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UNCERTAINTY AND INNOVATION

New Perspectives from Nineteenth-Century Patenting Behavior

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Following Knight (1921), economists distinguish between economic contexts characterized by risk and by uncertainty, respectively (see de Jong, Chapter 19 in this volume). Simply put, “risk” refers to situations in which agents have a sound understanding of all the possible outcomes of their decisions and can calculate, with good approximation, their relative odds. “Uncertainty” refers to situations in which the agents’ understanding is significantly more rudimentary, so they are not in the position to calculate dependable odds and often cannot even fully envisage all the possible outcomes of their decisions (Dequech 2006). In this respect, the search for innovation is clearly an economic activity characterized by ubiquitous uncertainty.

Knight’s distinction between risk and uncertainty complements, to some extent, Schumpeter’s views on entrepreneurship and innovation. Schumpeter (1934) argued that investments in innovation activities were not the outcome of rational calculations, but rather were undertaken by a special class of individuals (“entrepreneurs”) who, even if not able to formulate fully accurate forecasts about the future, were willing to incur the hazards and difficulties related to the introduction of innovations.

The subsequent literature, while preserving the emphasis of Schumpeter (and Knight) on the role of uncertainty, has gradually moved away from this somewhat heroic and idealized perspective of entrepreneurship, instead trying to reconstruct the cognitive heuristics and the organizational mechanisms that lead to the formulation of expectations and forecasts in the context of innovative processes. To be sure, most of the research carried out during the 1970s and 1980s on the role of expectations in innovation projects was critically aware of the role of Knightian uncertainty in research and development (R&D) decision-making. Accordingly, the main approach was the use of company-based case studies or of small samples of innovations to unravel the difficulties and potential biases which characterized these types of decisions. For example, in an important study Beardsley and Mansfield (1978) examined in detail the accuracy of the forecasts on the profitability of innovations carried out by a large US company, noting their overall fragility, which they ascribed to the “inherent uncertainty” of innovation processes.¹

This stream of detailed empirical research on the accuracy of and the biases affecting expectations and decision-making in inventive activities gradually petered out during the 1990s. In fact, despite the empirical evidence suggesting that innovation processes were typically surrounded by Knightian uncertainty, formal models of innovation, both in industrial organization—the literature on “patent races” (Reinganum 1989)—and in growth theory (Aghion and Howitt 1992), began to represent the stochastic features of innovation by means of simple probability distributions. Furthermore, it was also assumed that these probability distributions were known to the agents. In this way, these formal models completely removed the issue of Knightian uncertainty from the picture, preferring to settle for the more comfortable and mathematically treatable notion of risk.

In these models, the agents can resort to standard risk-adjustment methods to formulate their strategies. In other words, one of the key assumption of this literature is that agents can formulate “rational technological expectations.” This made it possible to apply game theory and standard neoclassical investment frameworks to the case of innovation (Hall and Lerner 2010). However, the insights emerging from this theoretical literature have found limited application in empirical studies, as the models are based on a wide range of parameters and variables for which it is difficult to find clear-cut empirical counterparts. In an empirical study of the pharmaceutical industry, where the patent race model seems plausible, Cockburn and Henderson (1994) found that the characterization of strategic interactions found in the patent race literature was of little relevance.²

On reflection, the disconnect between theoretical literature and empirical studies in this context is not surprising. Clearly, the notion of technological expectations is inherently elusive and of difficult empirical operationalization, especially in large scale samples. In the field of economic history, primary and secondary sources have been used to chart the dynamics of expectations about trends in economic activity and inflation (Binder 2016; Lennard, Meinecke, and Solomou 2023), but so far there has been no systematic research on expectations relating to innovation returns.

In this chapter we take advantage of a peculiar characteristic of the nineteenth- and early twentieth-century Italian patent system which allows us to carry out a systematic assessment of the profits expectations of innovators at different moments in time. Indeed, since the seminal contribution of Schmookler (1966), patents have become one of the favorite “guinea pigs” of innovation scholars. They have provided a way of gathering important insights on patterns of innovation at multiple levels of analysis, ranging from individual inventors and 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) and PATSTAT datasets.

Following the pioneering contributions of Dutton (1984) and Macleod (1988) for England (not the UK as a whole), 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 in economic history, too. Since then, historical patent data have been insightfully employed to reconstruct profiles of inventive activities for countries such as Germany (Streb, Baten, and Yin 2006), Italy (Vasta 1999; Nuvolari and Vasta 2015, 2017), Japan (Nicholas 2011a), Spain (Saiz 1999, 2012), France (Nuvolari, Tortorici, and Vasta 2023), Norway (Basberg 2006), Sweden (Andersson and Tell 2016), and in international comparative perspective (Nicholas 2011b).

To assess the expectations of innovators about the economic prospects of their inventions, this chapter, following the approach by Bessen (2008), expands on this line of research by providing new estimates of the inventors' evaluations in relation to their patents, based on a large sample of Italian historical patents and using the renewal method. We focus on the expectations on innovation returns at two critical instances: the moment of applying for the patent and the moment at which the inventor decides to abandon patent protection by not paying the required fee. By comparing *ex ante* and *ex post* evaluations, we can explore the different attitudes of innovators concerning the radical uncertainty surrounding the innovation process (see Nützenadel and Streb, Chapter 8 in this volume). We estimate the value of patents using renewal data (Schankerman 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), who used the method to estimate the value of British patents in the period 1852–1876. The approach assumes a rational (in the limited sense of profit-motivated) behavior of the patentee, who will keep on paying the renewal fees only as long as this is economically justified by the revenue streams generated by the patent.

The chapter is structured as follows. In the next section, we introduce the salient institutional features of the Italian patent system in this period, before going on to discuss the sources and outlining the main patterns of innovation as captured by patent data. Subsequently, we present the patent renewal model that we adopt to describe the distribution of patent values and carry out its econometric estimation. The *ex ante* and *ex post* patent values are then used to study innovators' attitudes toward uncertainty, before finally drawing some conclusions.

The Historical and Legal Background

The first Italian patent law was enacted in 1864 (Law n. 1657, January 31, 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 the Kingdom of Sardinia (Piedmont) in 1855. The Italian patent system was a registration system and, accordingly, there was no examination of the actual novelty of the invention patented. Controversies on the novelty of patents were intended 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, patents could also be registered in the name of companies.³ This peculiarity of Italian patent law enables an immediate 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 were the rules determining the cost of registering a patent and thereafter keeping it alive. These costs affected the choice of inventors as to whether and how long to protect their inventions. In Italy, the system was extremely flexible: an inventor could register a patent for a duration of their choosing, ranging from 1 to 15 years. 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, up to 150 Lire for 15 years). In addition, it was necessary to pay an annual renewal fee for keeping the patent in force, which increased over time: 40 Lire for the first three years, 65 Lire from the fourth to the sixth year, 90 Lire for the seventh up to the ninth year, 115 Lire for the tenth to the twelfth year and 140 Lire for the last three years. The *Gazzetta Ufficiale del Regno d'Italia* kept regular track of the lifetime of patents by publishing a list

of patents that had expired due to non-payment of the renewal fee. Furthermore, the law foresaw the possibility of extending the life of a patent initially registered for a shorter period. To do this, the inventor had to apply for an *attestato di prolungamento* (extension certificate). This cost 40 Lire plus all the other fees required for a normal patent of the same duration. Hence, since a *prolungamento* involved this additional cost of 40 Lire, if the inventor was sure about the prospects of their invention it was more convenient to immediately register the patent for the whole of the desired duration. However, when the prospects of the invention were uncertain, the possibility of applying for a *prolungamento* provided 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 precisely compare the costs of patenting in different countries. The renewal fee structures for the UK and Germany have been recently discussed, respectively, by Nicholas (2011c) and by Streb, Baten, and Yin (2006).⁴ If the annual fees are measured in terms of the average weekly wages of workers in the engineering sector, for example, the costs for keeping a patent alive turns out to be systematically lower in Italy compared to Germany and the UK, with the sole exception of the initial year (cf. Nuvolari and Vasta 2015, 864). The lower cost of the Italian system is also confirmed when considering the total amount of the fees paid over the patent's lifetime. It is also worth mentioning that the most expensive annual renewal fees (those to be paid in years 13, 14, and 15) were lower than the cost in year 1. For this reason, it seems very unlikely that an inventor who had been able to register a patent in the Italian system paying the costs in year 1 was later affected in their renewal behavior by credit constraints. This feature of the Italian fee structure supports the use of renewal data as an 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. Still, these inventors are not included in our sample (as without registration, we do not know about them) and consequently 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.

Nuvolari and Vasta (2015) also offer evidence of the dynamism in patent applications for the period 1861–1913, known as the Liberal Age in Italy. 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 the period, was not very different from that of a leading country of the Second Industrial Revolution such as Germany. This dynamism was coupled with the activities of some Italian inventors that were able to successfully develop “macroinventions” (Mokyr 1990). These included Ascanio Sobrero (1812–1888), an academic chemist working in Torino, who, in 1847, discovered nitroglycerine; Alessandro Cruto (1847–1908) who during the 1880s invented an extremely efficient electric light bulb that in a systematic series of experiments clearly outperformed Edison's; and Guglielmo Marconi (1874–1937), who pioneered the first successful long-distance radio transmission equipment, for which he was awarded the Nobel Prize for Physics in 1909.

Figure 21.1 provides a comprehensive comparative perspective on the “openness” of different patent systems, measured as the share of patents granted to foreign residents between 1871 and 1913. It 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,

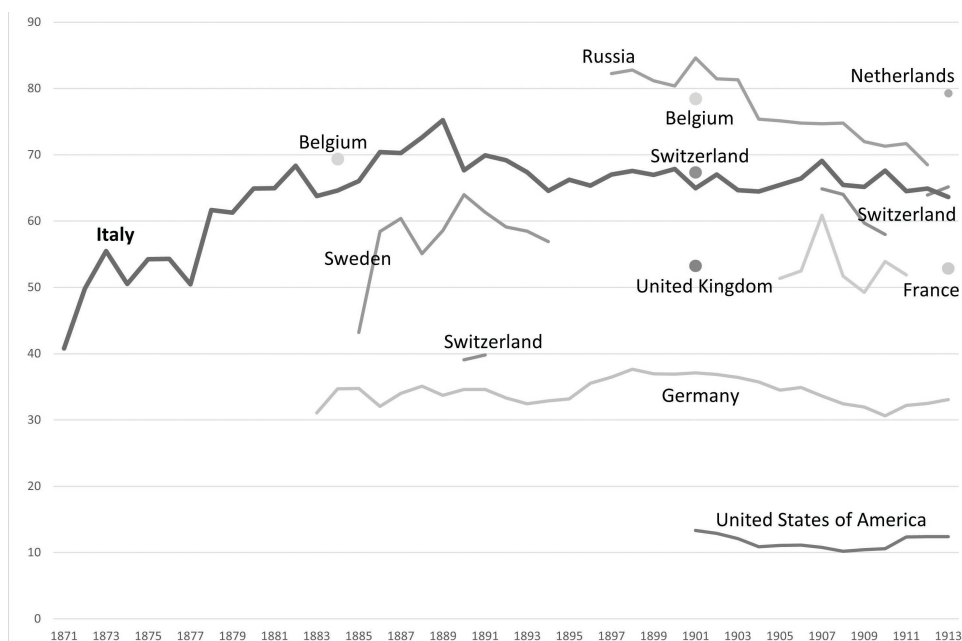


Figure 21.1 Degree of openness (share of foreign patents on total) of different patent systems, 1871–1913.

Source: Author’s own elaboration on WIPO Statistics Database (last accessed June 2017), data for Italy from MAIC (various years).

Netherlands, Sweden, and Switzerland. The significant activity of foreign inventors makes Italy a particularly interesting context to study the attitudes toward uncertainty among different (especially domestic vs. foreign) categories of inventors.

The Data

In this paper we use an updated version of the dataset on Italian patents constructed by Nuvolari and Vasta (2015) and fully described in Nuvolari and Vasta (2020). The dataset contains detailed information on all the Italian patents granted in five benchmark years: 1864–1865, 1881, 1891, 1902, and 1911 (selected in broad correspondence with the census years and providing an even coverage of the Liberal Age period of 1861–1913). 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 dataset, see Nuvolari and Vasta 2015, 2020). This updated version of the dataset contains not only the patents registered in Italy, but also the “imported” patents, that is, patents that were originally registered in a foreign country, and for which the patentee applied for the Italian registration under the protocol of the Paris Convention of 1883.⁵ “Imported” patents are available for the years 1891, 1902, and 1911, but they are particularly significant only in the last benchmark year, corresponding to 22.1% of total patents (compared to 2.9% in 1891). Speculatively, this may suggest that the Convention became (at least for Italy) effective only from the 1910s (Nuvolari and Vasta 2020).

Based on the available information, it is possible to classify patents assigned to independent inventors and those assigned to firms, and further distinguish them according to whether they are Italian or foreign. As a result, our dataset includes, for the last three benchmark years, two categories 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 that was a member of the Paris Convention, who applied for the registration of that patent in Italy.

Some characteristics of the data are worth mentioning to better frame the results of the econometric model presented in the next section. Two broad trends characterize the analyzed time period: the first is the increase in the share of firm patents or, from the alternative perspective, a decline in the share of independent inventors from 96% in 1864 to 1865 to 75.9% in 1911; correspondingly, the share of firms in the total number of patents increases from 4% in 1864 to 1865 to 24.1% in 1911. When imported and priority patents are excluded, the share of firm patents increases to 28.2% in 1911. This decline of independent invention in Italy in this historical period is common to other major countries, including the US, the UK, Japan, Spain, and Sweden (Nuvolari and Vasta 2015; Andersson and Tell 2016), and 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 companies concomitantly with the unfolding of the Second Industrial Revolution.

The second trend is that the share of firm patents in the case of foreign patents is significantly larger than the share of firm patents for domestic patents. When imported and priority patents are excluded, the 1911 share of firm patents is 31.9% in the case of foreign patents versus 14.3% in the case of domestic ones (Nuvolari and Vasta 2015). The share is even higher when imported and priority patents are considered (42.9% in 1911).

A Patent Renewal Model

In the analysis, we consider, as mentioned above, two kinds of duration. The first is what we call “ex ante” (planned) duration, that is, the number of years for which the patent was registered initially. The second is what we call “ex post” (realized) duration, that is, the number of years for which the patent was kept in force by the patentee through payment of the annual fee.

Figure 21.2 plots the distribution of the planned and realized duration of our sample of patents, by benchmark year, in terms of percentage share. The realized (ex post) duration (Figure 21.2a) confirms the notion 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 for the maximum patent duration. In contrast, the distribution of planned (ex ante) duration (Figure 21.2b) shows a modal outcome at six years. Durations of one year, three years, six years, and 15 years also appear to be chosen frequently ex ante by the inventors, with very few applications for the periods from 7 to 14 years. Looking in detail at the data, we find that the planned duration is confirmed in 24.4% of cases, whereas more often the patent is abandoned earlier than its planned duration (57.3% of patents). In 18.3% of cases, the patent is extended beyond the originally planned duration. The differences between the two distributions of Figure 21.2a and 21.2b, in combination with the variety of the patent trajectories, suggest that our patent sample provide an insightful perspective on the inventors’ strategies under uncertainty.

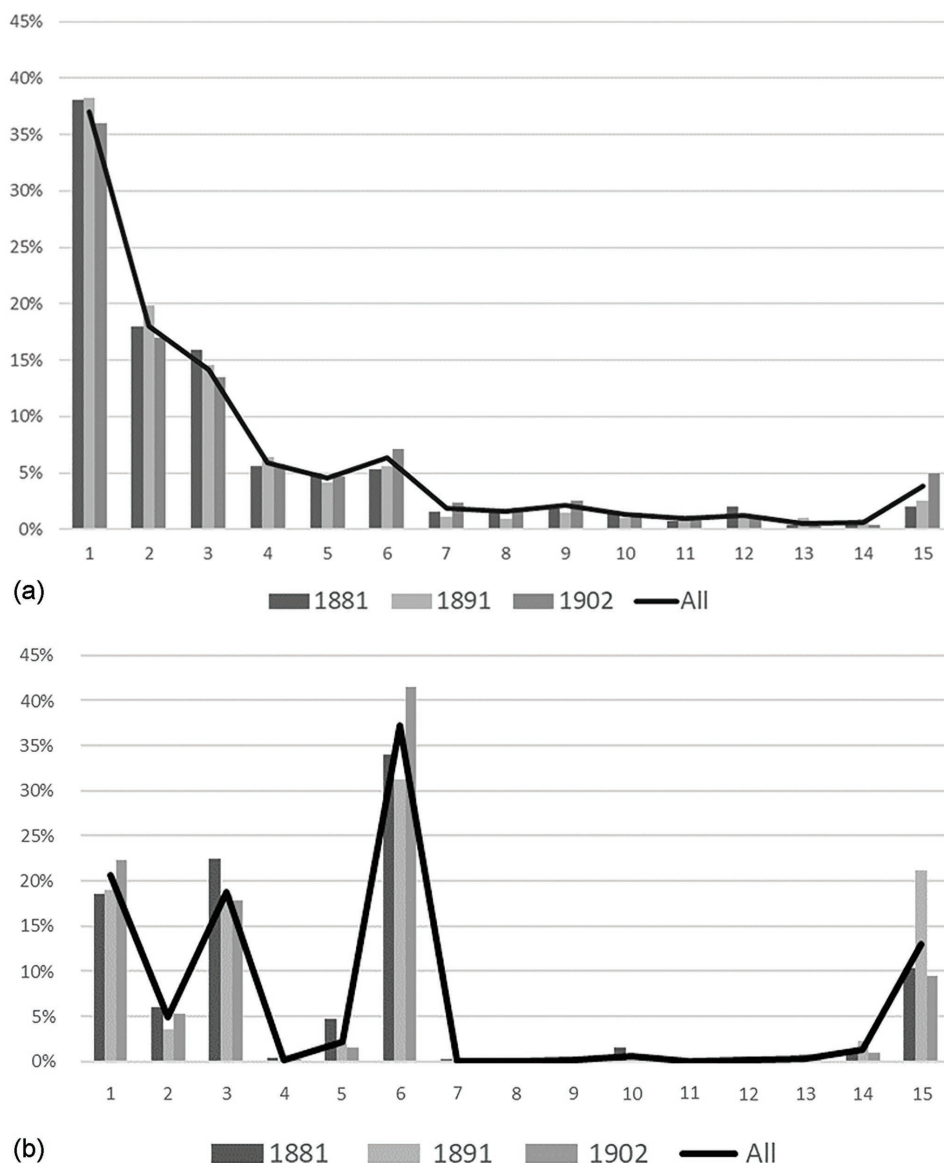


Figure 21.2 Planned (ex ante) and realized (ex post) durations. (a) Realized duration, share. (b) Planned duration, share.

Source: Author creation

In more detail, Table 21.1 compares the average value of the two types of duration (in years), while also distinguishing between patents of different types. Table 21.1 shows that ex post duration is on average lower than ex ante duration, so that a non-negligible share of inventors initially overestimated patent duration (value). Firm patents are characterized by longer durations than the patents of independent inventors and foreign patents are characterized by longer durations than Italian ones. Also, patents in high-tech sectors have a

Table 21.1 Average patent duration for benchmark years (in years)

	1864–1865	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
Hi-tech	6.1	6.0	7.3	5.7	6.0
Low-tech	6.5	4.8	6.1	4.6	4.2
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	
Hi-tech		3.8	3.7	4.2	
Low-tech		3.0	3.0	3.4	
Imported and priority patents			5.9	5.1	

Source: Nuvolari and Vasta (2020) and our computation on the dataset.

longer duration than those in low-tech ones. Finally, the patents with the longest duration are usually those registered under the Paris Convention. These patterns apply for both ex ante and ex post durations and for each benchmark year.

We estimate the determinants of the value of patents based on the renewal behavior of patentees, that is, the choice of keeping a patent “alive” or “aborting” it by not paying the renewal fees, using an econometric model. In the case of ex ante duration, it is reasonable to assume that applicants for inventions perceived as most valuable at registration will apply to register the patent for a longer duration. Analogous reasoning leads us to claim that also in the case of renewal (ex post) behavior, patentees are acting to an extent as rational/profit-motivated agents, meaning that at each moment in time, patentees assess the (potential) revenues arising from the patent and compare them with the costs of the renewal fee. This means that, as time goes by, only the most valuable patents are kept in force. The difference between the two distributions allows us to assess patentee attitudes toward uncertainty.

The renewal behavior of patentees is depicted in Figure 21.3a–d that compares observed ex post renewal rates with the initial ex ante durations. The figure is constructed by showing patent duration in years on the horizontal axis and the share of patents that are kept alive for any given duration on the vertical axis. In terms of ex ante duration (dotted lines), as we have mentioned, one can assume that the patents perceived as most valuable will be registered for a longer period. The diagrams show that ex post duration is on average lower than ex ante duration, suggesting that a non-negligible share of inventors initially overestimated the value of their inventions.

Remarkably, in terms of ex post duration, in the period 1878–1914 patentees using the Italian system exhibited a renewal behavior very similar to that of German patentees (Streb, Baten, and Yin 2006). The study found that in the period 1887–1907, the share of patents

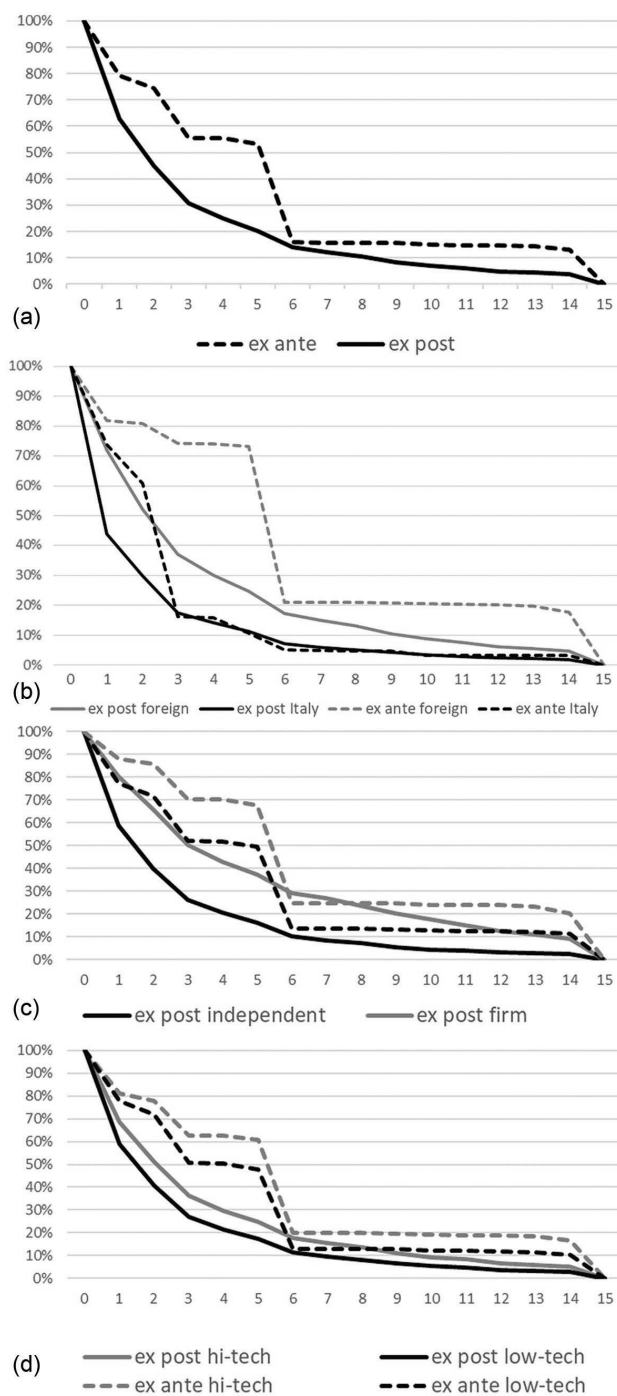


Figure 21.3 Observed renewal rates and ex ante duration, 1881–1902. (a) All patents. (b) By nationality. (c) By type of patentees. (d) By technological intensity.

Source: Author creation.

renewed for ten years or more ranged from 8% to 11% of the total. In the Italian case, we have a corresponding share of 8.4%. The renewal behavior of British patentees in the second half of the nineteenth century seems characterized by a similar pattern, with about 10% of patents kept in force for a duration of ten years or more (Nicholas 2011c, 327). Fascinatingly, these results suggest that nineteenth-century patentees adopted similar rules of thumb for assessing the value of patents. Note also that Table 21.1 shows plausible patterns in terms of a rational behavior of patentees. If we assume that “foreign,” “firm,” and “high-tech” patents will typically be more “valuable,” we correspondingly find longer durations.

Following Schankerman and Pakes (1986), we estimate the value of patents by considering the cost structure of the patent system and the renewal behavior of the patentees. Then, the estimated model is employed to compute ex ante values on the basis of ex ante planned durations. Let L be the patent length, $L = 1, \dots, 15$ years where the initial fee to be paid at the moment of the application was equal to $10 \cdot L$ Lire. Then, for each year of patent duration, the patentee is required to pay a fee to keep the patent in force, and this fee increases with patent length (Nuvolari and Vasta, 2020). As previously mentioned, the fee (in Italian Lire) is 40 for years 1–3, 65 for years 4–6, 90 for years 7–9, 115 for years 10–12, and 140 for the last three years (13–15). Example: a patentee who decides to take a patent for six years initially pays a registration fee of 60 Lire. Then, the renewal decision has to be made each year, with the patentee paying 40 Lire annually for the first three years and then 65 Lire annually from the fourth to the sixth year. We indicate with C_t the yearly fee at the time t (for example when $t = 6$, $C_t = 65$ Lire).

The estimate of the determinants of patent value are obtained on the basis of ex post durations using the approach developed by Bessen (2008).

Let $r_i(t)$ be the (unobserved) annual flow of rents for the patent i in year t . The annual flow of rents may be assumed to comprise the returns from directly commercializing the product covered by the patent, licensing it, but also any other economic returns arising from the strategic use of the patent (Penin 2012). We assume that the profit stream depreciates at a constant rate d , so that $r_i(t) = r_i(0) e^{-dt}$. In each period, the patentee has to decide whether to pay the patent fee to keep the patent in force for one more year or to give up. The patentee will renew the patent at time t if the present value of profits in the additional year exceeds the (observed) renewal fee, C_t . The present value of profits from t to $t+1$, can be computed as:

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

With $z_t = e^{-(d+s)t} \frac{1 - e^{-(d+s)}}{d+s}$, with s the discount rate. We follow the literature and set $s = 10\%$.⁶ In other words, at time t , the patent fee will be paid to keep the patent in force for an additional year if $r_i(0) z_t \geq C_t$, or:

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

In this context, an estimate of the profit flow can be obtained by exploiting the yearly decision related to patent renewal. As an example, a patent that is renewed up to time 6, would have a value $r_i(0)$ such that $C_7 / z_7 \geq r_i(0) \geq C_6 / z_6$. Note that no upper bound would be

available to the estimated profit flows for those patents that are renewed at all time periods (up to year 15).

To characterize the profit flow as a function of observable characteristics of the patent, we consider the following equation:

$$\ln \cdot \eta_i(0) = \mathbf{x}_i' \boldsymbol{\beta} + u_i$$

The model parameters are estimated using a maximum likelihood approach, under the assumption that u_i is normally distributed with mean zero and standard deviation σ . The estimated parameters will allow us to characterize (estimate) patent value as a function of patent characteristics.⁷

The results of the estimated model are shown in Table 21.2. In Model 1, a dummy for high-tech industry is included among the regressors,⁸ whereas in Model 2 the dummy variable that identifies high-tech industries is replaced by a full set of industry-specific dummy variables.

Results are broadly consistent across the two model specifications and confirm the descriptive evidence provided above (Table 21.1 and Figure 21.2). The value of foreign patents is higher with respect to Italian patents, as well as patents in the high-tech sector (as opposed to low-tech patents), patents issued to companies (as opposed to patents registered by independent inventors), and the patents applied for under the Paris Convention (as opposed to domestic patents). As for the dynamics of value over time, patents granted in the year 1891 have a lower value compared to patents granted in the year 1902 (no difference emerges to patents granted in the year 1881). This could perhaps be related to the severe slump of the Italian economy in 1891, which fell in the middle of the period (1889–1994) that has been eloquently termed as the “darkest years of the economy of new Kingdom [of Italy]” (Luzzatto 1968).

The patent renewal model is further explored in Models three and seven, in which we estimate the value equation considering selected subsamples of the set of patents. In particular, Model three only includes patents granted to independent inventors; Model four is estimated on the set of patents granted to firms; foreign and Italian patents are considered in Model five and six, respectively; and Model seven only takes into account high-tech patents.⁹ The estimated value of σ is coherent across the different subsamples; whereas the value of the parameter d seems to be different across the subsample, ranging from a value of 0.3451 (95% confidence interval: 0.2124; 0.4778) that characterizes firm patents to a value of 0.5377 (95% confidence interval: 0.4129; 0.6627) for patents assigned to independent inventors. To explore this pattern, in Model eight and Model nine the parameter d is written as a function of the patent characteristics. As the parameter d (depreciation rate) is bounded in the 0–1 interval, the logistic function is used in the maximization process.¹⁰ This parametrization is used also in Model eight and nine. Being a monotonic transformation, the sign of the coefficients is directly linked to the direction of the effect (i.e. a positive coefficient indicates a positive effect of the associated variable). However, in order to enhance the readability of the results, Table 21.2 also shows, among squared brackets, the estimated value of the depreciation rate, d , for each patent type. The estimated values of d are coherent with the value of the depreciation rate estimated on the specific subsamples. The model confirms that foreign patents have a higher depreciation rate with respect to Italian patents. This might be due to a lack of knowledge of the local context, resulting in a lesser ability to

Table 21.2 Estimates of the ex post patent value model (discount rate = 10%)

	Model 1	Model 2	Model 3 (independent inventors)	Model 4 (firm)	Model 5 (Italian)	Model 6 (foreign)	Model 7 (high-tech)	Model 8	Model 9	Model 10 ($d = 15\%$)
Foreign	1.6859*** (0.1547)	1.6475*** (0.1527)	1.8520*** (0.1947)	1.1642*** (0.2798)	--	--	1.8927*** (0.2397)	1.8994*** (0.1878)	1.8738*** (0.1851)	0.9017*** (0.0549)
Independent	-1.9419*** (0.1747)	-1.8961*** (0.1718)	--	--	-1.9148*** (0.3192)	-1.9057*** (0.2052)	-2.1734*** (0.2574)	-1.0988*** (0.1732)	-1.0475*** (0.1707)	-1.0324*** (0.0599)
High-Tech	0.5657*** (0.1005)	--	0.3877*** (0.1129)	1.1156*** (0.2343)	0.1166 (0.1632)	0.7661*** (0.1283)	--	0.4015*** (0.1304)	--	0.3015*** (0.0493)
Imported and priority	0.8731*** (0.2356)	0.8347*** (0.2328)	0.9806*** (0.3011)	0.6439* (0.3815)	3.0307*** (1.7057)	0.8343*** (0.2474)	0.6765** (0.3129)	1.0883*** (0.3485)	1.0405*** (0.3464)	0.4681*** (0.1213)
Year 1881	-0.1052 (0.1296)	-0.0680 (0.1292)	-0.1284 (0.1469)	-0.1017 (0.3037)	0.0996 (0.2089)	-0.2326 (0.1627)	-0.1811 (0.1971)	0.3080* (0.1813)	0.3484* (0.1812)	-0.0547 (0.0688)
Year 1891	-0.3658*** (0.1077)	-0.3609*** (0.1074)	-0.3627*** (0.1255)	-0.4934** (0.2268)	0.2938 (0.1842)	-0.6741*** (0.1385)	-0.3884** (0.1540)	-0.0559 (0.1449)	-0.0339 (0.1443)	-0.1964*** (0.0557)
Constant	6.0051*** (0.2249)	5.7952*** (0.2985)	4.2922*** (0.1382)	5.3906*** (0.3410)	5.7612 (0.3670)	7.8151*** (0.3831)	6.3463*** (0.3352)	5.1336*** (0.2230)	4.8822*** (0.2997)	4.8026*** (0.0746)
s	3.1957*** (0.2237)	3.1560*** (0.2205)	3.2968*** (0.2827)	3.0527*** (0.3854)	2.8689*** (0.3633)	3.3016*** (0.2759)	2.9844*** (0.2929)	3.2192*** (0.2240)	3.1782*** (0.2201)	1.6994*** (0.0223)
d	0.4692*** (0.0468)	0.4677*** (0.0466)	0.5377*** (0.0636)	0.3451*** (0.0677)	0.3861*** (0.0744)	0.4981*** (0.0583)	0.4106*** (0.0596)			0.1500 (imposed)
								$d_i = \exp(x_i'g)/(1 + \exp(x_i'g))$		
Foreign								0.1870** (0.0897)	0.2035** (0.0894)	
Independent								[0.3667]	[0.3687]	
								0.5901*** (0.0861)	0.5945*** (0.0858)	
High-Tech								[0.4642]	[0.4633]	
								-0.1266* (0.0745)	-0.1601** (0.0746)	
								[0.2973]	[0.2887]	

(Continued)

Table 21.2 (Continued)

	<i>Model 1</i>	<i>Model 2</i>	<i>Model 3</i> <i>(independent</i> <i>inventors)</i>	<i>Model 4</i> <i>(firm)</i>	<i>Model 5</i> <i>(Italian)</i>	<i>Model 6</i> <i>(foreign)</i>	<i>Model 7</i> <i>(high-tech)</i>	<i>Model 8</i>	<i>Model 9</i>	<i>Model 10</i> <i>(d = 15%)</i>
Imported and priority								0.1460 (0.1634) [0.3572]	0.1394 (0.1635) [0.3539]	
Year 2 (1881)								0.3571*** (0.1090) [0.4070]	0.3547* (0.1084) [0.4045]	
Year 3 (1891)								0.2658*** (0.0853) [0.3852]	0.2781*** (0.0851) [0.3862]	
Constant								-0.7334*** (0.1922) [0.3244]	-0.7415*** (0.1917) [0.3227]	
Industry Dummies	No	Yes	No	No	No	No	No	No	Yes	No
N	5,769	5,769	4,642	1,127	1,849	3,920	2,391	5,796	5,769	5,769
Log lik.	-11,838.3	-11,790.36	-8994.06	-2804.87	-2946.44	-8875.77	-5204.29	-11794.99	-11744.42	-11916.76

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

use the patent to prevent imitation. Furthermore, a higher d is also observed for independent inventors, who might have less resources to exploit the full potential of the patent when compared to companies. High-tech patents, which were probably more difficult to imitate, are characterized by a lower depreciation rate (even if the difference is different from zero only at a 10% level of significance), whereas the change in the value of the depreciation rate for imported and priority patents is not statistically different from zero. Overall, the depreciation rate that emerges from our estimates is higher with respect to the value that is usually found in the literature, which is about 15% (e.g., Pakes 1984; Pakes and Schankerman 1986; Sullivan 1994; Lanjouw 1998; Bessen 2008). Note that, with few exceptions (see Sullivan 1994), these estimates are based on patents applied for in more recent time periods. However, this may raise concerns related to the reliability of our estimates. To check the robustness of our results, Model ten is estimated by constraining $d = 15\%$. The magnitude of the estimated coefficients changes, but relevant patterns are coherent with the previous specifications, and results confirm the higher value of foreign, high-tech, and imported and priority patents, as well as the lower value of the patents granted to independent inventors.

The estimated coefficients in the patent renewal model are then exploited to obtain an estimate of the net present value of patents, using Monte Carlo simulation methods as in Bessen (2008).¹¹ 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. In the latter case, we simulate the value of the patent that would be estimated if the initial decision on the patent duration would be confirmed in each period. As a result, we are able to compute an estimate of the patentee's evaluation of each patent at two different points in time: when the patent is first applied for, and after some time, when the value of the innovation is "revealed." The distribution of simulated patent values is analyzed in the next section.

Uncertainty, Expectations, and Patent Values

The estimation of the monetary values of each single patent at two different moments of its life can provide insight into the changing perceptions of inventors and, more generally, their attitude toward uncertainty. Intuitively, an over-optimistic inventor will be inclined to attribute a significantly larger value to their patent at the moment of registration than the actual cumulative returns over the entire patent life. By contrast, an over-pessimistic inventor will perceive the initial value of the patent to be significantly lower than the actual cumulative returns (on beliefs under uncertainty see Schweighofer-Kodritsch, Chapter 4 in this volume).

Table 21.3 Distribution of estimated ex ante and ex post values by patent characteristics

	<i>All patents</i>	<i>Foreign patents</i>	<i>Independent patents</i>	<i>High-tech patents</i>	<i>Imported and priority patents</i>
Ex post duration					
Mean	2.6	3.0	2.1	3.0	4.3
Median	1.0	2.0	1.0	2.0	3.0
Ex-ante duration					
Mean	4.5	5.7	4.2	5.2	6.6
Median	5.0	5.0	4.0	5.0	5.0

(Continued)

Table 21.3 (Continued)

	<i>All patents</i>	<i>Foreign patents</i>	<i>Independent patents</i>	<i>High-tech patents</i>	<i>Imported and priority patents</i>
Estimated ex post value, Model 1					
1st quartile	17.65	29.91	14.85	23.34	220.59
Median	222.73	452.91	216.88	440.90	1,093.99
3rd quartile	1,180.55	2,047.603	1,069.66	2,061.01	4,277.32
Mean	128,104.1	162,753.9	74,48	184,603.8	197,696.2
Estimated ex post value, Model 8					
1st quartile	19.43	32.46	17.16	24.87	264.48
Median	272.56	366.66	251.53	301.51	1,244.39
3rd quartile	1,663.46	2,909.72	1,166.71	2,237.63	7,379.72
Mean	152,687.30	204,156.65	167,074.33	158,885.74	218,496.47
Estimated ex post value, Model 10					
1st quartile	22.89	30.28	20.88	26.57	84.94
Median	85.32	130.85	84.34	128.37	225.32
3rd quartile	233.06	296.87	223.15	297.62	453.38
Mean	772.43	955.77	521.36	1,032.33	1,316.05
Estimated ex ante value, Model 1					
1st quartile	226.66	530.30	215.41	456.64	3,816.20
Median	3,698.43	3978.39	1,993.20	3,865.43	4,091.84
3rd quartile	4,167.38	4344.09	4116.31	4,290.34	378,971.7
Mean	386,750.4	532605.3	307,425	517,868.8	308,665.9
Estimated ex-ante value, Model 8					
1st quartile	258.33	813	215.27	364.86	2,529.04
Median	1,993.87	4,951.35	3,042.74	3,054.91	6,720.44
3rd quartile	7,189.40	9,070.44	7,196.92	7,308.74	159,913.69
Mean	835,711.26	1,162,557.88	983,018.91	779,759.80	610,381.67
Estimated ex ante value, Model 10					
1st quartile	86	146.08	84.1	131.4	422.1
Median	412.8	432.7	293.52	424.9	441.4
3rd quartile	445.69	457.83	441.94	454.15	4,526.16
Mean	1,913.05	2,581.64	1,609.43	2,443.85	2,203.61
Difference, Model 1					
Median	441.95	3,066.71	441.31	468.14	2,269.24
Mean	258,636.25	369,836.96	232,935.05	333,251.35	110,965.79
Difference, Model 8					
Median	416.62	2,455.37	431.59	421.74	1,892.25
Mean	683,022.68	958,399.56	815,943.20	620,872.52	391,883.01
Difference, Model 10					
Median	114.62	220.2	115.27	117.08	160.76
Mean	1,140.62	1,625.87	1,088.07	1,411.52	887.56
N	5,769	3,920	4,642	2,391	223

Table 21.3 compares the distribution of ex ante and ex post values for different groups of patents, as estimated using Model one, eight, and ten, respectively. The results of the three models are very similar, so that we focus on Model one and the following analysis will only consider estimated values obtained based on estimated coefficients in Model one.

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, under this calculation the most valuable profile, considering ex post value, is that of the “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 large difference between the mean and the median estimated values can be explained in terms of the skewed distribution of patent value and can be ascribed to the contribution of the most valuable patents when computing the mean. Indeed, patents that are renewed over the entire life (up to year 15) would be characterized by a value that satisfies the condition $r_i(0) \geq C_{15}/z_{15}$. The inability to “observe” an upper bound to patent value is one of the main criticisms of patent renewal analysis. However, there is evidence that extrapolation of patent value does not actually result in a major bias to the estimated value of patents (Bessen 2009a). Moreover, estimates based on the log-normal distribution fits the exogenous measure of value quite well (Scherer and Harhoff 2000).

For each patent, we also considered the difference among the two estimated values (ex ante and ex post). The difference tends to be positive (as expected, as more than 50% of patents are abandoned earlier than their planned duration), with differences across the different groups.

Looking at patent characteristics, larger differences emerge for foreign patents, both in the average and median values. High-tech patents exhibit the larger mean difference, whereas imported and priority patents are characterized by a large difference in the median value, but are 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. Digging further into the analysis of the difference between ex ante and ex post value of the patents is interesting as this analysis can reveal the attitude of the different types of inventors in the assessment of the value of their patents.

To better understand the relationship between characteristics of the patent and difference (D) between ex ante and ex post values, we consider five categories: (1) large negative difference, i.e. the value of the innovation is largely understated at application (“very pessimistic expectations”): $D < P25$, with P25 the first quartile (25th percentile) of the distribution of negative values; (2) negative difference, i.e. the value of the innovation is understated at application (“pessimistic expectations”): $P25 \leq D < 0$; (3) no difference, i.e. the value of the innovation is well assessed at application: $D = 0$; (4) positive difference, i.e. the value of the innovation is overstated at application: $0 < D < P75$ with P75 the third quartile (75th percentile) of the distribution of positive values (“optimistic expectations”); (5) large positive difference, i.e. the value of the innovation is largely overstated at application (“very optimistic expectations”): $D \geq P75$. The distribution of the observations in the five categories is reported in Table 21.4. The number of observations is the same for all the three models considered, since the categories are defined on the basis of the quartile of the difference in the model-specific estimated value. Table 21.4 also reports the percentage of concordances in the classification of the differences across the three models used for simulating patent values, showing that there is large concordance between the categories defined based on Model one and Model ten, whereas some minor

Table 21.4 Distribution of the differences of the ex ante and the ex post estimated values for different models

	<i>All models n obs. (%)</i>	<i>Concordance among the classifications</i>		
		<i>Models one & eight (%)</i>	<i>Models one & ten (%)</i>	<i>Models eight & ten (%)</i>
large neg. difference	263 (4.56%)	87.45	100.00	87.45
negative difference	791 (13.71%)	95.83	100.00	95.83
no difference	1,409 (24.42%)	100.00	100.00	100.00
positive difference	2,480 (42.99%)	98.95	99.72	98.95
large positive difference	826 (14.32%)	96.85	99.15	96.85

differences are detected when comparing the classifications provided by Model eight. As the results of the three models are very similar, the following analysis will only consider estimated values obtained on the basis of estimated coefficients in Model one.

In Table 21.5 we present the differences between ex ante and ex post values according to the duration decision of the patentee at the moment of the application and at the point where the patentee decides not to renew the patent. This allows us to map the attitudes of the patentee toward uncertainty on the basis of the final economic outcome of the patents and to introduce an empirical characterization of the attitudes of inventors toward uncertainty. In the rows of the table we consider the ex ante duration of the patents, while the columns represent the ex post duration. The value of each cell is the average difference (in thousands of Italian lire) between the initial expected value of the patent and its actual value at the end of its life (due either to non-renewal or to expiry). Of course, an average value of zero is reported for cells along the main diagonal where the initial and final duration are the same. This group of patents is the one for which the evaluation by the patentee did not change during the life of the patent. In this case, we can assume that these patentees have accurately forecast the value of their patents.

In the upper triangle of the table, above the diagonal, we find patents whose value was underestimated at application. We distinguish between “pessimistic” (negative values in italic) and “very pessimistic” (negative values in bold) patentees. In the lower triangle of the table, there are “optimistic” (positive values in italic) and “very optimistic” (positive values in bold) patentees. Table 21.5 shows that it is crucial to focus on differences in values rather than simply on the differences in patent duration in year. For example, when looking at the values, a patentee taking a patent with initial duration of six years and dropping it at five years is classified as “optimistic” (average difference in value being 2.07 thousand Italian lire), whereas a patentee who takes a patent for ten years and drops it at nine years is classified as “very optimistic” (30.67) even if the difference in the duration is the same in both cases.

In Table 21.6, we show the share of patents in each behavioral category of our empirical characterization (from “very pessimistic” to “very optimistic”), distinguishing different type of patents (foreign and Italian patents, patents by independent inventors and by firms, high-tech and low-tech patents, imported and priority versus all the other patents). The share for the full sample is reported in the first column for the sake of comparison. The Pearson chi-squared test reported at the bottom of the table show that the distribution

Table 21.5 Average values of differences between ex ante and ex post values by patent durations (000 Italian liras)

		<i>Ex post duration</i>														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>Ex ante duration</i>	1	0.00	-0.20	-0.47	-1.08	-1.92	-3.97	-8.30	-14.48	-29.33	-58.72	-104.40	-196.67	-399.60	-696.20	-3,172.12
	2	0.21	0.00	-0.27	-0.88	-1.71	-3.85	-8.07	-14.55			-97.69				-2,208.59
	3	0.47	0.27	0.00	-0.61	-1.44	-3.51	-7.76	-14.37	-28.39	-56.69	-101.90	-194.12	-397.94	-705.22	-2,912.94
	4	1.10	0.87		0.00		-3.00									
	5	1.92	1.72	1.44	0.84	0.00	-2.11	-6.35		-26.98	-56.60	-98.42			-660.51	-2,048.73
	6	3.98	3.79	3.51	2.92	2.07	0.00	-4.36	-10.81	-25.06	-54.90	-99.87	-193.85	-389.93	-709.87	-3,087.10
	7				7.54	6.34		0.00								
	8	15.07			13.11		10.82		0.00							
	9	28.59	29.33					17.96		0.00						
	10	58.74	58.25	59.21	56.27	59.17	54.03		44.34	30.67	0.00					-2,777.66
	11		97.81									0.00				-2,391.38
	12		199.26	200.25			189.07			164.75	138.87		0.00			
	13	392.00	390.97	373.78	388.86					383.14				0.00		
	14	685.48	690.53	701.66	689.55	682.03	673.40	652.77	671.68	638.55	625.17	592.27			0.00	-2,668.57
	15	2,759.89	2,795.98	2,806.90	2,835.35	2,878.17	3,194.57	2,813.92	2,932.27	2,961.22	2,643.71	3,066.18	2,809.54	2,230.63	1,986.69	0.00

Table 21.6 Distribution of patentee attitudes toward uncertainty across different categories of patents (%)

	<i>By Nationality</i>			<i>By patentee type</i>		<i>By tech. intensity</i>		<i>By application type</i>	
	<i>Total</i>	<i>Italian</i>	<i>Foreign</i>	<i>Firm</i>	<i>Independent</i>	<i>Low-Tech</i>	<i>High-Tech</i>	<i>Domestic</i>	<i>Imp. & Priority</i>
Very pessimistic	4.56	2.81	5.38	11.09	2.97	3.61	5.90	4.45	7.17
Pessimistic	13.71	15.14	13.04	15.35	13.31	13.56	13.93	13.76	12.56
Consistent	24.42	31.75	20.97	20.05	25.48	25.43	23.00	24.36	26.01
Optimistic	42.99	45.81	41.66	33.63	45.26	45.26	39.77	43.42	32.29
Very optimistic	14.32	4.49	18.95	19.88	12.97	12.14	17.40	14.01	21.97
Pearson test	—	270.67		203.56		56.44		19.62	
(p-value)		(<0.001)		(<0.001)		(<0.001)		(<0.001)	

Note: differences larger than 20% with respect to total are emphasized in bold.

across the behavioral categories displays significant differences according to specific patent characteristics.

In Table 21.6 we have highlighted (in bold) the values higher than 20% of the total to pinpoint the major differences across patent types. The results show that foreign patentees are more likely to be “very optimistic” compared to Italian patentees, who are better forecasters. This is likely to be related to the better knowledge of the internal market of the Italian patentees, while the “very optimistic” behavior of the foreign patentees is perhaps due to the combined effect of a scanty knowledge of the Italian market and of a larger availability of resources to cover the patent costs. Interestingly enough, firm patentees are overrepresented in both the “very pessimistic” (+243%) and the “very optimistic” categories (+139%) than the independent ones. Concerning the “very optimistic” behavior this reflects the prominent role of foreign companies, which amount to almost 80% of the total in this category. The finding about the very high share of the “very pessimistic” patentees is more difficult to interpret since it concerns both domestic and foreign companies. We speculate that this may be related to the nature of firm innovations, which were characterized by a higher degree of novelty, prompting the patentees to have initially a more cautious attitude, taking a patent for a short period and gradually exploring its potential. As for the technological characteristics of the patent, as expected we find that the high-tech patents are characterized by greater uncertainty; this makes their value more difficult to predict since there is a larger share of both “very pessimistic” and “very optimistic” patentees in comparison to the low-tech ones. Although the number of imported and priority patents is not very high, it is interesting to note that the patentees of these inventions are systematically characterized by an overrepresentation in both the “very pessimistic” and “very optimistic” categories. Considering that all these patents have already been tested in another market, one would have expected a larger fraction of accurate forecasters in this category of patentees. Instead, since this is not the case, our finding suggests that, in our case, technological transfer was surrounded by a high degree of uncertainty.

Conclusion

In the field of innovation studies, there has been a strong emphasis on the uncertainty which surrounds all phases of the innovation process. However, our knowledge of the implications of this uncertainty for the behavior of inventors has remained very limited. This is essentially due to the lack of systematic data that can adequately capture the changing perceptions of inventors about the possible returns of their innovations during the different phases of the innovation process. As a result, data on the expectations and profit prospects of innovations are available only by means of case studies or small-scale samples. In this paper, by exploiting a characteristic of nineteenth-century Italian legislation, we have been able to study the expectations and behaviors of inventors in different moments in time and to provide an empirical characterization of the heterogeneity in the attitudes of different type of inventors toward uncertainty. These results, if confirmed in other contexts, could represent new important stylized facts on the nature of innovation processes.

The analysis is not without limitations, mainly in relation to the econometric specification. The empirical analysis relies on a fully parametrized model that assumes a log-normal distribution of the value of patents. However, the log-normal distribution seems to be well-suited for the analysis of these data. Furthermore, the estimates of the long tail of patent value are constrained by the inability to observe an upper bound to the distribution of

returns. In this respect, it is reassuring that the model fits the empirical data to a meaningful extent, and our characterization of patentee behavior is only marginally affected by the censoring problems.

A further development of this research agenda would be to combine estimates of patent values based on renewal data, as in this paper, with other measures of patent values such as those constructed using data on actual sales of patents.

Notes

- 1 Schnaars and Berenson (1986) examine forecasts of market growth of 90 major technological innovations published in the US business press in the period 1960–1979: 50 percent of these turned out to be widely mistaken. Reviewing this literature, 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. See also the discussion in Mansfield et al. (1971, 47–63) who also argued that, notwithstanding the adoption of quantitative techniques of risk assessment, “intuition and gut reaction” played a very important role in R&D decision making.
- 2 For a thorough criticism of the representation of innovation processes in the patent race and the endogenous growth literature, see Dosi and Nelson (2010).
- 3 Article 27 of the *Regolamento* (regulation) of the 1864 law stated explicitly that the application for a patent could be submitted both by individuals and by corporations or other organizations.
- 4 The maximum patent duration of the German system was 15 years, whereas in the British system the maximum patent duration was 14 years.
- 5 For an historical account of the Paris Convention, see the classic work by Penrose (1951).
- 6 See e.g., Bessen (2008). Note that, by changing the value of the discount rates, estimated effects do not change.
- 7 Refer to Bessen (2008) for additional details on the estimation procedure.
- 8 The classification is drawn from Nuvolari and Vasta (2015) who defined as high technology sectors those that, by the standards of the time considered, can be regarded as characterized by a certain degree of technological sophistication. This comprises both the emerging industries of the Second Industrial Revolution (such as steel, electricity, and chemicals), but also, in order to take into account Italy’s status as a latecomer country, some breakthrough technologies of the First Industrial Revolution such as steam, machinery, and machine tools. Accordingly, the sectors classified as high-tech are chemicals, electricity, machine tools, machinery, components and metalworking, steam engines, and weapons. In contrast, the low-tech sectors in our database are agriculture, construction and construction materials, food and beverages, mining, paper and printing, various instruments, textiles, apparel and leather, transport, and other manufacturing sectors.
- 9 A separate model for “imported and priority” patents is not estimated due to the small number of observations that characterize this group (223 patents).
- 10 We exploit the invariance property of the maximum likelihood estimator. Estimates of d are reported in Table 21.5, Models 1–7. Standard errors are computed using the delta method.
- 11 On the basis of the estimated values of β , σ and d we first determine 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 ($r_i(0)$) is calculated. The average of 20 Monte Carlo iterations is considered for each patent. Estimates obtained in Model 1, Model 8, and Model 10 are used for providing the value of patents.

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