Profiling independent inventors in Italy

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Abstract

Although the total number of innovations developed by independent inventors is currently smaller than the output of organizations' R&D departments, the literature indicates that they are relevant contributors to technological advancements. Empirical studies investigating the individuals who retain the IPRs of the patented inventions are relatively few. In this work I analyze 28k Italian inventors who filed at least one patent in the years 1994-2017 at the Italian Patent Office (UIBM) as independent, i.e., they are also applicant/assignee. In these cases, UIBM reports the national tax ID which identifies gender and birth date. I have reconstructed the full patent portfolio of each inventor using their names and filtered the sample with criteria that reduce the presence of false positive or negative matches. The analyses confirm the presence of a female underrepresentation (although declining), and gender differences in mean age and age distribution at the patenting debut. Age at first patent is increasing, in particular for women in the age group 45-64. The dynamic process of being an independent or organizational inventor is then considered. The group of always independent inventors is characterized by a higher presence of women, one-shot inventors, older mean debut age than dependent ones. The survival analysis on the time to become dependent suggests the presence on average of an advantage for men, corresponding for a woman to a debut age before 35 years or a portfolio of circa 13 patents, an extremely rare case.

Keywords

Independent inventors; gender studies; age; innovation; Italy

1 Introduction

Innovation is fundamental for economic and social growth and its generation is an increasingly complex task (Bloom et al., 2020). Innovating is often referred to as a combinatorial process of mixing existing pieces of knowledge (Fleming, 2001) and involving organization capabilities, technical and human capital, with the latter being of primary importance (Bhaskarabhatla et al., 2021). Scientific advancements are harder and harder to reach, hence larger and larger teams of researchers are required to cope with the complexity and specialization of scientific activities (Hunter and Leahey, 2008; Wuchty et al., 2007).

This shift to the dominance of large team started at the beginning of the 20th Century and per capita inventiveness has been decreasing since then (Lamoreaux and Sokoloff, 2011; Larivière et al., 2015). In this framework, the contribution to innovation of single minds is quantitatively small when compared to the output of organizations' R&D activities. However, the role of independent inventors is not marginal: their inventions are commercialized, support the development of technological trajectories, and provide grounds for new ventures (Amesse et al., 1991; Daemmrich, 2021; Dahlin et al., 2004; Lamoreaux and Sokoloff, 2011; Spear, 2006). In some cases, independent inventors have a higher technological impact than those employed in companies (Lettl et al., 2009). In addition to the anecdotal evidence of the "garage" geniuses and the theorized Schumpeterian entrepreneurial innovator, Dahlin (2021) provides the additional evidence that the advancements of individual innovators can be complementary to those produced in large laboratories and actually contribute to science and technology. Even with limited or no initial access to large resources, independent inventors (e.g., startuppers, hobbyists, practitioners) are found to significantly impact in innovative activities.

The characteristics of the independent inventors have been studied with limitations due to data availability, especially in large empirical settings and with respect to demographics which could provide evidence to the systematic exclusion of some groups from the innovation activities (Sarada et al., 2019). In addition, previous literature has not focused on the individual-level dynamics of changing the status from independent to dependent, and vice versa. This study focuses on independent inventors, i.e., individuals with patents filed with no organization as assignee, in Italy in the years 1994-2017, provides details on demographics and a typology of their characteristics. Gender and age will be examined with respect to their career development. The results are expected to contribute to both the literature that observes the presence of a significant gender gap in patenting and STEM areas in general (e.g.,: Lai, 2020; Lax Martinez et al., 2016) and the one that investigates the productivity of inventors across their career (Kaltenberg et al., 2023). The empirical approach leverages on the presence of the Italian tax identifier for independent inventors. This code provides several information and in particular gender and date of birth. The information on the selected inventors is enriched by the reconstruction of their individual patent portfolio in the examined years through their name. The reliability of the identification and selection process is supported by several manual checks that combined online searches and direct contacts with the inventors.

Section 2 provides references to the research framework. Section 3 summarizes the data processing (additional information is reported in the appendix). Section 4 presents the characteristics of the examined sample with the aim to profile the independent inventors along different dimension of analysis. Section 5 concludes and links the results to the existing literature.

2 Review

2.1 Literature on independent inventors

An inventor is considered independent when s/he is the owner of the intellectual property rights of her/his patented invention; "dependent" when an organization (either the employer or a third entity) own the IPRs at the time of filing (Dahlin, 2021; Guimarães et al., 2015; Spear, 2006) and it is thus recorded as the applicant/assignee. The independent inventors can be students, unemployed, employed in their own or someone else's company but patenting autonomously in the same or another technical field, hobbyists, practitioners or entrepreneurs with or without a clear startup project, lone garage inventors or members of a community sharing a passion / interest related to the independent patent (Lettl et al., 2009).

Previous literature indicates several drivers to their decision to independently patent, ranging from direct economic rewards from patent sales/licensing, consultancy or entrepreneurship (Åstebro and Dahlin, 2005; Spear, 2006), to indirect recognition from peers, venture capitalists or potential employers (Lerner and Tirole, 2003), and/or the intellectual challenge to find a solution to a problem (Harhoff et al., 2003; Torrisi et al., 2016).

Independent inventors had a relevant historical role (Dahlin, 2021; Hintz, 2011). The literature has focused primarily on the US and provided evidence of a significant contribution to global technological development from the end of 19th Century until the beginning of the 20th. In that period, inventive activity was democratized (Khan, 2005): independent inventors contributed more than organizational ones both quantitatively, i.e., more granted patents (Dahlin, 2021), and qualitatively, i.e., higher citation levels (Nicholas, 2010). In the 1930s, the central role of independent inventors started to decrease: companies and research organizations invested in R&D laboratories where technical assets and human capital of teams of scientists and engineers supported the generation of innovations. Initially, the independent inventors seemed to support and complement the innovation activities of organizations (Dahlin, 2021; Nicholas, 2010). Later, as anticipated by Schumpeter (2013), R&D activities carried out in large laboratories became the main drivers of patenting (Lamoreaux and Sokoloff, 2011), even if the role of the independent inventors was not completely displaced (Dahlin, 2021; Hintz, 2011).

The universal trend in science and technology towards large teams is due to the increased complexity, the need to combine highly specialized knowledge in broader systems, and to rely on multiple business areas to finally realize an innovation (Hunter and Leahey, 2008; Lemley, 2012; Milojevic, 2014; Wuchty et al., 2007). As a result, per capita inventiveness has been decreasing. However, in a recent work Wu et al. (2019) indicated that in the years 1954–2014 smaller teams were more likely to disrupt science and technology than larger teams, which instead favor incremental innovations. The authors argue that the individual level is the layer responsible for the difference, since researchers shift from small to large teams and vice versa. Furthermore, Dahlin (2021) introduced the concept of complementarity between independent and organizational inventors. Industrial R&D is the most frequent source of innovations thanks to the scale of activities and the capabilities to face the complexity of science and technology. Nevertheless, US data for the years 1963-2014 shows that the number of independent patents is quite stable in size and there is evidence of a bi-directional positive externality between the two types of inventors: independent inventors rely on the vast technical knowledge developed by organizations and at the same time their patents can unlock or foster a technological trajectory. This idea is consistent with the concept of ecosystems of innovation, the local communities where different actors share resources and knowledge with a flywheel mechanism that spurs the generation of innovations (Agrawal and Cockburn, 2003; Cooke, 1997; Etzkowitz and Leydesdorff, 2000; Jaffe et al., 1993; Marshall, 1920; Spigel, 2017). In ecosystems of innovation, practitioners, entrepreneurs and hobbyists can file for independent patents and contribute to subsequent innovations developed in companies or research organizations.

The technological impact of independent inventors is in general lower than corporate ones (Lettl et al., 2009) but it appears to be extremely skewed. Studies on specific industries, such as tennis racket (Dahlin et al., 2004) and medical devices (Lettl et al., 2009) showed that the group is heterogeneous with both hobbyists and individuals generating highly cited patents, who can in some cases outperform dependent inventors. Similarly, the analyses on the commercialization of independent inventions show a high level of skewness, as well (Amesse et al., 1991; Spear, 2006): generally the performance is worse than company patents, which are generated with the specific goal of support firm sales, but in some cases the economic returns are extremely high (Åstebro, 2003).

2.2 Identification and characteristics

The identification of independent inventors and the exam of their characteristics has been carried out in the literature in multiple ways. Some studies relied on local or national associations of inventors to collect a list of individuals (e.g., Amesse et al., 1991; Ivančič et al., 2014), other on patent repositories analyzing the inventor and the applicant/assignee fields (e.g., Dahlin, 2021; Nicholas, 2010). The characteristics of the inventors were determined through direct surveys (e.g., Åstebro, 2003; Mieg et al., 2012) or secondary data and patentometrics (e.g., Dahlin, 2021; Lettl et al., 2009) and the analyses were at the individual or patent level respectively.

The most frequent country that has been studied is the US (Daemmrich, 2021; Dahlin, 2021; Dahlin et al., 2004; Guimarães et al., 2015; Lamoreaux and Sokoloff, 2011; Lettl et al., 2009). A few studies focused on other countries, e.g., Canada (Amesse et al., 1991; Åstebro, 2003), Italy (Schettino et al., 2013; Sirilli, 1987), Germany (Mieg et al., 2012; Zwick et al., 2017), United Kingdom (Spear, 2006) and Slovenia (Ivančič et al., 2014). In addition to the analysis of historical data between the 19th Century and the beginning of the 20th (Lamoreaux and Sokoloff, 2011), the most frequently examined years are between 1980 and 2010 (Amesse et al., 1991; Åstebro, 2003; Dahlin et al., 2004; Guimarães et al., 2015; Ivančič et al., 2014; Lettl et al., 2009; Schettino et al., 2013; Sirilli, 1987; Spear, 2006; Zwick et al., 2017), while only Dahlin (2021) has focused on data after 2010.

The presence of independent inventors seems to vary in time and nations, but the comparison is not easy due to the different operationalizations of the measurement. Patent level measurement for the US indicates an average of 11% independent granted patents in the years 2006-2019 (Dahlin, 2021), 14% in the field of medical devices in 1980-2005 (Lettl et al., 2009), 65% in tennis rackets industry (Dahlin et al., 2004); the share of independent patents in other countries ranges is around 40% in Slovenia in 2007 (Ivančič et al., 2014) and in Canada in 1986 (Amesse et al., 1991). Person level measures indicate the presence of 40% independent inventors in Marche region in Italy in 1981 (Sirilli, 1987) and 2% in Germany from a sample of 1700 German inventors who applied for European patents between 2004 and 2008 in cleantech and mechanical fields

Independent inventors enjoy more freedom to develop inventions because they are not responding to a company and its need to solve a specific problem and finally commercialize the result of the R&D effort (Lettl et al., 2009). The openness translates in more diversified base of prior knowledge to inventions than corporate inventors, potentially favoring breakthrough inventions (Lettl et al., 2009). This is expect to be connected to a more prominent approach of thinking outside of the box (Dahlin et al., 2004), free from the traditional schemes in the industry (Lettl et al., 2009).

This is in line with the results of the survey of Amesse et al. (1991), Canadian independent inventors are on average highly experienced and educated, and with the psychological analysis in Mieg et al. (2012): German independent inventors are associated to higher levels of extraversion and openness to experience than non-inventors. However, according to the model developed in Kobayashi and Yu (1993), inventors with a high index of inventive ability are more likely to be affiliated with organized research.

On the other hand, independent inventors face resources constraints that limit their activities more than organizational inventors. This is particularly detrimental to innovation activities when complexity and deepness produce a knowledge and technical load which is not manageable by individuals with no support from an organization (Lettl et al., 2009).

2.3 Gender, age and productivity

Patenting activities are in general dominated by the presence of men over women (Heikkilä, 2019; Lax Martinez et al., 2016), in line with the underrepresentation in STEM areas The share of patents granted to female inventors in US increased from less than 4% at the end of the 19th Century, to 6.5% in the 1940 (Sarada et al., 2019). Current studies indicate that at the USPTO and EPO the share of female inventors is around 13% (Tahmooresnejad and Turkina, 2022; USPTO, 2020). The studies focusing on independent inventors indicated that they were almost all men in the period between 1970-80s, 89-99% (e.g., Amesse et al., 1991; Åstebro, 2003; Sirilli, 1987).

In general, previous studies indicate that creative productivity peaks around the age of 30-40 (Dennis, 1958, 1956); however, the presence of older contributors is globally increasing in the last years, due to the increased time necessary to acquire the human capital used in the invention process and the scientific and technological complexity (Bloom et al., 2020; Jones, 2009).

Focusing on patenting, most studies point to an average age of 40-45 years as summarized in Table 1. Few studies calculated the age at the first patent (here "debut" date), relying on an approximation from the earliest priority filing or linking patent data to external sources. Jung and Ejermo (2014) found a decreasing debut age for Swedish inventors: from 43-45 in the years 1985-1997 to 40 in 2007. The authors uncovered a difference between genders: average age of female inventors is more than 4 years lower than that of male, with the gap reducing in the time window. Jones (2009) focused on the subsample of inventors in the age range 25-35 an estimated an increasing trend in the debuting age of 0.6 years per decade between 1975 and 1999.

Table 1 Summary of selected previous studies providing information about the age of inventors.

Source	Country	Examined Years	Mean age	Mean age at debut
(Sarada et al., 2019)	US	1870-1940	41 43.5 in 1940	
(Bell et al., 2019)	US	1996-2014	43.7	
(Jung and Ejermo, 2014)	Sweden	1985-2007	45-46 until 1997 43.4 in 2007	43-45 until 1997 40.4 in 2007
(Kim, 2018)	Rep.of Korea	1991-2005	34.0	
(Jones, 2009)	US	1975-1999		29 (Approx. for subsample 25-35)
(Kaltenberg et al., 2023)	US	1976-2018	Solo: 45.4 Team: 43.0	Not stated but Figures with distribution for selected subsamples
(Walsh and Nagaoka, 2009)	Japan	1995-2001	39.5	
(Walsh and Nagaoka, 2009)	US	2000-2003	47.2	
(Väänänen, 2010)	Finnish at USPTO	1988-1999	41	
(Sirilli, 1987)	Italy	1981	46.5 **Independent**: 48.7	
(Amesse et al., 1991)	Canada	1986	**Independent**:46	
(Macdonald, 1986)	Australia	1981-1982	**Independent**: Mostly 30-59	

The recent work of Kaltenberg et al. (2023) dig deeper in the analysis of the age of inventors. The authors examined US inventors over the years 1976-2018 and provided charts for the distribution of age. Solo inventors record an average age of 45.4, inventors in teams 43.0. When focusing on inventors with more than one patent, their debut is mainly in the late 20s or early 30s, but many filed their first patent in their 40s and beyond. The debut age of this group of inventors is decreasing in recent years.

No recent data are available for the specific subsample of independent inventors. Amesse et al. (1991) indicates a mean age of 46; Sirilli (1987) 48.7, higher than that of organizational inventors; working for a firm; Macdonald (1986) reports that 70% are between 30 and 59.

In terms of productivity, studies on inventors, with no distinction between independent or not, found the presence of an inverted U-shape with a peak in productivity in late 30s - early 40s (Bell et al., 2019; Jones et al., 2014; Schettino et al., 2013; Väänänen, 2010). This peak comes earlier for female inventors than male (Kaltenberg et al., 2023). The argued explanation refers to a theory of human capital accumulation at the early life-cycle and a deterioration of incentives (and inventive ability) at later stages in career. The median patent portfolio of an inventor is made of only one patent (Schettino and Sterlacchini, 2009; Väänänen, 2010).

Focusing on independent inventors, most studies confirmed that most of them hold one patent, with an average portfolio between 1.1 and 2.2 (Table 2). A very different result, mean portfolio size equal to 10, is found by Dahlin et al. (2004) in their work that focused on 225 patents in the tennis racket industry: the authors note however that the inventors considered independent in this sector are not so in other industries at the same time.

Table 2 Summary of papers in the literature providing information on the patent portfolio of independent inventors.

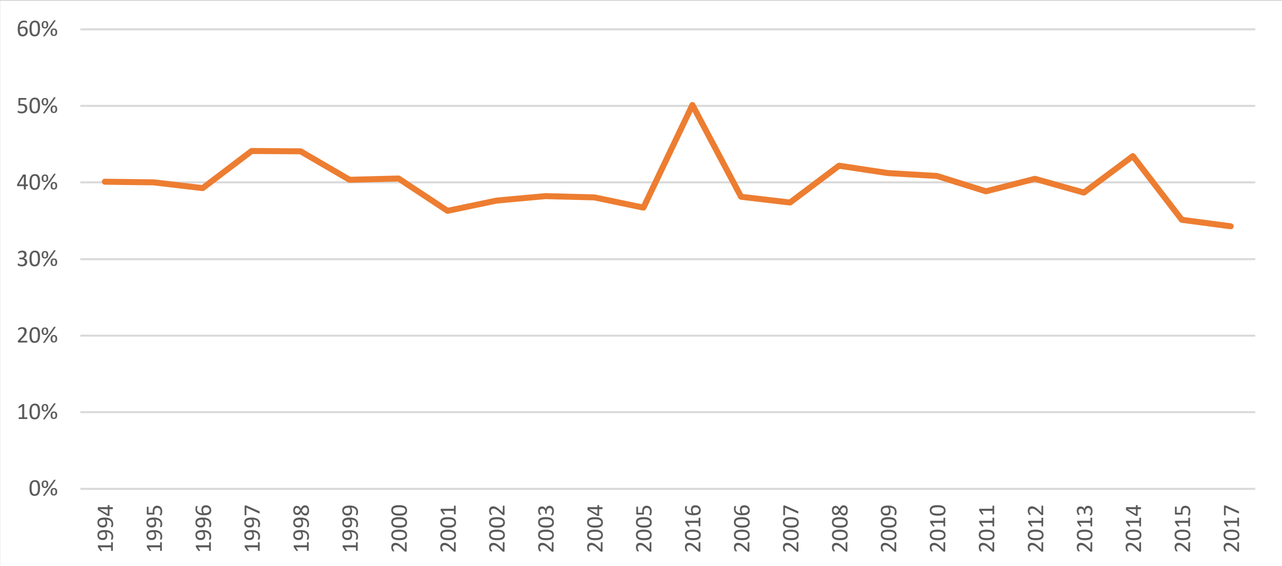
Source	Country	Years	Average portfolio size age	Perc. of inventors with a portfolio of one patent
(Amesse et al., 1991)	Canada	1986	2.2	55.4
(Macdonald, 1986)	Australia	1981-1982	1.96	
(Guimarães et al., 2015)	US	2000-2009	1.45	80.7
(Lettl et al., 2009)	US	1980-2005	1.18	
(Dahlin et al., 2004)	US	1981-1991	10	

The review of the literature seems to provide insufficient data on independent inventors about their age, gender, productivity and career changes from and to being independent. In this study I exploit the presence of a relevant piece of information for the Italian inventors and try to contribute and fill this gap.

3 Data collection and cleaning

Data were retrieved from the Italian Patent Office ("Ufficio Italiano Brevetti e Marchi" - UIBM) website[1] in October 2020. The retrieved information for the Italian patent applications and granted documents starts from the filing year 1994 and I cut the right tail of data to 2017 to avoid potential delays in digital reporting of patent information. When one or more inventors are also the applicants/assignees, the system reports the tax identifier (in Italian it is called "Codice fiscale"): more than 90 thousand patents (circa 40% of all the available patents) report at least one inventor's tax ID, corresponding to 50 thousand diverse IDs. The share of this type of patents appears quite constant, with a decrease in the last two years (Figure 1).

Figure 1 Share of patent applications reporting at least one inventor's tax ID on total applications at the UIBM per application year.



"Codice fiscale" is a 16-digit string that makes possible to univocally identify gender and birth date. The objective of this study is to provide an assessment of age, gender, productivity and dynamics of independent inventors. To this aim, the whole portfolio of each inventor must be identified, since an independent inventor might have started her/his career in a company. Individual's patent portfolio is reconstructed by associating patents having inventor's same name. This process involved several steps of data cleaning and sample selection that are detailed in the appendix. The priority drivers of data treatment were: i) to minimize the introduction of potential biases with respect to the focal dimensions of gender and age of the inventors, debut year and time of the first patent as a dependent inventor; ii) to maintain a sufficiently high accuracy in the identification of the patent portfolios, capturing all the filings of an individual and at the same time avoiding mixing different persons with the same name. The appendix provides details on the whole process of filtering out inventors towards a consistent and accurate sample and on the controls performed to test the accuracy. The whole process cannot completely exclude errors but the results of the tests on random inventors support the reliability of the approach, especially with respect to the dimensions of interest.

The data processing leads to a final sample of 28,223 inventors that filed their first Italian patent between 1994 and 2017. Their combined patent portfolio amounts to 48 thousand patents (22% of the total patent filings recorded in UIBM in the same period). I highlight again that this sample is not representative of the

[1] Last access in December 2022: https://uibm.mise.gov.it/index.php/it/ .

whole population of Italian inventors because it focuses on those who at least once in their career filed an independent patent.

The definition of a "dependent" inventor is operationalized through three approaches. The first consider an inventor as dependent when the list of assignees includes an organization (i.e., a company, a university, a research center, a government agency, or anything that is not an individual). The second considers only the case when the organization is a company. This distinction was made by identifying universities and research centers in Italy through queries on the corresponding patent fields (more details in the appendix). This operationalization is expected to capture employment in most of the cases, but it still includes few academic inventors that collaborate with firms. Hence, the third approach excludes those inventors with at least one patent reporting a university or a research center among the assignees. The excluded cases are 568 (2%) and should not impact significantly on the analyses[2].

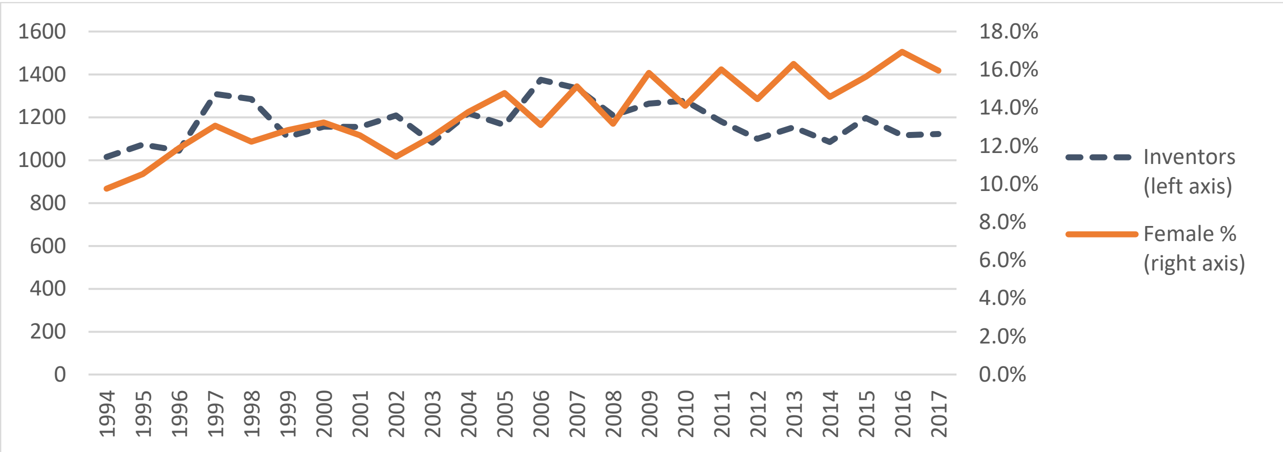
The appendix provides a list of the most relevant limitations due to the sample selection.

4 Profile of independent inventors

4.1 Gender and age

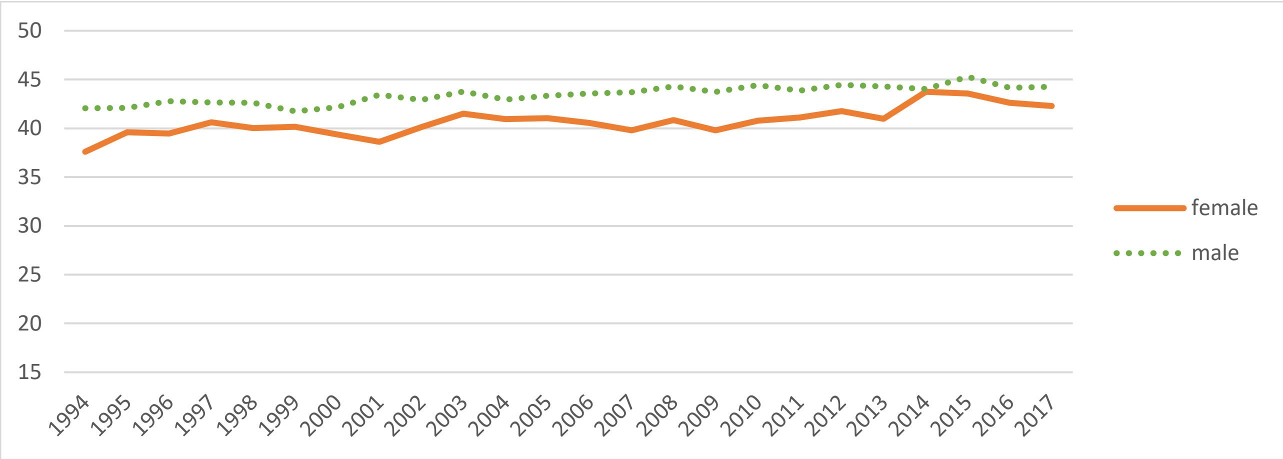
The examined 28,223 individuals are quite uniformly distributed by debut year: circa 1.2 thousand new inventors per year. Female represent 13.8% of the sample with an increasing trend from the 9.8% in 1994 to 16.0% in 2017 (Figure 2). This is in line with the global results both in terms of share and increasing representation of women in patenting (Caviggioli et al., 2022; Tahmooresnejad and Turkina, 2022; USPTO, 2019).

Figure 2 Number of inventors (left axis) and share of female individuals (right axis) by debut year.



[2] Although the identification strategies are not the same, for comparison, the 2% value is much smaller than what Amesse et al. (1991) found among Canadian inventors in their 1986 survey, 13%, while it is more similar to the 4% among the German data in cleantech and mechanical industries in Zwick et al. (2017). This exclusion might exclude cases when company inventors collaborated with universities.

Figure 3 Mean debut age by debut year, distinguishing between male and female inventors.



The average debut age in the sample is 43.1 years. For comparison, Sirilli (1987) reported an average age for Italian inventors in 1981 equal to 46.5, but it included both debutants and experienced persons.

Female inventors on average file their first patent earlier than male, at the age of 40.8 while men at 43.4 (the t-test on the difference is statistically significant). Figure 3 shows that the debut age of both men and women is increasing, with the latter having a faster pace, reducing the difference between the two genders.

Figure 4 Kernel density estimation of the debut age for female and male inventors.

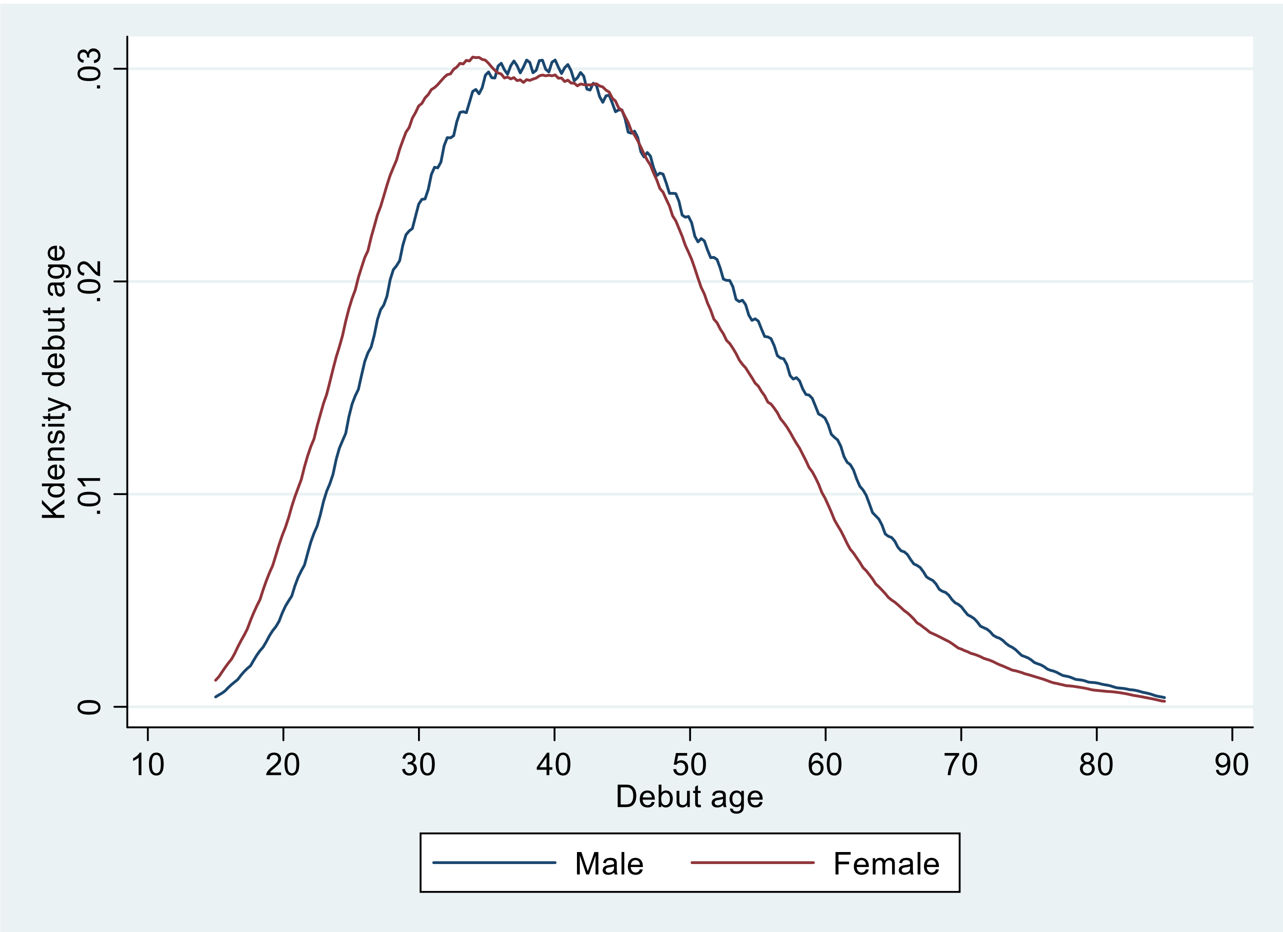


Figure 4 shows the estimated kernel density of male and female inventors by their debut age in the whole sample. On average the relative share of women debuting before 35 years old is higher than men's, while the opposite emerges when considering those debuting after 50: Around the age of 32-45 female debutants seems to be underrepresented. This might be related to childbirth, reducing the propensity to patent in those years[3].

Figure 5 Share of inventors by selected debut age groups, comparing the subsample of women (whole lines) and men (dotted lines). The values are calculated as mobile mean on a three-years windows.

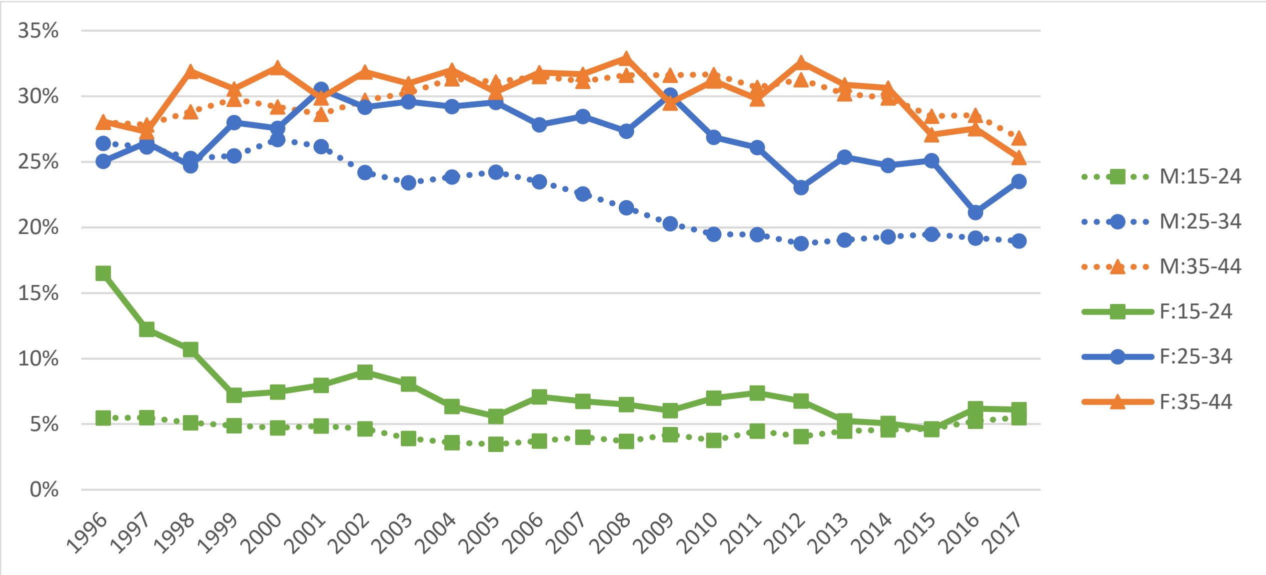
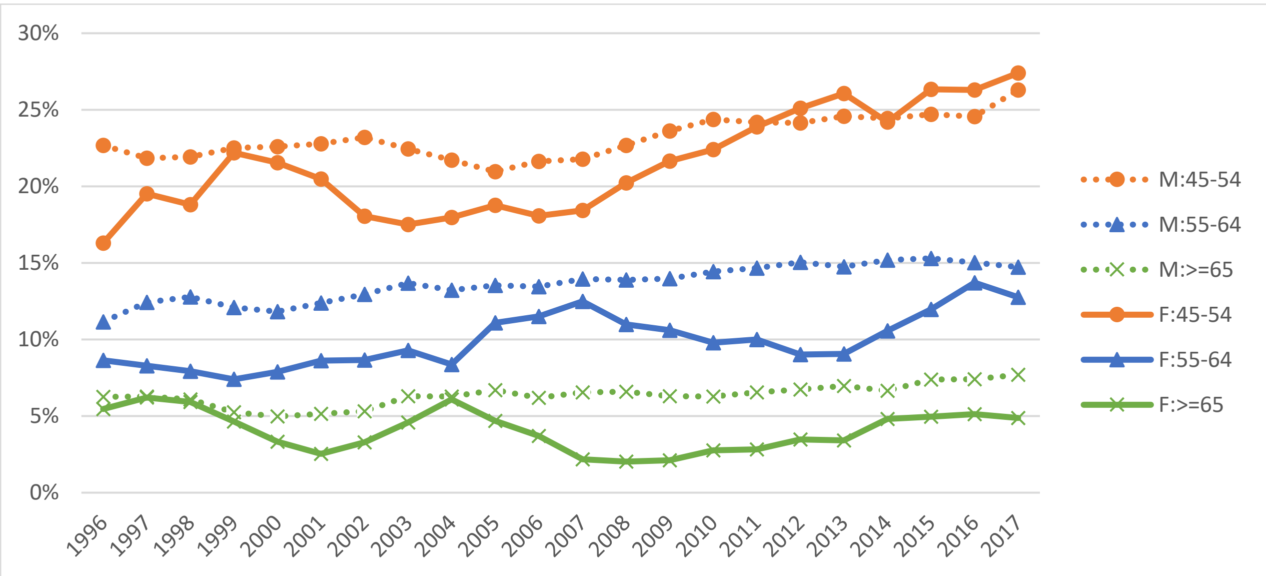


Figure 6 Share of inventors by selected debut age groups, comparing the subsample of women (whole lines) and men (dotted lines). The values are calculated as mobile mean on a three-years windows



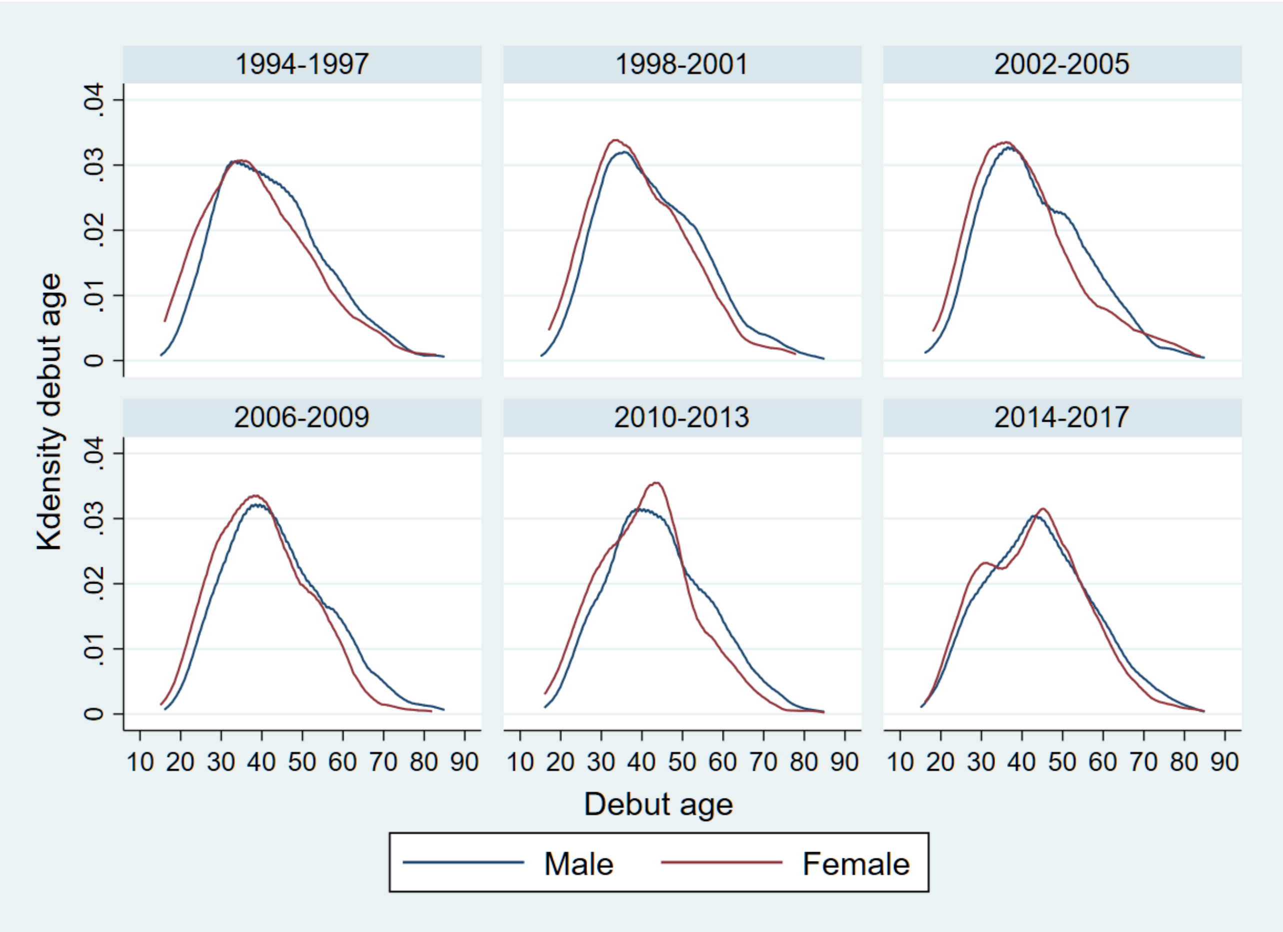
With the aim to identify trends, Figure 5 and Figure 6 show the share of male and female inventors at their debut for different age groups: the reported values are calculated as the mobile mean on a three-years windows. The first figure focuses on the earlier stages of life: the values in 2017 are smaller than in 1996, indicating a decreased representation of young debutants. The group of inventors below 25 years old at the debut is quite constant for male, around 5%, while it decreased for women until reaching men's share in

[3] in the observed time window the mean age of mothers in Italy increased from 28 to 32 (source: https://www.oecd.org/els/family/database.htm).

2017. The group 25-34 is where the largest difference between genders can be observed: both started around 25%; the trend of the male group is quite constantly decreasing and from 2010 it is below 20%; female increased up to 30% until 2009 and then dropped in recent years below the initial level. The share of inventors filing their first patent in the age group 35-44 has a similar trend for both genders: a slow increase from 28% to around 32% until 2008 and then a decreasing pattern until 25-27% in 2017.

In Figure 6 the shares of the later age groups are plotted. In general, the data suggest the presence of a shift towards the late part of the career especially due to more debutants in the age 45-64, with the largest increase observed for women (female between 45-54 from 16% to 27%; 55-64 from 9% to 13%).

Figure 7 Kernel density estimation of the debut age for male and female inventors in six periods.



Comparing the distribution of male and female debut age in time (Figure 7) highlights that in general women are relatively more present until 35-40 years, and less after 50. However, in the last two periods (especially in the most recent years), data on female inventors show a neat change in the distribution, getting closer to male but with an anomaly around the year 35: in the previous ten years, female are overrepresented, and in the following ten underrepresented.

4.2 Productivity

With the aim to compare inventors' productivity, I focused on the first ten years from the debut (i.e., limiting the sample to those with a first filing before 2008). This criterion excluded 10,493 inventors (37%). Most of the inventors filed only one patent, 70.4%; 26.9% from two to five; and 2.7% more than five. The men's average productivity in the first ten years of patenting career is slightly higher than women's, 1.69 vs. 1.44 (statistically different according to the t-test). 69.4% of male inventors have a portfolio of one patent, while the same share for female is 77.1%.

Whenever available, the IPC codes of patents were retrieved and linked to the 35 WIPO fields through the WIPO concordance Table[4]. Note that some patent documents do not report the IPC code, hence only for 82% of the inventors it is possible to identify at least one technical field of activity. Table 3 shows the presence of female inventors in the 35 technical fields. The ranking is very similar to the one found in the US (Caviggioli et al., 2022) with Pharmaceuticals, Biotech and Medtech having the share of female inventors above the sample average.

Table 3 Share of female inventors in the examined sample by WIPO 35 technical fields.

WIPO code	WIPO Field	Observations	Share of female inventors
15	Biotechnology	194	0.320
14	Organic fine chemistry	179	0.313
16	Pharmaceuticals	379	0.280
11	Analysis of biological materials	95	0.274
28	Textile and paper machines	447	0.170
34	Other consumer goods	1351	0.159
18	Food chemistry	382	0.152
13	Medical technology	1492	0.144
19	Basic materials chemistry	245	0.139
20	Materials, metallurgy	252	0.135
22	Micro-structural and nano-technology	15	0.133
33	Furniture, games	1,642	0.131
	total	14,499	0.120
21	Surface technology, coating	244	0.119
17	Macromolecular chemistry, polymers	98	0.112
25	Handling	1185	0.102
10	Measurement	615	0.098
8	Semiconductors	137	0.095
30	Thermal processes and apparatus	636	0.094
24	Environmental technology	456	0.092
23	Chemical engineering	542	0.090
1	Electrical machinery, apparatus, energy	796	0.087
29	Other special machines	1376	0.085
3	Telecommunications	436	0.083
6	Computer technology	478	0.082
7	IT methods for management	86	0.081
35	Civil engineering	1,671	0.080
9	Optics	291	0.079
31	Mechanical elements	737	0.079
2	Audio-visual technology	271	0.074
12	Control	748	0.074
32	Transport	1579	0.072
5	Basic communication processes	45	0.067
27	Engines, pumps, turbines	441	0.066
26	Machine tools	657	0.061
4	Digital communication	105	0.010

Since productivity is related to sector specificities and the general trend in patenting, while female representation is increasing, a multivariate approach is required to evaluate the presence of actual differences related to gender. I tested a set of negative binomial regression models with the following characteristics: the nonnegative count dependent variable is the individual 10-years productivity; the regressors are gender and debut age; the models control for the debut year and the WIPO fields; robust standard errors are calculated. The results are in Table 4. The debut age is not significantly correlated to productivity, nor when considering the quadratic function. The negative correlation between productivity and gender is of circa -5% (models 1 and 2). Models tested with no field dummies show a larger negative

[4] https://www.wipo.int/ipstats/en/docs/ipc_technology.xlsx (last access in March 2023).

correlation for female (-15%): this suggests that the majority of the gender gap is related to the presence of gendered fields.

Since the share of one-shot inventors is higher for women, models 4 and 5 consider the subsample of inventors with a portfolio of at least two patents. The female dummy is no longer statistically significant. It suggests that when considering serial inventors, the differences in productivity are not correlated to gender.

Table 4 Results of negative binomial regression on 10-years productivity with robust standard errors (incidence rate ratios reported).

Variable	Model (1)	Model (2)	Model (3) At least 2 patents	Model (4) At least 2 patents
Female (dummy =1)	0.9390***	0.9399***	0.9687	0.9685
	(0.0197)	(0.0197)	(0.0306)	(0.0305)
Debut age	0.9998	1.0038	1.0003	0.9998
	(0.0006)	(0.0037)	(0.0008)	(0.0051)
Debut age squared		1.0000		1.0000
		(0.0000)		(0.0001)
Debut year	1.0000***	0.9999**	1.0003***	1.0003***
	(0.0000)	(0.0000)	(0.0000)	(0.0001)
WIPO 35 dummies	Yes	Yes	Yes	Yes
Obs	14436	14436	4971	4971
Log lik.	-21262.7944	-21261.9629	-9517.7153	-9517.7056
chi-squared	9285.6060	9283.4444	17968.1250	17971.0973

4.3 Independent inventors: career types

All the inventors in the sample have filed at least one independent patent in the time frame by construction (i.e., they are listed as assignee with their tax ID). Since most of the inventors filed only one patent (71%), the largest part of inventors in the sample are considered independent and never filed a dependent patent, regardless of the employed operationalization of the definition of "dependent" (Table 5). In the whole sample, 13.6% of the inventors have at least one dependent patent. The percentage is similar when considering the same horizon for all the inventors, i.e., ten years since the debut, and increases to around 40% when excluding one-shot inventors.

Dahlin (2021) defined four scenarios of independence dynamics for two consecutive patents of the same inventor: independent-independent, independent-organizational, organizational-organizational and organizational-independent; he then moved the analysis from the patent level to a geographical level. In a similar fashion, I define four main patterns with respect to being independent or not at the individual level. In the selected sample, an inventor can debut as independent or dependent. An independent debutant can either remain so in all the eventual subsequent patents or become dependent, and vice versa. The possible types in this empirical setting are:

A. Always independent inventors (I-I): they filed one or more patents as independent, but no dependent patent is observed in the examined period. This group includes "one-shot inventors", which is the largest subsample. The inventions of this group are less likely to have become full-fledged innovations and commercialized on a large scale. Relatively to the sample, in general the individuals in this group may have lower inventive propensity and entrepreneurial attitude, faced life events that blocked them from being employed inventors (not even in their own venture), or developed a new invention which did not spur subsequent business-related innovations.
B. I-D inventors: this group is made of inventors that started with an independent patent and later filed at least one patent for an organization. The individuals could be actual entrepreneurs that

founded their own company or were hired by/collaborated with a firm and transferred their IP rights to such organization.

C. D-I inventors: they started patenting for an organization and, at some point, they filed an independent patent. This group potentially includes inventors that leveraged their knowledge and expertise in their field or applied them to another technical domain (e.g., collaboration with other inventors, hobby or passion in a different area from work). The independent patent could have been the first step to start a new venture or could be driven by the opportunity to sign a license agreement, either successful or not.
D. Dependent inventors (D-D) in a specific time window: this group includes the inventors having an organization as assignee when debuted and having no independent patents in a specific time frame: the selected horizon is ten years. In the time window this group can include one-shot inventors, even if it is sure that later they have filed at least another independent patent.

Two clarifications are needed. First, D-D inventors can be identified only in a specific time frame since by construction the sample is made of inventors that are independent at some point of their career. Inventors that patented only under an organization throughout their entire career are not included in this sample: even if gender could be statistically determined from names, tax codes are not available and hence there is no information on the birth date for this category. Second, since there is no information on the actual end date of patenting activities (due to death or other physical impairments), inventors that have debuted more recently have been exposed to the "risk of becoming dependent" for a shorter time: they could become dependent in the years outside the time frame. Hence, the analyses are first presented as aggregate on the whole sample and on comparable subsamples (i.e., the first ten years of career); then, survival analyses will be employed to account for the diverse cumulated hazard since the year each individual is at risk to become dependent (i.e., the failure in this setting).

Table 5 reports the relative shares of inventors' types (columns from A to D) according to the three operationalizations of the definition of independent (rows from 1 to 3) and for three different samples, i.e., the inner rows x.1, x.2 and x.3: x.1 represents the whole sample; x.2 is the subsample of those with at least ten years of career, with the aim to have a coherent group and compare the members in the same time window; x.3 is a subsample of x.2 that excludes those with only one patent in the first ten years of career. In the latter sample the share of I-I inventors is smaller by construction (65-71%), while when considering also the one-shot independent inventors, the share of I-I is the majority (85-89%). In general, D-D inventors, those always patenting in an organization in the ten years horizon from the debut, are a marginal share (1-2%). The share of I-D inventors is similar to D-I in all the operationalizations of the definition of dependent. For instance, the row 3.2 of Table 5 shows that I-D inventors are 14.7% of the sample and D-I are 12.2%. In the next analyses, I will focus on the strictest definition of dependent inventor (#3).

Table 5 Composition of different sample in terms of (in)dependent inventors: type A never filed a dependent patent; type B debuted as independent and then filed at least a dependent patent; type C debuted as dependent and later or in the same year filed an independent patent.

#	**Definition of dependent inventor**		**Reference sample (Number of obs.)**	**A % of always indep.inv. in time fram [Type I-I]**	**B % of inv. debuting as indep. and then becoming dep. [Type I-D]**	**C % of inv. debuting as dep. and then becoming indep. [Type D-I]**	**D % of always dep.inv. in time frame [Type D-D]**	**% tot.**
1	Dependent when an organization (any type) is among the assignees and the inventor is not an assignee.	1.1	All the selected inv. (N=28,223)	86.4	6.8	6.8	-	100
		1.2	First 10 yrs of career only (N=20,277)	85.4	6.5	6.5	1.6	100
		1.3	First 10 yrs and >1pat. (N=7,793)	65.0	16.3	16.5	2.1	100
2	Dependent when a company is among the assignees and the inventor is not an assignee.	2.1	All the selected inv. (N=28,223)	88.5	6.2	5.3	-	100
		2.2	First 10 yrs of career only (N=20,277)	87.6	6.2	4.9	1.4	100
		2.3	First 10 yrs and >1pat. (N=7,793)	70.3	15.5	12.3	1.9	100
3	Dependent when a company is among the assignees, the inventor is not an assignee and never collaborated with a university or a research center.	3.1	All the selected inv. (N=27,665)	89.1	5.9	5.0	-	100
		3.2	First 10 yrs of career only (N=19,796)	88.3	5.7	4.7	1.3	100
		3.3	First 10 yrs and >1pat. (N=7,399)	71.2	14.7	12.2	1.9	100

Table 6 reports descriptive statistics on the examined variables for the sample that focuses on the first ten years of career, thus excluding those who have debuted after 2007 (corresponding to sample 3.2 of Table 5). The average time to switch status is quite similar for both directions I-D and D-I, 4.4 and 4.7 years respectively (less than four months of difference). If a change happens, on average it occurs in the first five years after the debut.

Female representation is much lower among the employed, either the dependent patent is before or after an independent one. Note that considering only the 10-year careers censors the right part of the sample when female share of inventors is higher.

Table 6 Mean values for different characteristics of the three groups of inventors examined in their first 10 years of career (those debuting after 2007 are excluded). Dependent patents are defined according to the operationalization 3, i.e., having a company as assignee and excluding all the inventors involved with universities and research centers.

Data	**[Type I-I]**	**[Type I-D]**	**[Type D-I]**	**[Type D-D]**
Number of observations	17,476	1,128	931	261
Time to dep. pat. from debut (in years)				
Mean	-	4.7	0	0
Median	-	4	0	0
75th percentile	-	7	0	0
Time to indep. pat. from debut (in years)				
Mean	0	0	4.4	-
Median	0	0	4	-
75th percentile	0	0	7	-
Portfolio size (first 10 years)				
Mean	1.34	3.57	4.00	2.90
Median	1	3	3	2
75th percentile	1	4	5	3
Female	14.0%	4.7%	5.0%	3.4%
Debut age				
Mean	43.0	40.9	42.1	39.1
Median	41	40	41	39
75th percentile	51	48.5	50	46

The comparison of demographics and productivity dimensions across the four groups is performed through multinomial logit models to account for gender age and debut year at the same time, and controlling for technical fields. Table 7 shows the relative risk ratios considering as reference group the always independent inventors.

Female are underrepresented in the three types of dependent invnetors (always, before/after an independent patent): the female dummy variable is 64-78% less correlated than in the I-I group. In particular always dependent inventors are characterized by the relative lowest share of women. In terms of debut age, the difference is statistically significant, but it is small: the inventors in the three “D-related” groups are around 2% younger than those in the I-I type (considering the mean age, it corresponds to circa 10 months earlier). Across these groups debut age is not statistically different.

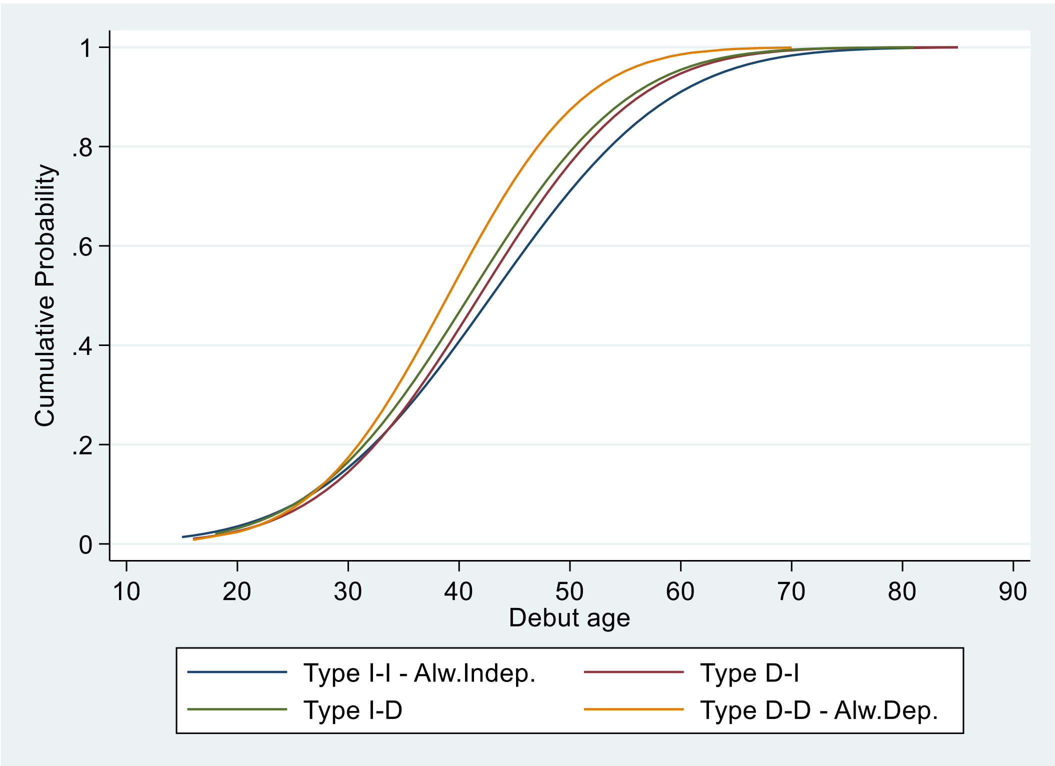
The average productivity of I-I inventors is much smaller than the others: I-D, D-I and D-D types file on average 72-83% more patents than I-I. Among “dependent” types the differences are not so relevant.

Table 7 Results of multinomial logit model with type I-I as reference, robust standard errors. Relative risk ratios are shown.

Variable	Type I-D	Type D-I	Type D-D
Female (dummy =1)	0.3065***	0.3611***	0.2185***
	(0.0537)	(0.0672)	(0.0813)
Debut age	0.9814***	0.9893***	0.9689***
	(0.0031)	(0.0034)	(0.0050)
Productivity (patent portfolio)	1.7975***	1.8370***	1.7192***
	(0.0835)	(0.0883)	(0.1022)
Debut year	0.9869	0.9712***	0.8368***
	(0.0087)	(0.0099)	(0.0130)
WIPO 35 dummies	Yes	Yes	Yes
Obs		14004	
Log lik.		-5968.4495	
chi-squared		5210.5721	
PseudoR2		0.2359	

The different distributions of debut age across the four types of inventors are shown in Figure 8. I-I and D-D types seem those with the most striking differences, with the former with more entries in the later part of individuals' life.

Figure 8 Smoothed cumulative distribution of the debut age for the types of independent inventors in ten years of career.



With the aim to consider the dynamic factor and the multivariate relationship, I tested a set of proportional hazards models via maximum likelihood on the time to become dependent (the first dependent patent is the failure event). The reference sample includes all the inventors (any career length) and excludes those with university or research centers as assignees. It corresponds to model 3.1 of Table 5. The survival-time data have the following characteristics for the sample of inventors with identified WIPO fields: 23,297 subjects, 2,986 failures in single-failure-per-subject data, 922,424 total analysis time at risk and under observation.

The results of the proportional hazards models[5] are in Table 8. All else equal, being female is associated to a delay in the time to become dependent (on average -65% in the likelihood to observe the failure in models 2 and 3). Figure 9 shows the smoothed hazard functions for the two genders derived from model 3 and considering the other regressors at their mean.

On average an increase of one unit in the debut age is associated to a risk reduction of circa 8%. Productivity is slightly positively associated to the event of filing a dependent patent: any additional patent on average is correlated to a 2.3% increase to observe the failure event.

Table 8 Results of survival analysis: proportional hazards models via maximum likelihood.

	(1)	**(2)**	**(3)**
Female	0.3086***	0.3500***	0.3505***
	(0.0270)	(0.0315)	(0.0315)
Age at debut	0.9267***	0.9199***	0.9200***
	(0.0019)	(0.0022)	(0.0022)
Portfolio size			1.0233***
			(0.0076)
Debut year		1.0062*	1.0070**
		(0.0033)	(0.0033)
WIPO 35 dummies	Yes	Yes	Yes
Obs	23297	23297	23297
Log lik.	-27746.0374	-26261.3115	-26257.1189
chi-squared	1836.6397	4806.0916	4814.4768

[5] Stcox command in Stata 17.

Figure 9 Smoothed hazard function (failure event is the filing of a dependent patent) for male and female inventors resulting from model 3 and keeping the other variables at their mean.

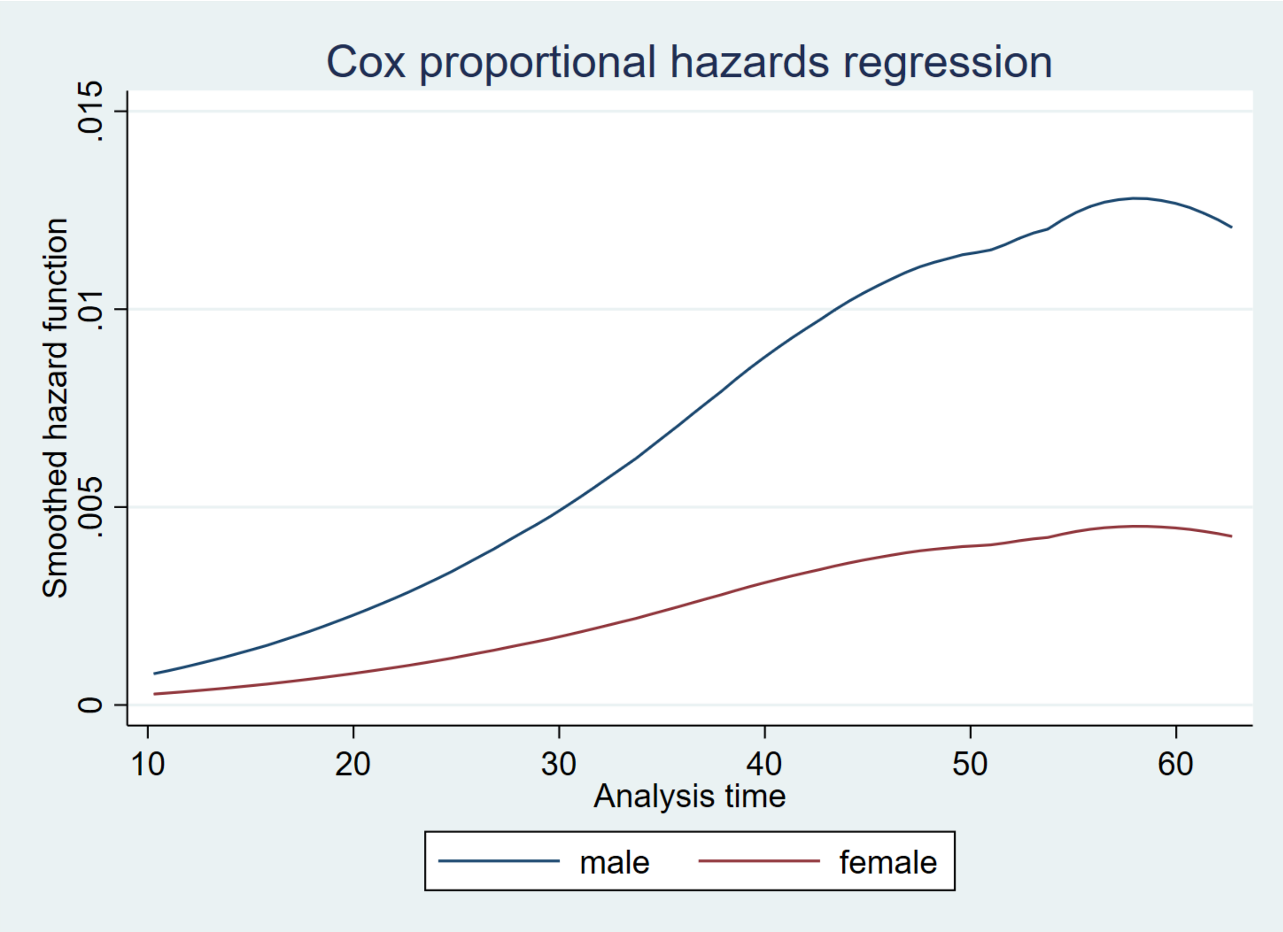
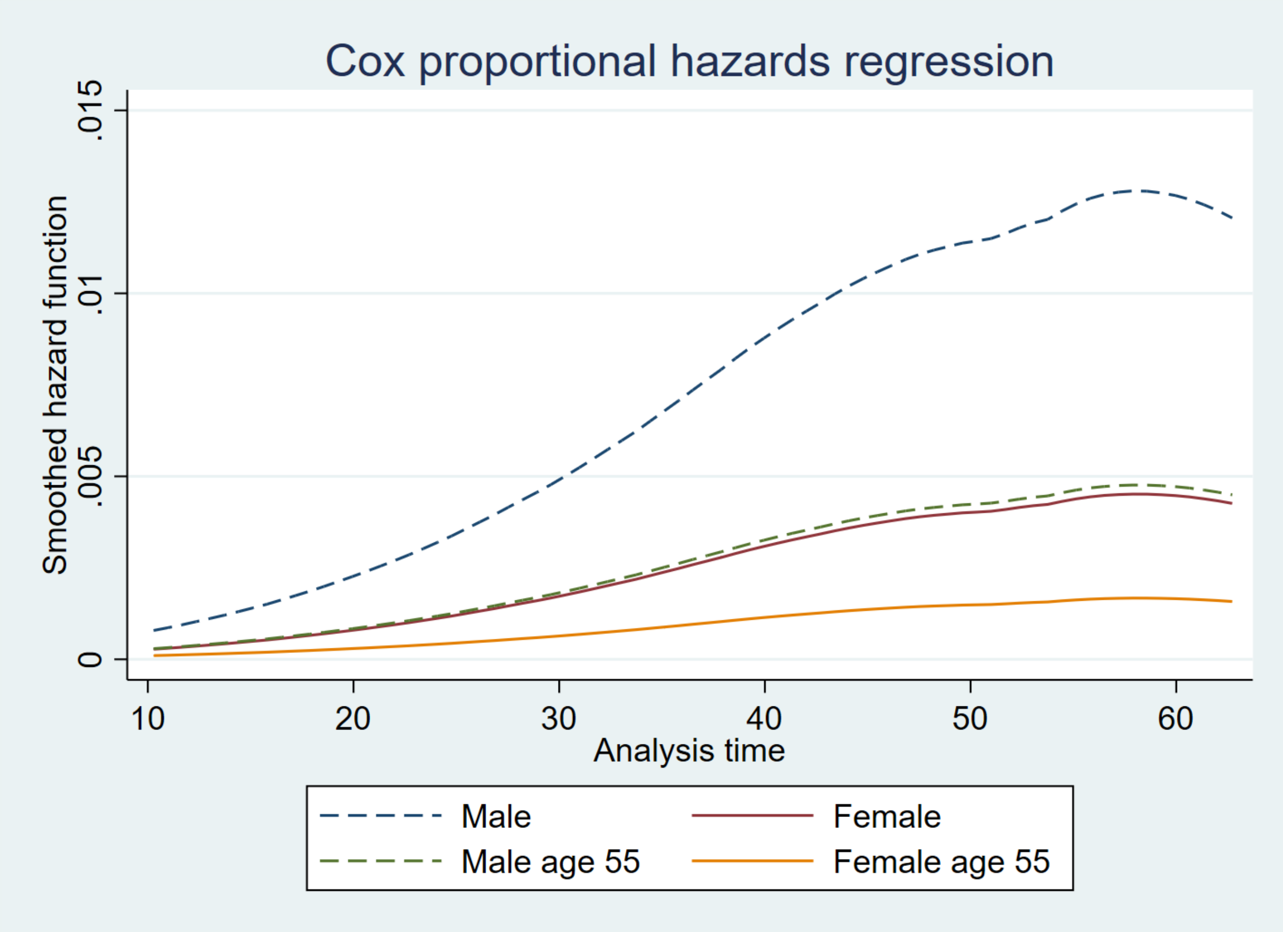


Figure 10 Smoothed hazard functions resulting from model 3 for selected characteristics of independent inventors in the sample (failure event is the filing a dependent patent).



For comparison, Figure 10 shows that the hazard function for being female is similar to those of male inventors debuting at the age of 55 years old, thus women are at risk of becoming dependent inventors on average with similar chances of men in the later part of their career, when it is harder to become an organizational inventor. In terms of productivity, the risk for a male inventor to become dependent is comparable to the one of a woman with a portfolio of at least 45 patents, an extremely rare case. The results indicate an advantage for the average man irrespective of the career age.

5 Conclusion

This study analyses a sample of inventors having filed an independent patent at the Italian Patent Office (UIBM) at least once in their career between 1994 and 2017 and debuting in the same period. For these inventors, the Italian tax code is reported and it provides gender and birth date, and consequently the age at the first patent filing. For a selected sample I reconstructed individuals' patent portfolio relying on the name. Spelling mistakes do not seem relevant, and I have introduced several exclusion criteria to avoid the risks of matching diverse individuals with the same name and of missing unmatched filed patents. Although the process has limitations, the validation tests on more than 800 random names among those with the highest risk of false positive or negative matchings resulted correct in 88% of cases.

The final sample of more than 28 thousand individuals covers 22% of the patent applications at the UIBM in the period. The sample is not representative of the average inventor, but of those that have been independent at least once from their debut between 1994 and 2017.

The analyses indicate a strong underrepresentation of women, although increasing from 10 to 16%, slightly higher than the global statistics in the same period (Lax Martinez et al., 2016; Tahmooresnejad and Turkina, 2022; USPTO, 2019).

The average debut age in the sample is 43.1 years. For comparison, Sirilli (1987) reported an average age for Italian inventors in 1981 equal to 46.5, but they included both debutant and experienced. The average woman debut at the age of 40.8 while man at 43.4. Female inventors on average file their first patent earlier than male, in line with the results for the US in Kaltenberg et al. (2023). For both genders the debut age is increasing in the examined period, with women having a faster pace and almost reaching men's age in 2017. This result goes in the opposite direction of what Jung and Ejermo (2014) found for their sample of Swedish inventors: a decrease from 43-45 in 1985-1997 to 40.4 in 2007. However, the finding of a general shift to an older debut age is consistent with the evidence of an increasing participation of experienced people in scientific and innovative activities (Bloom et al., 2020; Cui et al., 2022; Jones, 2009). This global shift is related to the increase in life expectancy, global patent propensity, time needed to acquire the knowledge and competences, and scientific and technological complexity. If more and more persons are innovating in the later part of their life, it seems reasonable to observe new inventors debuting later, having accumulated experience/knowledge and resources.

In the examined sample, the increase in the debut age seems to be driven by a shift: a relative decrease of the share of inventors filing their first patent before the age of 35 and an increase of those in the age 45-64, with differences between genders. The largest variations are found for women in the debut age groups 45-54 and 55-64, increasing from 16% to 27% and from 9% to 13% respectively. The decrease observed in the range 25-34 is smaller for women than for men. This suggests that, considering the general trend in delaying the debut age, the general increase in female participation is across all age ranges and especially in the age group 45-54.

In the years 2014-17, the distribution of the debut age of male and of female are more similar than in the previous years but with an anomaly around the age of 35. Until 2009 the data suggest an overrepresentation of debuting women until the age of 45; then this threshold seems to move to an earlier moment, around 35. Potential explanations on the persistence of the gender difference in the debut age distribution can be advanced. The increasing female participation might have more recently included some of those that have not patented in the previous intervals: they delayed the first patent to a later moment of their life. On the one hand this can be interpreted positively, as an indication of an increased access to the system. On the other hand, if they enter far later, their contribution is reduced since "inventing" time is lost. This is especially relevant when considering that, although quality is equally likely to occur across career, however the first years are more productive (Kaltenberg et al., 2023). The differences between genders in the central age interval, 30-45, might be related to childbirth, directly or in terms of sample selection, especially in the years 1994-2009. Until 2010 the female inventors might be a selection of women that were on average more likely to avoid childbirth. In recent years, the enlarged pool of women entering the patenting activities might include more mothers, who are directly affected in time resource by children or forced to anticipate or delay the activities that lead to a patent filing. This potential bias is even more relevant when considering that the affected time window overlaps the age expected to be the most prolific (Bell et al., 2019; Jones et al., 2014; Schettino et al., 2013; Väänänen, 2010).

The bias could also be related to differences in productivity, i.e., the patent portfolio size. The analyses suggest the presence of a small negative correlation related to gender (-6%) even after controlling for technical fields (gendered fields appear as the main factor in gender bias). However, when considering only the subsample of serial inventors (at least two patents), the difference in productivity is no longer statistically significant. Indeed, the share of one-shot inventors is a higher among female than among male (77 vs 69%).

The dynamic process of being an independent or organizational inventor is then considered. I applied the classification scheme of Kaltenberg et al. (2023) at the individual level and identified inventors that in a ten-years horizon are always independent (I-I), always dependent (D-D) or shifted status between the two (I-D, D-I). Descriptive statistics, multinomial logit models and survival analyses suggest that the four types have different characteristics, very distinctive for the group of always independent inventors.

Female representation is much lower among the employed, either before or after an independent patent. The survival analysis indicates that the estimated magnitude of the correlation with gender is much larger than age or productivity. All else equal, being female is associated to a delay in the time to become dependent (a reduction of 65% in the likelihood to file an organizational patent). Concerning productivity, in general, each additional independent patent is associated to an increase in the risk to become dependent of 2.3%. Several arguments can be linked to this result. In general, the serial inventors are more likely to be real innovators, i.e., the market recognizes the commercial value of their novelties. Hence, they are more likely to be employed and contribute to the innovative activities of firms, or to anticipate the value of their technological advancements and start their own venture, as Schumpeterian entrepreneurs. Under this lens, the selection mechanism slows down the generation of less worthy inventions, less able to provide commercial or social returns. Slightly larger in magnitude (-8%), but opposite in sign, the debut age is negatively related to the observation of organizational patents, as companies are more interested in individuals at the start of their career and entrepreneurial activities are more frequent in the first half of life.

On average, the results show the presence of a disadvantage for women in becoming organizational inventors, corresponding for a man to a debut age of 55 years or in terms of productivity in 45 patents, an extremely rare case. The potential reasons could be related to a lower propensity of companies to hire female independent inventors or of women to launch their own startup based on the patented technology. This finding is in line with the general evidence of the under-representation in all the STEM fields and also with the results of Dohse et al. (2021) on entrepreneurship attitude among German scientists.

The evidence on the gender-related differences should be taken into consideration in light of the social impact of having examples and role models. Bell et al. (2019) highlight that the generation of innovations is connected to some environmental factors, such as exposure to inventiveness and access to role models, especially among minorities. Hence, the disparities related to gender among independent inventors could hinder the diffusion of innovation-driven mindset and reduce the number of "lost Marie Curie's" (Caviggioli et al., 2022).

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7 Appendix

7.1 Details on cleaning process

The Italian tax code has a 16-digit format. In general, it includes six characters from the first name and the family name, five characters representing birth date and gender, four characters for the place of birth and one final character that works as a control. Official information can be accessed here:

https://www.agenziaentrate.gov.it/portale/web/guest/schede/istanze/richiesta-ts_cf/informazioni-codificazione-pf .

The selection process is summarized in Table 9. The first step excluded the IDs having transcription errors that either inhibit the identification of the gender, the birth year or place, or have inconsistencies in the final control digit.

The second step excluded the cases when a combination of last and first name is associated to more than one ID or when an ID is associated to multiple names. This helps to reduce the presence of homonyms. At the same time, since the probability of a spelling error increases with the number of entries, this selection might impact more on the exclusion of the most productive inventors.

Names that contain punctuation signs or a description of a company (e.g., Italian words for “consultancy”, “professional firm”, “individual firm”, etc.) were excluded (step 3 and 4 respectively).

Some first names that could be more frequently misspelled are excluded in step 5 (e.g., “Giampiero”, “Gianpiero”). Note that in the final sample I did not find any spelling mistakes or missing letters in first names.

The identified sample focuses on inventors with at least an independent patent in the years 1994-2017 but no info is reported before 1994. Hence, I used a crawler to scan Google Patents and identify the inventors with at least one patents filed before 1994: this search relied on first and last name. this sixth step excluded 3,052 inventors.

The presence of homonyms (same first and last name) is the potential major cause of error in the matching process. To reduce the impact of this issue, I excluded from the analyses the inventors having a last name that is very widespread in Italy. The most common last names (e.g., “Rossi”, “Russo”, “Bianchi”, etc.) are identified in a list of the 1000 most frequent last names. It is the result of an old project that analyzed the Italian phone books of the 1990’s and is available online[6]. Step 7 excluded more than 9,000 tax IDs.

Filtering based on last names is not expected to significantly affect gender or age distribution; however, geographical concentration of last names might potentially have an indirect effect if regions have very different aging patterns, which does not seem the case for Italy.

In step 8 and 9, the sample was refined by excluding those inventors that in the initial UIBM dataset debuted after the focal interval and those with a debut age before 15 and after 85 to avoid outliers. The latter selection was also useful to avoid the issue of the birth year coding in the Italian tax IDs that started again in 2000 (1900 is the same of 2000, 1901 of 2001 and so on). The final sample includes few cases with still doubts on the actual birth year and they were checked and proven correct.

The final step in the cleaning process is the exclusion of the IDs that resulted as an incorrect match from the tests in the next section. Whenever the reliability checks indicate that diverse individuals have the same name (false positive) or that patents belonging to one individual are not included in her/his portfolio (false negative), they are excluded from the analyses.

Table 9 Selection process: actions and number of IDs affected.

Step	Action	# of excl. IDs	Sample
			51,080
1	Exclusion of tax IDs with transcription errors	428	50,652
2	Exclusion of cases with either 1 name and many IDs or 1 ID and many names	6,277	44,375

[6] https://www.mappadeicognomi.it/classifica_cognomi_piu_diffusi.php last access in January 2023.

3	Punctuation and numbers in name	1,097	43,278
4	Individual firms	83	43,195
5	Frequently misspelled names	319	42,876
6	Exclude inventors debuting before 1994	3,052	38,853
7	Exclude top 1k most frequent last names	9,161	29,692
8	Exclude inventors debuting after 2017	1,275	28,417
9	Exclude inventors debuted before 15 or after 85	97	28,320
10	Exclude checked and resulted wrong in matching	97	28,223

7.2 Validation

The identification of potential patents belonging to an inventor having an organization as assignee was made by considering the string of last and first name (excluding spaces). The string was searched in the whole UIBM data on inventors as criterion to consolidate records on a single individual. Whenever an inventor name matches the string, s/he is considered a distinct individual.

This process could lead to two types of errors: i) diverse individuals have the same name and are wrongly considered as one (false positive); ii) patents belonging to an individual are not included in her/his portfolio (false negative) due to a different name writing. Both errors are not expected to affect statistics on gender but the debut year and the moments of first in/dependent patent can be wrongly assessed.

I performed random manual tests on specific subsamples that are at higher risk of error. These checks were carried out by comparing patent data (e.g., are coinventors the same? Are invention titles on the same subject? Are assignees located in the same town?) and screening the presence of the inventor online (e.g., linkedin, news, other social media) with the aim to assess the career and corroborate the matching procedure. In several cases, I directly emailed or messaged through LinkedIn the inventor and asked for clarifications. If the validation process was not leading to a clear confirmation, the individual was considered as a potential error and counted as a wrong match in Table 10, which summarizes the results of the accuracy tests.

False positive might occur when the name match increased the portfolio size of the independent inventors. In 1695 cases (6% of the studied sample) the match led to an anticipated debut year: for this subsample 83% of tested individuals were correctly matched. In 2239 cases (8%) the match did not change the debut year, but still they might lead to a wrong identification of the moment to become in/dependent: 88% of the tests on this subsample proven correct.

False negatives occur when a patent of an inventor is not included in his/her portfolio, because the name is misspelled or is a variation (e.g., includes/excludes a second name). The evaluation of the latter cases is performed by examining the most frequent potential causes of errors, that is when the first or last name includes spaces (e.g., "Del Piero" could be spelled "Delpiero", "Mario Rossi" could add a middle name as in "Mario Luigi Rossi", "Camilo Benso Cavour" could be registered as "Camillo Benso"). Note that last names made of more than one word (1822 records) start with the p/matronymic "Di", "De", "Del", "Della", "Degli", "Dei" in 31% of cases. The checks on this type of names reported no mistake. In general, no potential spelling error of names was found.

False negative cases could also be related to the rest of the sample, i.e., those individuals that when indicating their tax code reported a single first/last name. It is unlikely that in other patents they would add other parts of their last name or a second name, but I performed some tests and found no errors.

Table 10 Accuracy tests.

#	Sample	Cases	Perc. on tot.	Tested	Perc. on cases	Correct Identif.	Perc. on tested
1	Name match increased patent portfolio: debut year is anticipated	1695	6.0%	407	24.0%	338	83.0%
2	Name match increased patent portfolio: same debut year	2239	7.9%	189	8.4%	166	87.8%
3	Name match increased patent portfolio: individuals with more than one first/last name	430	1.5%	155	36.0%	132	85.2%
4	Name match increased patent portfolio: individuals with single first/last name	3504	12.4%	441	12.6%	372	84.4%
5	Name match did not increase patent portfolio: individuals with more than one first/last name	3478	12.3%	160	4.6%	150	93.8%
6	Name match did not increase patent portfolio: individuals with single first/last name	20908	73.8%	62	0.3%	62	100.0%
	Total	**28320**	**100.0%**	**818**	**2.9%**	**716**	**87.5%**

7.3 Identification of university and research centers

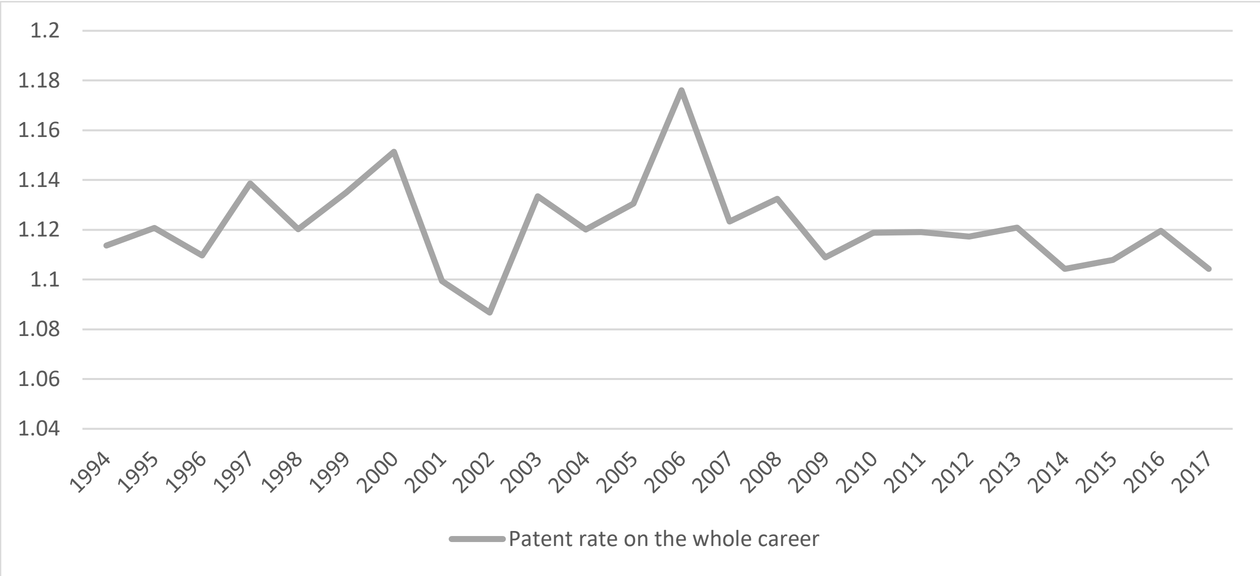
Some of the inventors in the sample are researchers that at some point filed an independent patent. This group of inventors could give the IPRs to the university or research center they are employed in, could retain them as a means of the "Professor's privilege" (since 2001), or assign them to a third collaborating organization. Partnerships and collaborations can be frequent for researchers in universities and other government centres but they do not identify employment in a company. Inventors in universities and the like are not independent according to the operationalization but their characteristics are more similar to the independent than the organizational. For this reason, the analyses are also carried out on a sample that exclude them.

Their identification is based on the presence of a university, a research center, or a government agency among the assignees. This process excludes also those inventors that are not employed in a university or the like but at some point, collaborate with them. The identification in patent data is based on two fields. First, UIBM data reports a field indicating the type of organization and I selected those for universities, national agencies, government entities. Second, the patent assignee first/last name fields were searched using keywords and jolly characters for the selection of universities (e.g., "cnr", "consiglio nazionale*ricer*", "politecnico", "universit*", "scuola", "istituto naz*" etc.). Foreign universities were also tagged.

7.4 Limitations

Data on retirement or death of individuals are not included in this dataset, hence nothing can be said with absolute certainty on the moment an individual exit the pool of potential inventors. In the dataset there are cases of inventors that have not been patenting for several years (more than 10) before filing for a new application in the late part of their life. However, the average patent rate is 1.122 and this value seems only partially influenced by the right censoring. Inventors debuting in 1994 report a yearly rate of 1.113 patents as of 2017 (Figure 11). In any case, inventors that have never been identified as dependent before 2017 could become so in the following years, outside the observed time frame. Hence, the empirical model will include a survival analysis approach.

Figure 11 Average yearly patent rate since the first patent, by debut year in the examined sample.



The selected sample focuses on the national route only. It is possible that inventors file for applications abroad or to regional offices such as the EPO with no corresponding patent family member for Italy. This option cannot be ruled out, but it is expected to be related to a very small fraction of cases, especially when considering the first patent of an independent inventor, due to limited available resources.