change largely dominated by independent inventors, mainly foreign but also with a significant contribution of the domestic ones. The contribution of company's patents appears to be rather limited accounting for at most 20 per cent of the total. The picture emerging from Figure 8b, which takes into account the estimates of patent value, is dramatically different. Indeed, it emerges clearly the predominant role played by company's patents which, in this case, have a share of more than 50 per cent of the total value of Italian patenting activity. It is worth noticing that the major contribution is due to foreign firms. Moreover, in this case the share of Italian independent inventors becomes very limited, less than 10 per cent of the total. This finding offers a significant corroboration to the interpretation provided by Nuvolari and Vasta (2015), which argued for the limited role played by independent inventors, despite their large number, in this early phase of the Italian industrialization process. A Chi-square test confirms that the distribution of patent counts and patent values are significant different at 1 per cent for the single benchmark years and for the aggregate.

[Figure 8a-b about here]

In Table 10 we compare the distribution of foreign patents granted in Italy using counts and value data disaggregated by countries. The data are presented also in Figure 9 using a radar diagram. It appears clear that *prima facie* there is a certain similarity in the two distributions since the two major countries (Germany and United States) have very similar shares both using simple patent counts and value-weighted patents. Nevertheless, Figure 9 shows also substantial differences in the profile of the two distributions. For example, Switzerland is characterized by a remarkably larger patent value share than the count one (20.1 versus 4.4 per cent). This means that Swiss patents should be considered, on average, of higher quality with respect to those of other countries. The opposite pattern is visible, although less marked, for France and England. Finally, it is worth observing that the contributions of minor countries (here labelled as “others”), those more distant from the world technological frontier, was, as one would have expected, much more relevant in terms of patent counts than in patent value. The different profiles of the two distributions are confirmed, also in this case, by the Chi-square test which is significant at 1 per cent level. However, we should point out that, since we are dealing with a probabilistic model, the estimates of categories with a limited number of patents may be somewhat erratic. Accordingly, one should interpret these results cautiously.

[Table 10 and Figure 9 about here]

7. Conclusions

In recent years historical patent data have received an increasing attention by economic historians. Without any doubts, the use of patent counts has strongly contributed to improve the understanding of the dynamics of technological change since the Industrial Revolution in many historical contexts. However, one the major shortcomings of the use of patent data, which is surfacing even in the most recent literature, is the issue of the different technological significance of patented inventions which, as well known, may range from incremental improvements (or even weird or "wacky” inventions)[15] to major technological breakthroughs. Some scholars have tried to overcome such limitations by constructing indicators of patent value that are also frequently used in the contemporary innovation studies literature, such as number of citations and/or renewal rates. Clearly, when dealing with historical sources, the adoption of this type of research strategy requires heavy efforts in data collection and processing. In particular, in most cases, we are dealing with a high resource consuming process since it is necessary to retrieve and integrate information from several sources, which are not easily accessible and sometime not even fully available. For example, in the case of patent citations it is necessary to control, in exhaustive manner, a large amount of patent information for the years following the grant of the patent. Similar considerations can be extended to patent renewals which require to make use of specific sources in order to assess for how long the patent has been kept alive.

[15] For an economic reappraisal of this issue in contemporary data, see Czarnitzki, Hussinger and Schneider (2011).

The main result of this paper is that these research efforts are really worthwhile. In particular, we have shown that patent renewals can shed a very useful light on the expectations and behaviors of inventors in different moment in time and in this way they can provide a useful empirical characterization of the attitudes concerning the uncertainty intrinsic in the innovation process. This is an interesting result, since data on the expectations and profit prospects of innovations are very hard to collect and usually they are available only by means of case-studies or on small scale samples. Our findings show that high-tech inventions are actually surrounded by both more pessimistic and optimistic expectations. We also find that a similar "bipolar" perception is also characteristic of foreign patentees, whereas independent inventors are instead characterized by a much more cautious outlook. Of course these results are still preliminary, but if confirmed in other contexts, they could represent interesting stylized facts on the nature of innovation processes.

We have also carried out a comparison of innovation patterns using patent counts and renewal data. We find that the profile of innovative activities reconstructed by using patent values is significantly different form the one arising from simple patent counts.

One of the most debated issues in the economic history of innovation is the dichotomy of independent versus company inventors during the Second Industrial Revolution. Nicholas (2010, 2011), by reconstructing the patent activity in three major countries such as Britain, US and Japan, has pointed to the significant role still played by independent inventors in the first decades of the XX century. In particular, he has shown that independent inventors were capable to develop higher value patents. Our findings suggest that the Italian context does not fit with the picture outlined by Nicholas: while the patents count distribution is largely dominated by independent inventors, as observed also in other countries, when considering patent weighted by their economic value, the contribution of companies becomes predominant. Similar considerations hold for the issue of foreign flows of technology in Italy. Also in this case, there are significant discrepancies between the two different profiles (patent count versus patent value) by countries. This vindicates the importance of taking properly into account the issue of patent quality when historical patents data are used.

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Table 1. Distribution of patents by different types for benchmark years

	1864-65	1881	1891	1902	1911
Type of patentee					
Total	520	941	1,618	2,987	4,058
Firm (%)	4.0	14.5	18.4	20.6	24.1
Independent (%)	96.0	85.5	81.6	79.4	75.9
Localization					
Foreign	263	603	1,132	1,965	2,264
Firm (%)	3.0	15.1	18.8	25.8	31.9
Independent (%)	97.0	84.9	81.2	74.2	68.1
Italy	257	338	486	1,022	1,794
Firm (%)	5.1	13.3	17.5	10.8	14.3
Independent (%)	94.9	86.7	82.5	89.2	85.7

Source: Nuvolari and Vasta (2015, Table 2).

Table 2. Distribution of domestic and 'imported' patents for benchmark years

Type of patents	1891		1902		1911	
	No.	%	No.	%	No.	%
Patents	1,618	97.1	2,987	94.5	4,058	77.9
Imported and priority patents	49	2.9	175	5.5	1,151	22.1
Total	1,667	100.0	3,162	100.0	5,209	100.0

Source: Nuvolari and Vasta (2018).

Table 3. Average patent duration for benchmark years (in years)

	1864-65	1881	1891	1902	1911
Average *ex ante* length (years)					
Total	6.3	5.2	6.5	5.1	4.8
Firm	6.0	6.0	7.9	6.8	6.5
Independent	6.4	5.1	6.2	4.6	4.1
Foreign	7.3	6.0	7.8	6.2	5.8
Italy	5.4	3.7	3.4	2.8	2.9
Imported and priority patents			9.1	7.2	6.7
Average *ex post* length (years)					
Total		3.3	3.3	3.8	
Firm		5.2	4.9	5.7	
Independent		3.0	2.9	3.2	
Foreign		3.8	3.6	4.4	
Italy		2.7	2.8	2.5	
Imported and priority patents			5.9	5.1	

Source: Nuvolari and Vasta (2018).

Table 4. Annual fee to keep the patent in force (Italian Lira)

Year *t*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fee C_t	40	40	40	65	65	65	90	90	90	115	115	115	140	140	140
Cumulative Fee $\sum_{i=1}^{t} C_i$	40	80	120	185	250	315	405	495	585	700	815	930	1,070	1,210	1,350

Table 5. Estimates of the ex post *patent value model*

	Model 1	*Model 2*
Foreign	1.6859*** (0.1547)	1.6475*** (0.1527)
Independent	-1.9419*** (0.1747)	-1.8961*** (0.1718)
Hi-Tech	0.5657*** (0.1005)	--
Imported and priority	0.8731*** (0.2356)	0.8347*** (0.2328)
Year 2 (1881)	-0.1052 (0.1296)	-0.0680 (0.1292)
Year 3 (1891)	-0.3658*** (0.1077)	-0.3609*** (0.1074)
Constant	6.0051*** (0.2249)	5.7952*** (0.2985)
σ	3.1957*** (0.2237)	3.1560*** (0.2205)
D	0.5692*** (0.0468)	0.5677*** (0.0466)
Industry Dummies	No	Yes
N	5,769	5,769
Log likelihood	-11,838.3	-11,790.36

Note: Asterisks indicate the level of statistical significance: * 10%; ** 5%;*** 1%. Omitted benchmark year is 1902.

Table 6. Distribution of estimated ex post *value as a function of planned and realized duration*

Duration	*Ex post value as a function of realized duration*				*Ex ante value as a function of planned duration*				*Ex post value as a function of planned duration*			
	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N
1	39.26	20.06	44.23	2,135	41.45	22.22	45.23	1,195	68,332.06	70.97	2,077,073	1,195
2	225.80	222.91	36.87	1,038	225.07	222.01	36.35	282	20,162.79	79.08	295,057.7	282
3	521.41	496.84	157.53	817	516.52	489.26	156.90	1,084	169,869.5	180.98	4,805,687	1,084
4	1,140.92	1,126.29	187.35	341	1,148.47	1,151.63	198.98	12	519.03	80.27	1,221.17	12
5	2,013.04	1,984.85	330.77	265	2,006.89	1,967.72	326.18	128	82,056.8	337.96	722,240.5	128
6	4,232.73	4,067.21	1,081.61	367	4,225.85	4,058.38	1,092.40	2,151	498,630.9	464.51	14,528,151	2,151
7	8,611.19	8,392.34	1,464.78	108	8,535.68	8,716.75	1,445.81	3	3,801.73	1,958.0	3,389.44	3
8	15,318.35	14,966.63	2,563.39	92	15,589.48	15,329.73	2,474.39	4	1,320.30	509.59	1,717.11	4
9	30,475.72	29,348.77	7,201.40	121	29,279.09	28,056.86	6,542.34	8	15,587.14	15,322.6	14,478.45	8
10	60,541.68	59,390.93	10,054.16	75	61,571.47	60,810.53	9,608.4	38	103,041.6	298.63	783,013.2	38
11	106,825.6	104,477.7	17,765.7	57	100,488	98,866.29	14,481.42	5	767,267.7	236.66	2,341,808	5
12	206,412.6	196,743.2	45,572.7	69	206,946.2	196,805.6	43,748.96	10	73,747.56	13,413.18	96,809.63	10
13	405,767.5	393,661.8	66,027.0	31	405,280.8	402,375.5	683,13.16	20	82,803.67	917.52	163,418.3	20
14	717,036.9	693,416.6	112,897.4	33	716,273	692,860.5	116,493.5	78	324,738.5	1,017.0	1,707,045	78
15	8,972,800	2,242,312	49,053,720	220	8,349,445	2,104,711	62,152,408	751	871,123.7	762.26	9,026,649	751

Note: mean, median and standard deviation of Monte Carlo results; N, number of patents in the original dataset.

Table 7. Distribution of estimated ex ante *and* ex post *values by patent characteristics*

Quantile	*All patents*	*Foreign patents*	*Independent patents*	*Hi-tech patents*	*Imported and priority patents*
Ex post					
.25	45.63	117.14	31.21	82.37	226.67
.50	252.77	343.65	218.17	318.69	1,077.75
.75	1,491.83	2,544.03	943.65	2,575.53	6,058.12
.90	23,955.92	51,738.61	6,909.02	62,690.17	377,556.2
.95	288,199.3	747,933.6	59,993.66	1,032,896.0	824,324.3
Mean	354,427.9	458,565.8	193,657.4	469,440.7	533,709.6
Ex ante					
.25	274.39	737.88	209.12	351.25	3,102.05
.50	2,844.78	3,872.80	2,413.84	3,298.16	4,694.90
.75	5,121.73	6,026.25	4,796.76	5,760.04	330,502.1
.90	1,298,805	1,865,259	1,092,200	1,759,264	772,698.7
.95	2,828,360	3,912,095	2,265,705	3,850,298	957,995.4
Mean	1,100,830	1,551,446	710,461.5	1,679,764	664,782.4
Difference					
Median	378.53	2,674.21	375.77	463.83	2,282.70
Mean	746,273	1,092,711	516,720	1,210,104	131,057
N	57,690	39,200	46,420	23,910	2,230

Note: mean, median and standard deviation of Monte Carlo results; N, number of patents in the original dataset.

Table 8. Distribution of the differences of the log ex ante estimated values and the log ex post estimated value for different aggregation criteria

	Most common	**Min**	**Max**
Y = 1 (large neg. difference)	582 (10.09%)	627 (10.87%)	496 (8.60%)
Y = 2 (negative difference)	472 (8.18%)	427 (7.40%)	558 (9.67%)
Y = 3 (no difference)	1,409 (24.42%)	1,409 (24.42%)	1,409 (24.42%)
Y = 4 (positive difference)	1,885 (32.15%)	2,505 (43.42%)	1,092 (18.93%)
Y = 5 (large positive difference)	1,451 (25.15%)	801 (13.88%)	1,451 (38.38%)

Table 9. Marginal effects (and standard errors) from the multinomial probit estimation (most common)

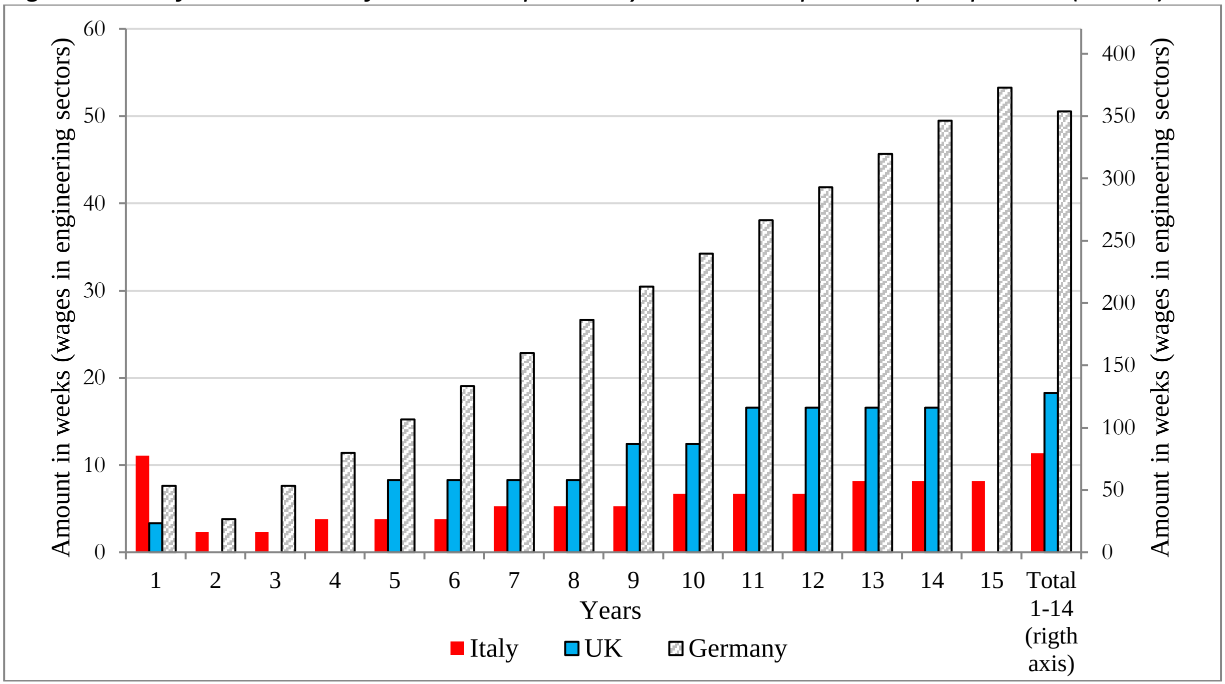
	ΔPr(Y=1)/Δx	ΔPr(Y=2)/Δx	ΔPr(Y=3)/Δx	ΔPr(Y=4)/Δx	ΔPr(Y=5)/Δx
Variable	Large neg. diff.	Negative diff.	No difference	Positive diff.	Large pos. diff.
Foreign	0.0311*** (0.0079)	-0.0384*** (0.0085)	-0.1084*** (0.0130)	-0.1633*** (0.0139)	0.2789*** (0.0096)
Independent	-0.1143*** (0.0128)	0.0160** (0.0093)	0.0449*** (0.0146)	0.0828*** (0.0157)	-0.0293** (0.0145)
Hi-tech	0.0254*** (0.0083)	-0.0084 (0.0078)	-0.0122 (0.0121)	-0.0342*** (0.0131)	0.0295** (0.0116)
Imported and priority	0.0072 (0.0198)	-0.0223 (0.0185)	0.0700** (0.0339)	-0.0715** (0.0327)	0.0166 (0.0281)
Year 2 (1881)	-0.0229** (0.0100)	-0.0220** (0.0097)	-0.0058 (0.0166)	-0.0094 (0.0179)	0.0600*** (0.0177)
Year 3 (1891)	-0.0634*** (0.0079)	-0.0109 (0.0085)	-0.0196 (0.0135)	-0.0355** (0.0145)	0.1294*** (0.0141)

Note: Asterisks indicate the level of statistical significance: * 10%; ** 5%;*** 1%. Omitted benchmark year is 1902.

Table 10. Distribution of patent by countries (number and ex post *values)*

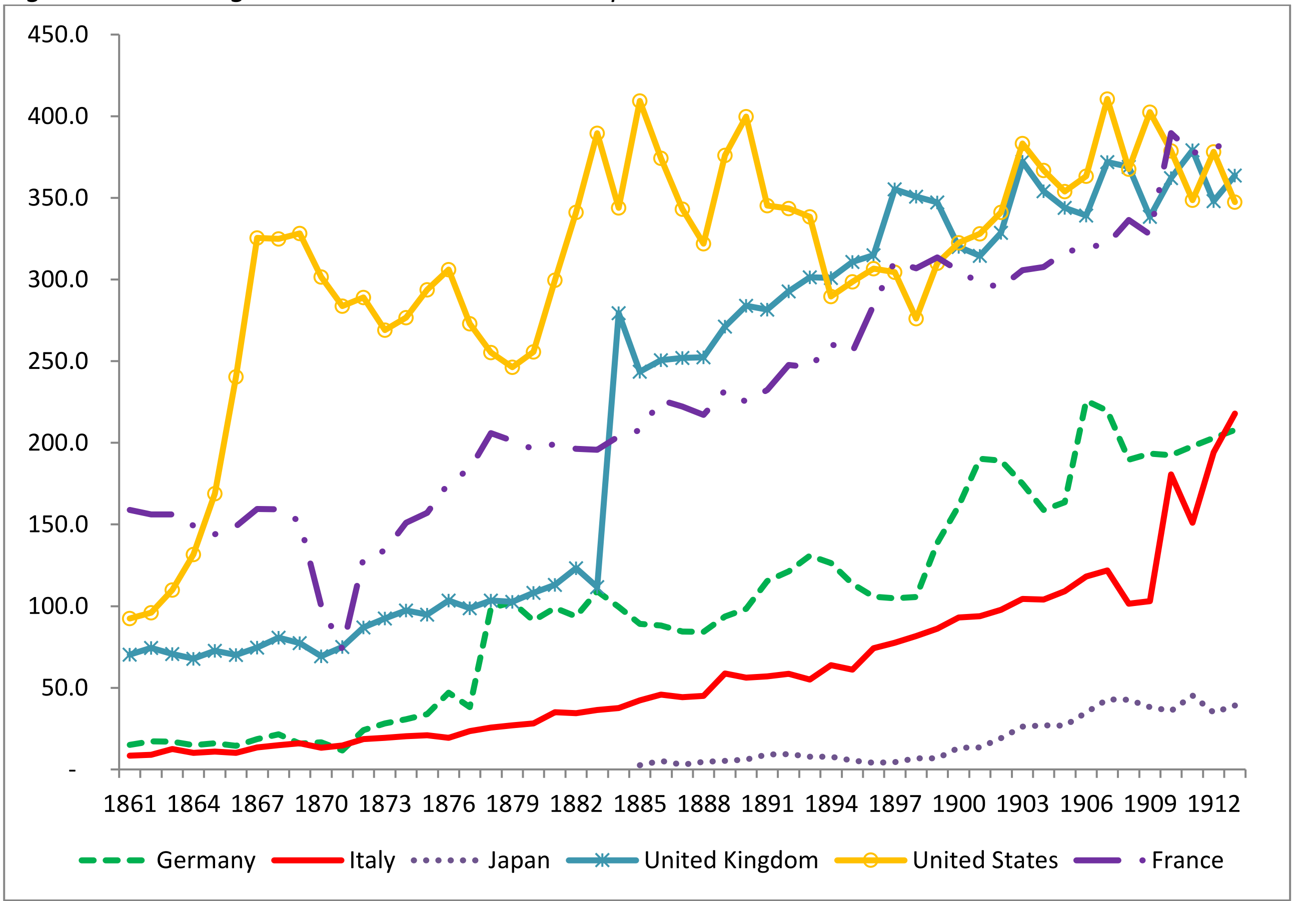
Country	Number	Value	% no.	% value
Germany	1,209	545,041,515	30.83	30.33
USA	561	279,918,141	14.31	15.57
France	753	249,400,508	19.20	13.88
England	530	134,077,007	13.52	7.46
Switzerland	173	361,720,063	4.41	20.13
Austria-Hungary	205	43,252,731	5.23	2.41
Belgium	122	47,606,891	3.11	2.65
Sweden	36	48,591,277	0.92	2.70
Scotland	32	17,081,344	0.82	0.95
Denmark	30	38,748,991	0.77	2.16
Other countries	24	17,030,043	0.61	0.95
Total	3,921	1,797,318,563	100.0	100.0

Figure 1. The fee structure of the Italian patent system in comparative perspective (1880s)



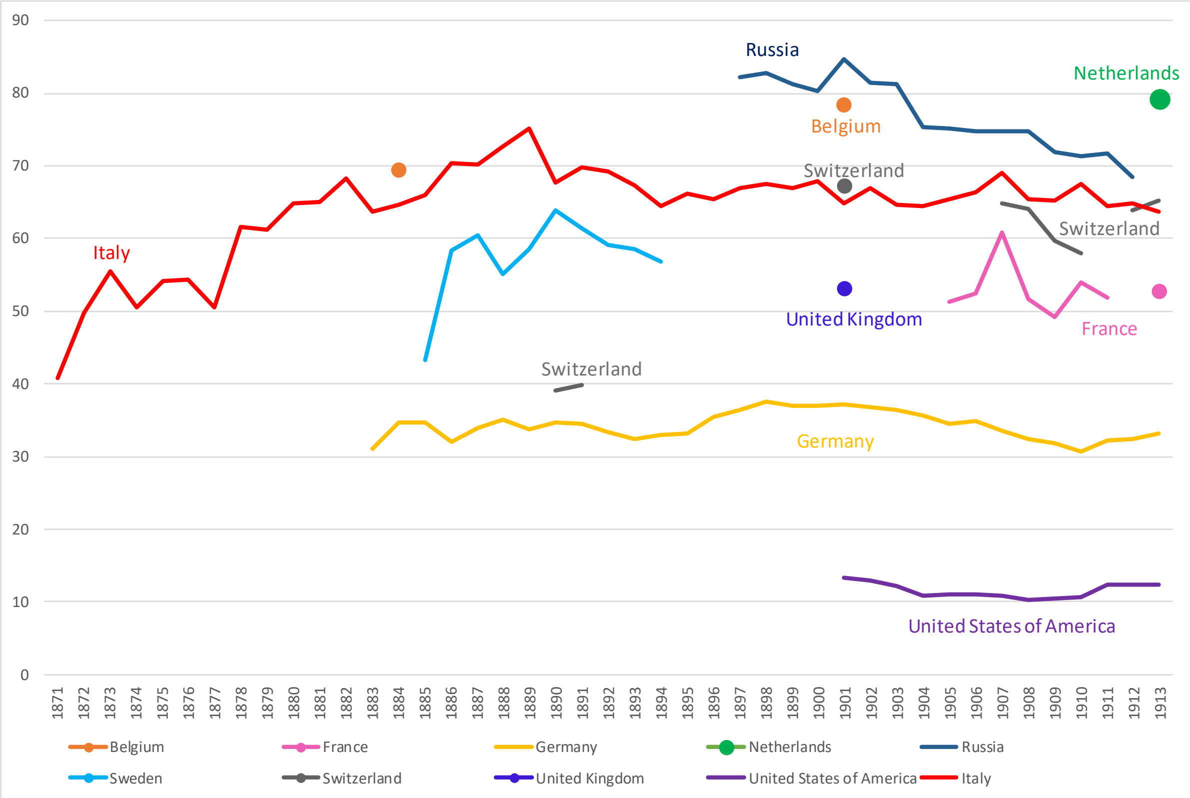
Source: Nuvolari and Vasta (2015, p. 864).

Figure 2. Patents granted in selected countries per million inhabitants



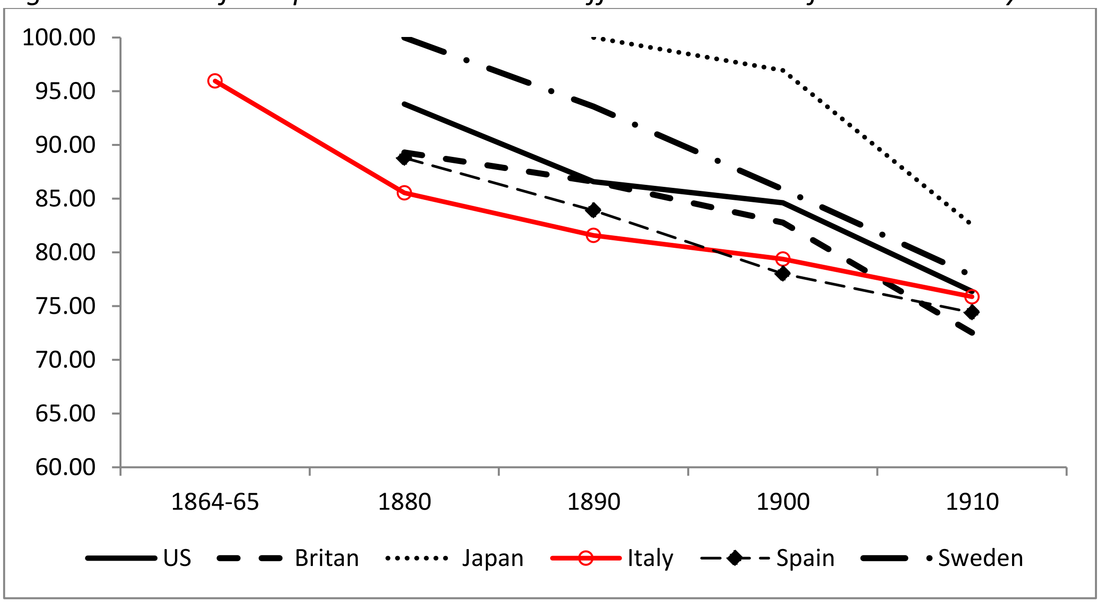
Source: own elaboration on 1883-1913: WIPO Statistics Database (last access June 2017); 1861-1882: Khan (2008); data for Italy from Nuvolari and Vasta (2015, Figure 3).

Figure 3. Degree of openness (share of foreign patents on total) of different patent systems (1871-1913)



Source: own elaboration on WIPO Statistics Database (last access June 2017) data for Italy from MAIC (various years).

Figure 4. Share of independent inventors in different countries for benchmark years



Source: Nuvolari and Vasta (2015, p. 868); Sweden from Andersson and Tell (2016).

Figure 5. Planned (ex ante) and realized (ex post) durations

Figure 5a. Realized duration, share

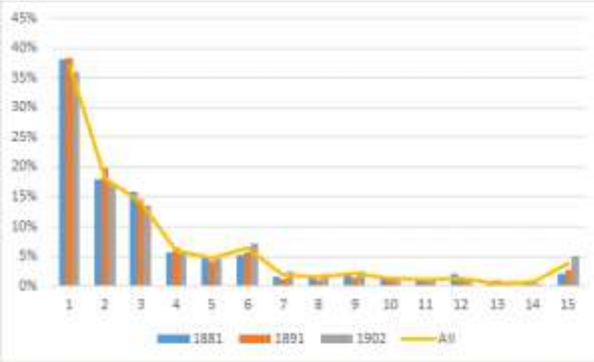


Figure 5b. Planned duration, share

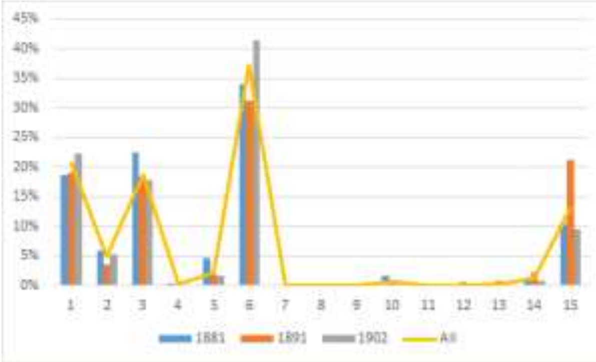


Figure 6. Observed renewal rates and ex ante duration (1881-1902)

Figure 6a. All patents

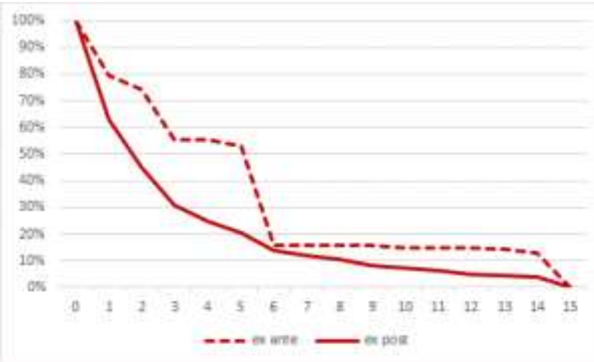


Figure 6b. By technological intensity

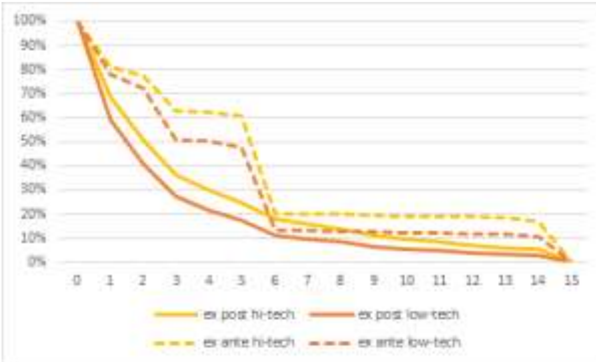


Figure 6c. By type of patentees

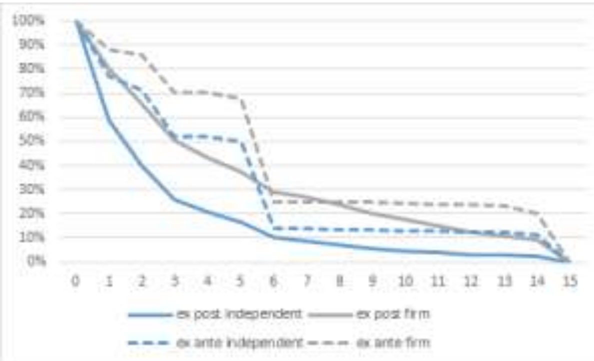


Figure 6d. By nationality

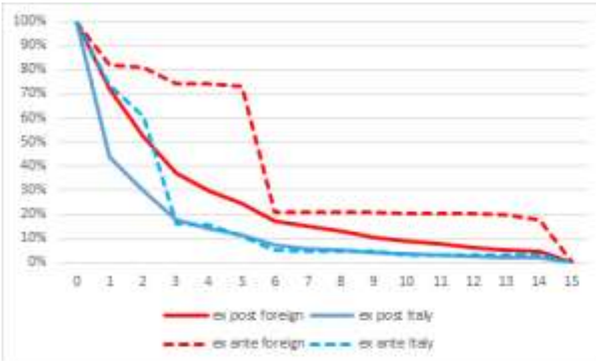
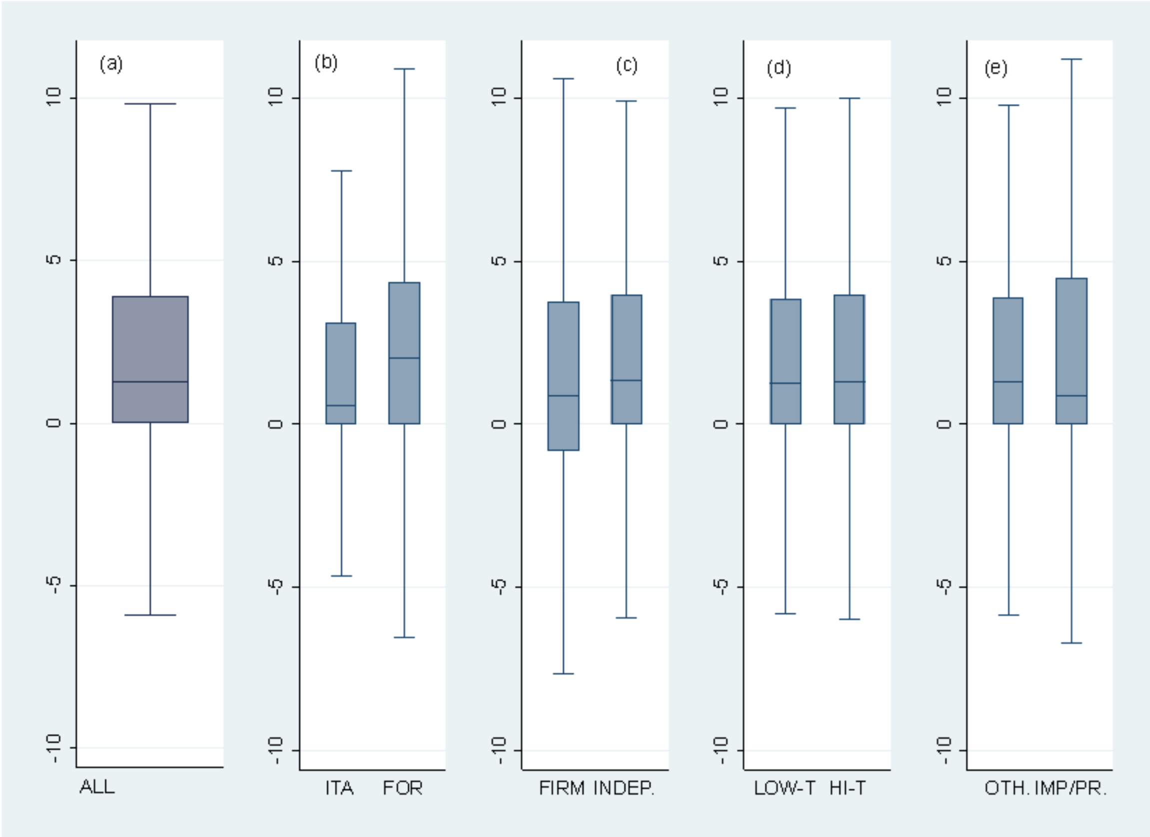


Figure 7. Boxplots of the distribution of the difference between log ex ante value and log ex post value (excluding outside values)



Note: (a) all patents; (b) Italian (ITA) versus foreign (FOR); (c) firm (FIRM) versus independent (INDEP.); (d) low-tech (LOW-T) versus hi-tech (HI-T); (e) all the others (OTH.) versus imported-priority (IMP/PR.).

Figure 8a. Distribution of patents (number) by type, 1881-1902

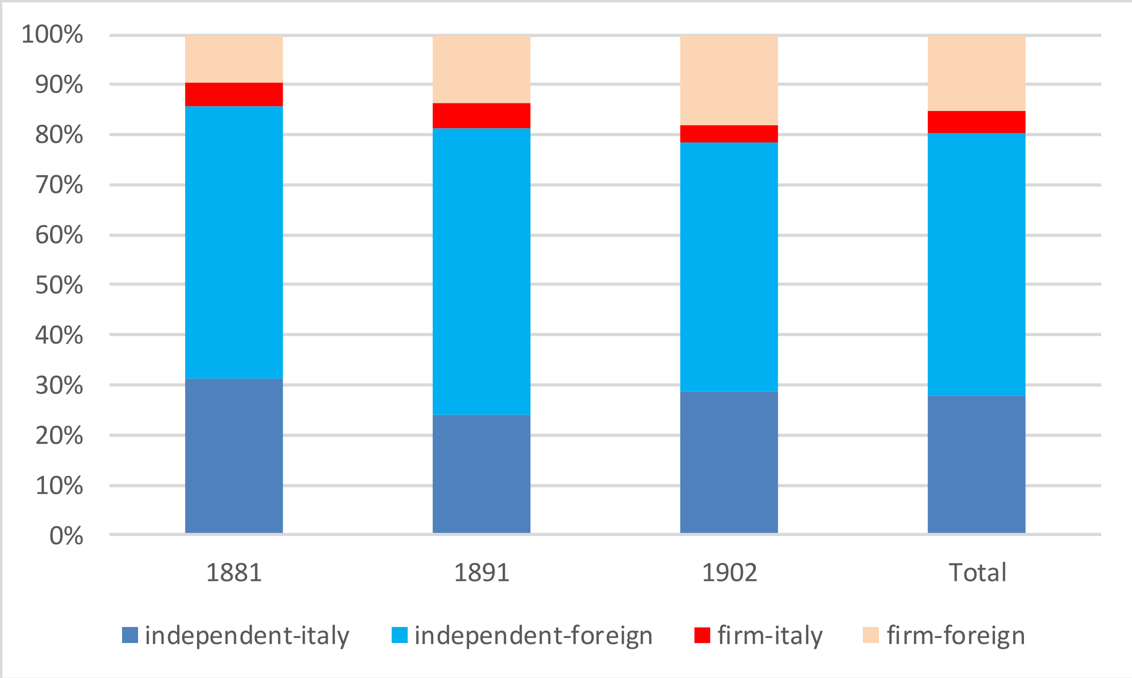


*Figure 8b. Distribution of patents (*ex post *value) by type, 1881-1902*

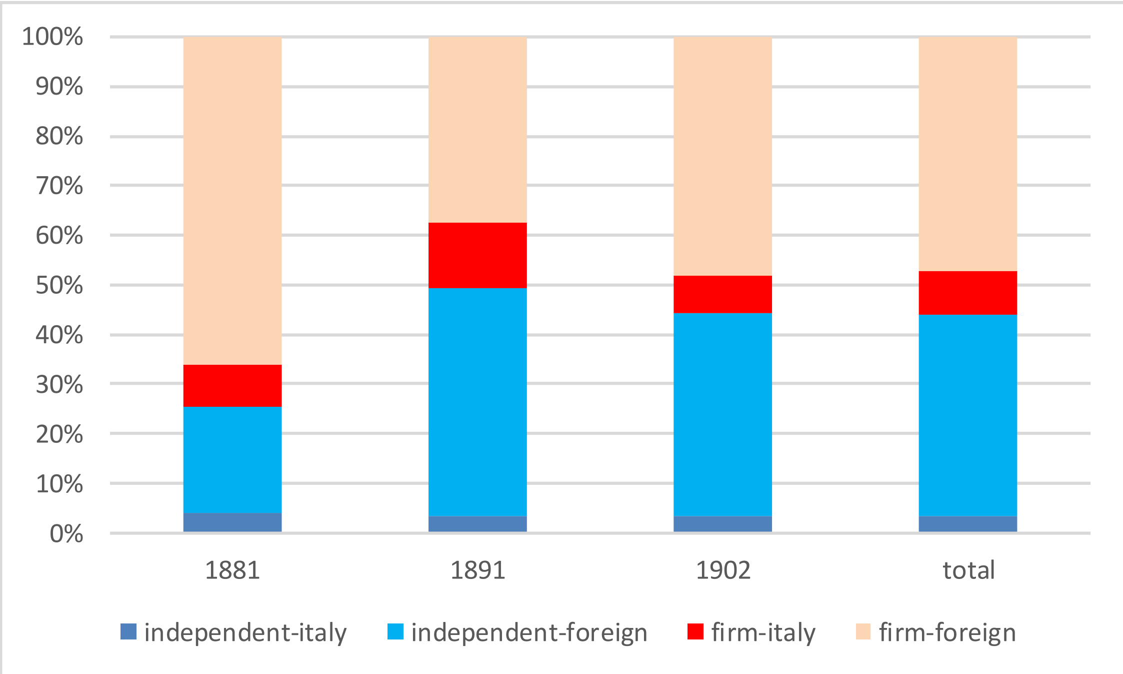


Figure 9. Distribution of patent by countries (number and ex post *values)*