Women inventors *

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Abstract

The share of female inventors in Italy (just 14 percent in the years 2010-2019) remains significantly lower than men's. The main aim of this paper is the analysis of gender bias in patenting activity, using a unique dataset that matches Italian administrative employer-employee records both to patent data from the European Patent Office (1987-2005) and to municipality-level information on Medieval guilds from the Italian Central Archive of State. We empirically verify whether women's low propensity to patent can be explained by the historical local conception of women's role in society, which we measure with the share of women in guilds' founders from the Middle Ages. Results indicate that the presence of women in Medieval guilds is associated with a higher probability of observing a female inventor and a higher number of yearly patent submissions by women.

Keywords: patents, women, inventors, guilds.

JEL Classification: J60.

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1 Introduction

Large geographical differences in female labor force participation persist across and within European countries, in spite of its growth since the 1980s (by about 20 percentage points; EuropeanCommission (2016)). In Italy, geographical differences in gender disparities are highly pronounced: in 2019 the gender gap in employment rates was 15 percentage points in the North and 24 in the South. The gender gap in women's patent activity is even larger: in the period 2010-2019, the percentage of women inventors was just 14.3 in Italy, more than in Germany (10.0 percent), but less than in France and Spain (respectively, 16.6 and 23.2 percent; EPO (2022)). Lowering this gap is important not only for gender diversity, which is a goal *per se*, but also because it has been proved that if women were to patent at the same rate as men both patents and per capita Gross Domestic Product would sensibly grow (in the US, for instance, patents could increase by 24 percent and GDP by 2.7; Saksena et al. (2022)). Although the gender gap in patenting is gradually closing up (in Italy the share of women inventors was just 4 percent in 1987), the pace at which this is occurring is not fast enough. According to Bell et al. (2019) it would take another 118 years to reach gender parity in the fraction of women inventors if the gap continued to shrink at the current US rate (i.e., 0.27 percentage points average increase between 1940 and 1980).

Social norms and attitudes in a conservative society may prevent women from entertaining professional aspirations. This may translate into a negative selection of women into the labor market and more specifically into the innovative sectors, possibly because of a lower probability of enrolling in a STEM (Science, Technology, Engineering, and Math) university, which then reduces further the likelihood of entering an R&D lab and thus becoming an inventor, in a sort of "leaking pipeline" mechanism. In Italy, the share of female students enrolled in college in the years 2010-2019 was around 45 percent, that of Ph.D. graduates in STEM was about 40 percent, and the percentage of women in R&D personnel and researchers was around 30 (EPO, 2022).

Most of the papers on social norms study gender differences across countries (Giuliano, 2017). However, the belief on the appropriate role of women in society may vary across areas of the same nation. Italy is very interesting in this respect because, between the end of the Roman Empire and Unification in 1861, it experienced a variety of political and economic regimes in different parts of its territory, which led to pronounced differences in social behavior. In this paper, we exploit the territorial variation originating in the Middle Ages to analyze the historical persistence of social attitudes toward women and its effect on female patent production today. More specifically, we collect novel information on the gender of the founders of the main eight Medieval guilds in Italian municipalities from the National Archives and we construct a new indicator of gender-egalitarian norms: the share of women in guild founders. Our hypothesis is that the cities that experienced higher female participation in the labor market since the Middle Ages developed a more gender-egalitarian culture that has been transmitted over centuries and generations and that today reduces the gender gap in innovation (proxied by patent applications like in many other studies, e.g. Akcigit et al. (2023)).

Guilds were medieval institutions that associated artisans and merchants who oversaw the practice of their craft or trade in a particular area. Typically, the key "privilege" of being part of a guild was that only its members could sell their goods or practice their skills within the city. Moreover, guilds controlled minimum or maximum prices of final and intermediate goods, hours of trading, and numbers of apprentices, and thus became a tool to certify quality, acting as a brand name (Cerrito, 2017). They regulated disputes, guaranteed trade rules, fought frauds, provided services, and offered credit. These rules made it difficult or impossible for non-members to run businesses in the same sector and helped create functioning markets for craftsmen (Gustafsson, 1987). Female participation in guilds was more intense than in sectors not protected by corporations and several historical records indicate that in the Middle Ages women were able to gain substantial decision-making and economic power through these institutions (Bellavitis, 2002).

In this paper, we analyze whether female workers born in cities with more intense historical participation of women in guilds have been exposed to a culture and gender norms that favor (or hamper less) their propensity to invent. We are thus hypothesizing that local economic and social regimes in the Middle Ages have a persistent effect on individual economic outcomes today. To empirically verify this hypothesis, we construct an indicator that classifies current Italian municipalities according to their share of women in Medieval guilds' founders, and we test its impact on the female propensity to invent. To identify the historical effect we exploit the fact that (a) corporations and the women who participated in their foundation were distributed rather uniformly in the Italian territory (see Figures 1 and 2) and that (b) our indicator of women's participation in guilds is computed on information restricted to the Middle Ages. Indeed, before this historical period guilds did not exist and in the XV century restrictions to female participation in guilds' activity began to arise (Bellavitis (2002) and Rescigno (2016)).[1] Precisely because

[1]Between the XV and the XVIII century, female participation in guilds became increasingly limited to widows or spinsters since married women ("femme coverte") were required to have lower public visibility than unmarried ones ("femme sole"). However, the formal exclusion of women from guilds did not mean that women were completely excluded from the labor market. In the second half of the XVIII century, many enlightened monarchs abolished guilds, in the cause of free market principles.

the institutions that enabled women to be involved in guilds' activity no longer exist (and actually ceased to exist centuries ago), our estimated persistence effect identifies a cultural shift, since it cannot be ascribed to the persistence of formal institutions.

Before analyzing persistence effects on innovation, we undertake a preliminary exercise, using the Labor Force Survey (LFS) conducted by the Italian Institute of Statistics (ISTAT) for the years 2002-2003 to analyze the correlation between our historical indicator of female participation in guilds with current female labor market and education outcomes. We link our indicator to the LFS by the municipality of residence. We find that the cities that in the past had a higher intensity of female participation in guilds today exhibit a higher female labor force participation, a lower percentage of housewives in total working-age women, a greater share of women working as employees, and higher chances of graduating from a STEM faculty. More specifically, a one percentage point higher share of women in guilds is associated with a 0.5 percentage points higher female labor force participation today, a 0.8 percentage point lower probability of being a housewife, and a 0.8 percentage points higher chance of being an employee (vs. being self-employed) in the private sector. These results suggest that cultural formation over centuries can affect current female education and labor outcomes.

However, since individuals can choose where to live, our variable of interest is potentially affected by endogeneity. Hence, this first set of results should be interpreted as correlations, not causal estimations. To reduce this endogeneity issue we compute the Middle Ages effects based on the inventors' municipality of birth rather than that of residence, using INPS-PatStat data, that is data from the Italian National Social Security (INPS) records matched with PatStat - the database of the universe of patent submissions to the European Patent Office (EPO). We find that cities with more intense female participation in Medieval guilds exhibit a 1.5 percentage points higher share of woman inventors today. In these cities, women are more likely both to submit patent applications to the EPO than elsewhere and to be granted a patent - once we consider the overall production of patents in inventors' lives. Moreover, we find that while on average the yearly contribution of women to patent applications is less frequent than men's, the marginal effect of being born in a city with more gender-egalitarian norms increases women's probability of submitting a patent to the EPO by 1.1 percentage points.

Finally, we verify that our results are robust to controlling for potential confounding factors: the political regime prevailing in the Middle Ages (namely, whether an inventor's city of birth was a Medieval free city-state), proximity to a Medieval trade route, and presence of a University.

The paper structure is the following: the next section presents the literature review, Section 3 the data and the variables, Section 4 the descriptive statistics, Section 5 the empirical strategy, while the following part reports and discusses the estimation results and the robustness checks. Finally, the last section concludes.

2 Literature Review

This paper contributes to three strands of the literature.

First, it contributes to the literature on the legacy of history on current economic performance. The literature on persistence dates back to Putnam (1993)'s seminal work, which argued that the efficacy of local governments in Italy today depends on the degree of local civic commitment that originated from the political regime prevailing in the Middle Ages. Namely, the accumulation of civic capital was more pronounced in the medieval Communes ("Comuni"), or city-states, which experienced an unprecedented period of self-government in the XI-XIII century, while the rest of the country was under the control of autocratic foreign rulers ("Regno di Sicilia"), feudal regimes, or the Pope (Papal State). While the "Regno di Sicilia" was characterized by a steep social hierarchy dominated by a feudal landed aristocracy ruling on a mass of peasants close to the limits of physical survival, and the civic life of artisans and merchants was regulated from above, the Communes experienced a more liberal and egalitarian form of governance, with high social mobility, flourishing trade and the birth of an entrepreneurial spirit. Guilds of craftsmen and tradesmen emerged in the XIII century as a form of mutual assistance, solidarity, and security. Along these lines, Guiso et al. (2016) show that the higher level of social capital developed in the Medieval communes persists today and conjecture that the transmission channel was self-efficacy, that is the belief in one's ability to complete tasks that people experienced during the period of self-government. The authors measure civic capital with the number of non-profit organizations, blood and organ donation, and self-efficacy with the frequency of children cheating in exams. They find that self-efficacy has been culturally transmitted over centuries. Based on these findings, a few papers analyze the effect of social capital on economic performance, on the grounds that the Medieval political regime shaped today's degree of local civicness without having other direct effects on current outcomes. de Blasio and Nuzzo (2009), for instance, study the impact of social capital at the provincial level on workers' productivity, entrepreneurship, and female labor market participation, while Alfonzo and Di Addario (2021) evaluate whether the experience of self-governance in the Italian *Communes* has a persistent effect on firm concentration and the probability to become entrepreneurs or independent workers. Finally, Cinnirella et al. (2022) focus on the XVIII-XIX century and find that both the density of the patents granted in Germany during the Industrial Revolution and the local density of exhibitors at the 1873 Vienna World's Fair increased with the local density of economic society members founded after the Seven Years' War.

We build upon these studies by arguing that the municipalities in which women had a chance to join guilds in the Middle Ages nurtured a culture more favorable to female work outside the home, and developed more gender-equal norms that persisted until today. The results of this paper add an outcome – the propensity to innovate – that is related to the historical roots of the inventors' municipality of birth.

Second, we contribute to an increasing body of work that studies which background characteristics, especially education, determine individual propensity to innovate (e.g. Bianchi and Giorcelli, 2020). In particular, Akcigit et al. (2017) and Bell et al. (2019) study the characteristics of American inventors by linking patent data to income tax records. The former find, among other things, that on average inventors are more educated and so are their parents, while the latter obtain that increasing exposure to innovation among disadvantaged groups (e.g. women, minorities, low-income children) may be more effective in boosting innovation than reducing tax rates. Kim and Moser (2021) find that female scientists are more likely to hold a Ph.D. than their male counterparts, and also that mothers have a distinct life-cycle pattern of productivity: their scientific output increases after they are 35 and continues to rise, in contrast to the other scientists. Finally, Jensen et al. (2018) show that women patent on average less than men, as a result of a lower acceptance rate of their patents. We contribute to this literature by studying to what extent cultural bias affects women's probability of patenting.

Finally, we contribute to the literature on gender norms. The extent to which societies accept women's participation in the labor market may originate from the past. Alesina et al. (2013), for instance, show that the agricultural system prevailing in the pre-industrial period (namely, whether it was based on shifting or plow cultivation) determined a production specialization along gender lines that affects contemporary views about gender roles and consequently the intensity of female participation to market activities today. While it has been shown that gender bias affects women's social and economic outcomes through the labor market (see, among others, Fernández et al. (2004), Cavapozzi et al. (2021)), to the best of our knowledge, this is the first study examining the effects of cultural norms on innovation (patenting). Moreover, most of the papers that analyze the effect of social attitudes toward women compare different countries (Giuliano, 2017), while we exploit territorial variation originating in the past and are thus able to estimate geographical differences within the same country, which allows more precise comparisons as regions have more similar institutions than countries.

3 Data

In this paper, we use various data sources, from surveys to administrative data. We also collect original historical information on guilds, which we match to current municipalities.

3.1 Labor Force Survey data

For the analysis of female labor supply, we pool the eight waves of the Labor Force Survey for the years 2002 and 2003.[2] ISTAT conducts this survey quarterly and in two stages, sampling about $1,300$ municipalities in the first stage and more than $75,000$ households in the second step (for a total of about $170,000$ individuals).

LFS is the main source of information on working conditions at the individual level in Italy and includes variables on gender, place of residence (municipality and region), age, education, type of high school, type of college, work condition (employed, unemployed, not in the labor force), type of job (blue collar, white collar, manager, other).

In the paper, we restrict the sample to working-age women (age bracket 15–64).

3.2 INPS-Patstat data

Our main data source is the INPS-PatStat matched database by Depalo and Di Addario (2014), who linked inventor information from PatStat to the longitudinal administrative firm-worker data from INPS.

INPS provides the entire work history of private sector employees and their firms since 1987. The available information regards individual features (gender, age, municipality of residence, and municipality of birth), job characteristics (work status, type of contract, gross yearly earnings), and firm details (size, sector, location, date of plant opening, and closure).

PatStat is the EPO Worldwide Patent Statistical Database. This dataset provides the universe of the patent applications submitted to the EPO since the 1980s. Depalo and

[2] We use the 2002-2003 waves because the information on individuals' municipality of residence is only available in these years (while the place of birth is not available).

Di Addario (2014) used the release of April 2009; we drop the years 2006-2009 because, in the last periods, PatStat may provide incomplete information on patent grants. Each application contains a detailed description of the patent: the title, the name, and address of residence of all its inventors, the name and location of the submitting firms, the dates of filing, the date the patent was granted (if it was), the abstract, the technological field, etc. Patents can be submitted by individuals, firms, institutes of research, universities, or governments. However, since INPS provides information only on private sector employees, Depalo and Di Addario (2014) selected the patents with one or more firms (resident in Italy) as assignees (thus excluding all the submissions to the EPO by individuals, universities, or public entities); they cleaned and harmonized all the relevant names (i.e., of inventors, applicants, and locations), assigned VAT codes to firms and Istat codes to municipalities.[3]

Upon request, INPS linked its databases to PatStat in three steps. First, it matched applicant firms to its list of employers based on name and location. Then, it matched the inventors to its employees by name and municipality of residence. Finally, it considered a match to be valid only if a linked employee was employed in a linked firm in the year of submission. INPS always used an exact matching algorithm (on all the variables or a subset of them) and returned de-identified records.

In 1987, the first available year from INPS, EPO received $1,330$ Italian patent applications, a number that by 2005, the last year considered in this paper, had risen to $3,557$. The total number of submissions received in the period 1987-2005 amounted to $44,372$, after excluding the submissions from universities, which cannot be matched because their inventors are not in INPS archives. INPS was able to match at least one inventor per patent for about three-fifths of the applications presented in the same period. The data covers the full work history of the employees working in any of the patenting firms that INPS was able to match, even if they moved from/to a non-patenting firm.

In this paper, we consider as an "inventor" any individual who contributed to a patent application to the EPO either individually or as a coauthor, independently of whether the application was eventually granted.

[3]Since a patent reports all the names of coauthors and applicant firms without specifying which is the employer of whom, in the case of multiple applicants the authors associated each inventor name to each applicant and relied on INPS to determine which was the correct match.

3.3 Historical data on guilds

We complement the INPS-Patstat data with information on female participation in Medieval guilds. Guilds were associations of craftsmen and merchants formed to promote the economic interests of their members as well as to provide protection and mutual aid. As both business and social organizations, guilds were prolific throughout Europe between the 11th and 17th centuries.

We leverage the fact that the foundation of a guild required a statute with an indication of the names of founding members. Most Italian guilds were funded between the 12th and the 13th centuries. For instance, the first merchant guild was founded in Pavia in 1159, followed by Genoa, Piacenza, Milan, and Florence.

We collected historical records of such statutes from the Central Archive of the State in Rome, Italy.[4] We use this information to reconstruct the gender of the founding members for the eight major guilds located in various Italian municipalities: wool, silk, spices, furs, goldsmiths, dyers, blacksmiths, and shoemakers.

Borders of municipalities in the Middle Ages were different from those in the present day. To geo-locate the ancient city of guilds, we overlapped with GIS the maps of Middle Ages municipalities collected from the Historical Archives to the 2001 map of municipality borders. We therefore input the guild founders to the specific municipalities based on this cross-walk. In doing so, we were able to match them to virtually all current Italian municipalities $(7,904)$.[5]

Since all female inventors in our sample were born in municipalities where all eight guilds were present, we do not distinguish between guild types. We construct indicators at the municipality level for the number of guilds existent in the Middle Ages and for the share of women in total founders joining any of the guilds. Figure 1 shows the intensity of guilds distribution, depending on whether the current Italian municipalities coincide with cities that in the Middle Ages contained all eight guilds or just a few of them.[6]

4 Descriptive Statistics

In the period 1987-2005, INPS-PatStat comprises $16,035$ inventors, $1,423$ of whom are women. We are able to associate 96 percent of the inventors in our INPS-PatStat sample to at least one Medieval guild by their municipality of birth. We disregard the 603

[4] We accessed the *Fondi Carte Medievali*, buste 112-129, in Summer 2013.

[5] Except for the two municipalities of Cermes (Bolzano) and Misiliscemi (Trapani).

[6] Thus, a lighter color may imply a higher specialization in one specific sector rather than the absence of guilds *tout-court*.

unmatched individuals, who could not be matched mostly because they were born in a foreign municipality for which we do not have information on the existence of guilds. We are left with $15,433$ inventors, 9 percent of whom are women.

Although the gap is slowly reducing, women are a minority among patent inventors not only in Italy but also worldwide. In 2019 the percentage of women inventors was 13 in Europe (it was just 2 percent in the late 1970s), 15 in the US, and 9.5 in Japan (EPO, 2022). As Table 1 exhibits, the share of female inventors in our sample increased from 4 percent in 1987 to 10 percent in 2005. However, when examining the share of inventors who submit an application on a yearly basis, we do not find much difference between men and women, and in some years the gap is even in favor of the latter (Table 1). Thus, on average, women are not less productive than men; however, the gap enlarges when we focus only on the applications that will eventually be granted (the last two columns of Table 1).

Table 2 reports the descriptive statistics of our sample of inventors. Like in other European countries (EPO, 2022), women tend to work in teams and with a higher number of co-authors (Table 2): the share of solo-authored patent applications is 3.8 percent for women and 20 percent for men. Moreover, when focusing on the inventors within the 95th percentile of the patent application distribution, we observe that men have at most 4 coauthors, while women have at most 6.

On average, women inventors are younger than men (35 versus 40 years old), are less likely to be blue-collar workers, more likely to be white-collar, and equally likely to be managers. Among the people who provided information on the type of contract (just about half of the sample), the great majority have an open-ended contract irrespective of gender. Finally, male inventors tend to work full-time to a higher extent than women.

When examining the distribution of inventors by the municipality of birth, we observe that the totality of female inventors in the sample were born in a city that included all the 8 guilds considered in this paper, while the corresponding figure for men is 72.5 percent. Figure 2 reports the share of women in total guild members in the Middle Ages (ranging from 0 to 12 percent): the map does not exhibit any specific territorial pattern.

Finally, Table 3 shows the distribution of male and female inventors according to the intensity of women's participation in guilds in the Middle Ages. While men are equally distributed among the quartiles of the distribution, female inventors are more concentrated in the cities that had a higher presence of women in Medieval guilds. This is in line with the hypothesis that the cities that in the Middle Ages experienced higher participation of women in guilds developed a culture in favor of women working outside the home and more gender-egalitarian norms in terms of professions undertaken that still persist today.

5 Empirical Strategy

The positive auto-correlation of female participation over 800 years may be an indication of a historical persistence of the social norms regarding the role of women in society. In the following sections, we aim to analyze whether these norms are incorporated into the environment and transmitted through peers within municipalities till our days.

Our hypothesis is that the cities in which women had a more active role in the labor market in the Middle Ages (i.e. participated in founding guilds to a higher extent than elsewhere) developed a more gender-egalitarian culture that over the centuries "legitimized" women to work outside the home, to study longer and to undertake careers more similar to men's (for instance in Innovation).

The data we collected from the National Archive of State enables us to compute our variable of interest: the fraction of women in total guilds' members (FWG_c). By exploiting the information on the number and gender of the founders of the eight major Medieval corporations (i.e. wool, silk, spices, furs, goldsmiths, dyers, blacksmiths, and shoemakers) we construct the following indicator for each municipality c:

$$FWG_c = \frac{\sum FemaleGuildFounders_c}{\sum TotalGuildFounders_c}, \tag{1}$$

In Section 6.1 we analyze the sign of the correlation between our indicator of female participation in Medieval guilds and current female outcomes at the municipality level: labor market participation, the propensity of working within the home, the share of employees in total workers, the share of college graduates and the percentage of women who graduated from a STEM faculty. We use quarterly individual data from the LFS, which is the primary source of information on working conditions at the individual level in Italy. We estimate the following equation on the working-age women:

$$Y_{ict} = \beta_1 FWG_{c(i)} + \beta_2 X_{ict} + \phi_c + \gamma_t + \epsilon_{ct}, \tag{2}$$

where the outcome variables are (alternatively) labor force participation, being a housewife, a private-sector employee, a college graduate, and having graduated from a STEM faculty in municipality c at time t; X is a quadratic form of individuals' age, ϕ_c represents province-fixed effects, and γ_t contains the year, quarter-fixed effects, and their interaction with year. Standard errors are always clustered at the municipality level.

The variable of interest is $FWG_{c(i)}$ (equation (1)), which we link to LFS by individuals' municipality of residence. We are aware that this variable may potentially be affected by endogeneity since people can choose where to live. For instance, the women who have a weaker cultural bias may decide to move and work in the municipalities that are more open to female inventors and that may have experienced a higher fraction of women in total guilds historically. Thus, the results of Section 6.1 are to be taken as descriptive.

To partially address this concern, in Sections 6.2-6.3, which examine the labor market of inventors, we link FWG_c to INPS-PatStat data by individuals' municipality of birth, which is arguably exogenous (however, as a robustness check, we repeat all the exercises using the municipality of work).

More specifically, in Section 6.2 we estimate the following equation in the sample of inventors:

$$Y_{ict} = \beta_1 FWG_{c(i)} + \beta_2 X_{ict} + \phi_c + \gamma_t + \delta X_{c(i)} + \epsilon_{ct}, \tag{3}$$

where Y_{ict} is a dummy variable equal to one if the inventor is a woman; X_{ict} includes workers' age, work status, type of contract, and firm size; and ϕ_c contains region-fixed effects. In addition, to ensure that our variable of interest is not capturing other characteristics of the municipality of birth that could have an impact on the outcome, we add geographical features ($X_{c(i)}$) such as altitude, land area, and a dummy variable if the city is located on a coast. Observations are weighted by municipality size (measured by the number of workers) and standard errors are clustered at the municipality level.

In Section 6.3 we focus on inventors' "productivity" in terms of patent applications and we estimate the following OLS model (in the sample of inventors):

$$Patent_{ijt} = \beta_1 Female_i + \beta_2 FWG_{c(i)} + \beta_3 Female * FWG_{c(i)} + \beta_4 X_{it} + Z_j + \gamma_t + \delta X_{c(i)} + \epsilon_{ijt}, \tag{4}$$

where $Patent_{ijt}$ is the number of patent applications submitted to the EPO by inventor i working in firm j in year t, or, alternatively, the subset of these applications that have eventually been granted in our observational period. X_{it} is a vector containing individual observable characteristics such as age and features of the employee's job in firm j: work status and type of contract (whether full-time or part-time and whether open-ended or short-term). We also control for the number of patent-coauthors, year dummies γ_t, municipality characteristics $X_{c(i)}$ (i.e. altitude, area, and a coastal dummy), and for firm-fixed effects Z_j, because the decision to apply for the patent is taken by the company, not by the employee, and not all firms have the same propensity to patent. Observations are weighted by municipality size. Errors ϵ_{ijt} are always clustered at the municipality level.

Since patents can be submitted also by men, in equation (3) our variable of interest is the interaction between gender and the Medieval intensity of women's participation in guilds in inventor i's municipality of birth ($Female * FWG_{c(i)}$ from now on), after controlling for the $Female$ dummy and $FWG_{c(i)}$. In this case, the coefficient of interest represents the marginal effect of applying for a patent for a woman born in a municipality that experienced higher female participation in Medieval guilds.

Finally, we always test whether there are non-linearities by replacing FWG_c with a dummy variable equal to 1 if city c is in the 75th percentile of the distribution of women participation to medieval guilds (FWG_c^{75}).

6 Results

We start our analysis by documenting that the municipalities that developed more gender-egalitarian social norms since the Middle Ages, today are characterized by a higher female labor force participation, a lower share of women choosing to be housewives, and a higher percentage of women working as employees. Moreover, in these cities it is more likely that women graduate from college, enroll in STEM majors, and become inventors. We then examine whether in these municipalities female inventors are more productive in terms of patent applications and/or are more likely to obtain a granted patent.

6.1 Women in guilds and current female outcomes in Italian municipalities

The estimation results of equation (2) are reported in Table 4. We have three outcome variables. In specifications (4.1) and (4.4), the dependent variable is a dummy equal to 1 if the woman works or is unemployed in municipality c at time t, zero otherwise (computed in the sample of working-age women). Results in (4.1) indicate that a one percentage point increase in Medieval guilds' female ratio is associated with a 0.5 percentage points higher female labor force participation today (at the 1 percent statistical level). When we test whether there are non-linearities (by replacing FWG_c with a dummy variable equal to 1 if city c is in the 75th percentile of the distribution of women participation to medieval guilds), results are confirmed (column (4.4)), although the coefficient almost halves with respect to before.

In columns (4.2)-(4.5) the outcome variable is a dummy equal to 1 if the person is a housewife. We obtain that a one percentage point increase in the share of women in municipality c's guilds members 800 years ago is associated with a 0.8 percentage points lower chance of being a housewife in the same city (specification (4.2)), in line with the idea that higher female involvement in Medieval corporations continues to be associated with a lower propensity to work in the home today. A similar result, although lower in magnitude, is obtained when we test the effect of FWG_c^{75} ((4.5)).

In contrast, specification (4.3) shows that a one percentage point higher share of female guild members is associated with a 0.8 percentage points greater share of the city's female employees in total employed women (at the 1 percent statistical level). When we substitute FWG_c with FWG_c^{75} the sign and significance level of the previous result is confirmed: living in a municipality that in the Middle Ages had a particularly stronger female role in founding guilds is associated with a higher probability of being an employee today (column (4.6)).

We have thus far shown that there is a positive correlation between working in the labor market today and having been more exposed to more gender-egalitarian social norms since the Middle Ages. As the objective of this paper is the study of the specific labor market of inventors, who are highly specialized workers, we now turn to analyze whether the social norms that originated 800 years ago induce women to study longer. In particular, we investigate whether girls are more likely to obtain a college degree and, in particular, a degree from a STEM faculty (i.e. engineering, mathematics, physics, chemistry, biology). Table 5 exhibits the results. As expected, FWG_c is positive and highly significant in all the specifications. In particular, female students are 1.2 percentage points more likely to graduate from college, and 0.1 percentage points more likely to graduate particularly from a STEM faculty (conditionally on graduating from college) for each percentage point increase in the share of female guild founders in the Middle Ages (respectively, columns (5.1) and (5.2)). Again, the results on the municipalities in the 75th percentile of the distribution of women participation to Medieval guilds confirm the sign and statistical significance level of previous outcomes (see specifications (5.3) and (5.4)).

6.2 Women in guilds and female inventors in Italian municipalities

We now turn to examine the labor market of inventors, using INPS-PatStat. The dataset contains information on individuals' municipality of birth, which we use to match our variable of interest, FWG_c, to inventors. Since the place of birth can be considered exogenous (once parents have chosen their location), we can now interpret the FWG_c coefficient as the causal effect of being born in a city with more intense female participation in Medieval guilds on the current share of female inventors in municipality c.

We thus regress a dummy variable equal to one if the inventor is a woman on FWG_c, in the sample of inventors. Results indicate a positive impact of gender-egalitarian rules within municipalities on the share of women inventors today (Table 6). Columns (6.1) and (6.3) report results including controls at the individual- and municipality-level and year-fixed effects, while specifications (6.2) and (6.4) add region-fixed effects. Specifically, a one percentage point increase in the city *c*'s share of women founders in Medieval guilds is associated with a 1.5 percentage points higher share of female inventors in that city at the beginning of the 21st century (column (6.1)). After controlling for region-fixed effects, the estimated coefficient of interest decreases to 0.9 (column 6.2).

Finally, we test whether there are non-linearities. Results, reported in columns (6.3)–(6.4), continue to show a positive effect. However, the coefficients are lower than in the previous specifications and are significant only when region-fixed effects are not included.

6.3 Women in guilds and current patent activity of female inventors

Having found a positive effect of a more gender-egalitarian culture in Medieval cities on the current share of women inventors, we now examine whether this translates into a more intense patent application activity by women inventors in these municipalities.

We first estimate equation (4) using the number of yearly patent submissions as the dependent variable. The first two specifications of Table 7 report the results. As it is apparent from column (7.1), on average women apply for patents less intensively than men on a yearly basis; however, the marginal effect of being born in a city with more gender-egalitarian norms ($Female * FWG_c$) increases women's probability to submit a patent to the EPO by 1.1 percentage points (the effect is significant at the 1 percent level).

We also estimate the effect of being born in a city in the upper quartile of the Medieval female participation distribution. Thus, column (7.2) replicates specification (7.1) after substituting FWG_c with the dummy variable FWG_c^{75} and $Female * FWG_c$ with $Female * FWG_c^{75}$. Also in this case the coefficient of interest is positive and statistically significant at the 1 percent level, but its magnitude is lower than before: for a 1 percentage point increase in the share of women in guild founders, the female share of patent applications rises by just 0.02 percentage points, suggesting that the historical persistence effect grows less than proportionally with female participation in the Middle Ages.

We now turn to examine whether these results are confirmed in terms of quality. To this aim, we run the same regressions reported in the first two columns of Table 7 after substituting the dependent variable with the number of patent applications that have been granted, which represent the highest-quality applications (Griliches, 1990). Note that almost 60 percent of the $26,919$ applications presented overall in our sample were granted between 1987 and 2009. Results are reported in columns (7.3)-(7.4). On average, the coefficient of our variables of interest $Female * FWG_c$ and $Female * FWG_c^{75}$, reported in columns (7.3)-(7.4), are not significant. These results suggest that higher female participation in economic life in the Middle Ages favored the development of gender norms that enable today's women to be more assertive, leading them to apply more often for a patent grant; however, such a mechanism acts on female behavior without affecting the probability of actually being granted the patent.

Finally, we test two other sets of specifications (Table 8), in which the dependent variable is the overall productivity of inventors ($Patent_i$), computed either in terms of the total number of patents that each individual submits to the EPO over the entire observational period (columns (8.1)-(8.2)), or, alternatively, in terms of the sum of granted patents that they ever obtain (columns (8.3)-(8.4)).

The number of observations drops from over $210,000$ to $15,430$ because we can keep only one observation per individual (we select the observation relative to the first year the individual appears in the dataset). In all specifications, we control for the number of years the employee is present in the dataset, in addition to firm size, region-, sector-, and time dummies. In line with Jensen et al. (2018), the female dummy is always negative and significant at the 1-5 percent statistical level, while FWG_c and FWG_c^{75} are non-significant. In contrast, our variables of interest, $Female * FWG_c$ and FWG_c^{75}, are always large, positive, and highly significant, both for the number of applications and for the number of obtained granted patents.

In summary, gender norms may be transmitted by peers through the city environment. In particular, women born in municipalities with a more gender-egalitarian culture are more likely to become inventors and apply for patents than those born elsewhere.

7 Robustness checks

We also undertake several robustness checks. Indeed, there could be some geographic or preexisting historical characteristics that are correlated both to women's involvement in Medieval guilds and to the propensity of being a female inventor today (the "geography hypothesis"). Thus, to strengthen our identification strategy, we now include in the regressions three alternative potential confounding factors: the political regime prevailing in the Middle Ages, proximity to a Medieval trade route, and the presence of a University founded before the XIII century.

Thus, we first verify whether our results hold after we control, in addition to the previous covariates, for a dummy variable indicating whether the inventor's municipality of birth was a free-state in the Middle Ages (Tables 9 – 11, Panel A). To construct this variable we use Guiso et al. (2016)'s definition, reported in their NBER WP. According to the authors, the cities that experienced self-government in the Middle Ages today exhibit a higher level of civic capital, and above all, a higher degree of self-efficacy, i.e. the belief in one's own ability to reach goals. It could indeed be argued that the greater gender equality that we observe today in the cities that had experienced more intense female participation in the Medieval guilds, which is the object of this paper, should be in fact be ascribed to the city's past experience of being a free-state. If this was the case, controlling for whether the municipality was a free-state should capture all the effects arising from the Middle Ages.[7]

Second, we verify whether our results hold after controlling for whether an inventor's municipality of birth was a commercial center in the Middle Ages. Bertocchi and Bozzano (2016) find that the women who were living near a commercial route in the Middle Ages were more educated than those living elsewhere and that the Medieval trade patterns were still affecting female education in 1861. Indeed, the increased intensity of international trade in the XIII century made male merchants leave for long periods of time and forced their wives to take charge of their business while they were traveling. Thus, in these cities, women had to be able to read and write and had to study math and bookkeeping. It is then possible that the higher education level obtained by women in the trade centers led them to be more involved in guild foundations. The extent to which the higher literacy rates at the time of Italy's Unification are positively correlated to the share of female inventors today, the coefficients estimated in the previous sections would be biased and inconsistent.

[7]Note, however, that while the political experience of free city-states was limited to the Center-North of the country, the economic activity of guilds was virtually equally spread over the whole territory of what is currently Italy.

Thus, in Panel B of Tables 9 – 11 we add a dummy variable equal to 1 if an inventor's municipality of birth belongs to a Province that contained a commercial hub in the late Middle Ages (for the list of such Provinces see Bertocchi and Bozzano (2016)).

Third, it might be the case that the presence of a University affected women's propensity to be active in guilds in the Middle Ages. Before the XIII century, the period considered in this paper, only 15 universities had been founded.[8] Thus, in Panel C we add to the previous specifications a dummy variable equal to 1 if the province of birth was the seat of a University in the XII century.[9]

Table 9 reports the results for the share of women inventors (replicating specifications (6.2) and (6.4)), while Tables 10 and Tables 11 show, respectively, the outcome for the yearly and overall number of patent applications and grants. All the outcomes confirm the previous Section's results.[10] Thus, while we clearly cannot rule out the "geography hypothesis", we have shown that our results are robust to take into account three major possible confounding factors.

Finally, we test whether results are confirmed when we measure Middle Ages effects on the municipality of residence (rather than that of birth), since people may move throughout their lives. These are not our preferred specifications as results are likely to suffer from an endogeneity bias because people may choose the city of residence based on their chances of working and of progressing in their careers as inventors. The outcome is overall consistent with our main findings, indicating the persistence of a cultural bias despite migration. Note that the coefficients reported in columns (9.7)-(9.8) of Table 9 (Panel D) are larger in size than those relative to the city of birth (see Table 6, specifications (6.2) and (6.4)), probably because to some extent women inventors do sort themselves into the cities that offer the best opportunities and better satisfy their aspirations. In contrast, the results relative to the yearly number of applications (Table 10, Panel D) are of the same order of magnitude as those relative to the city of birth (Table 7). This is not surprising because in equation 4 we always control for firm fixed effects, and thus for the city of work (that basically coincides with the municipality of residence).[11]

[8] They were located in Bologna, Salerno, Modena, Reggio Emilia, Parma, Pavia, Ivrea, Turin, Cremona, Firenze, Fermo, Verona, Vicenza, Forli, and Lucca.

[9] Results do not change if we use a dummy variable for the presence of a University at the municipality level.

[10] Note that in Table 9 the FWG_c^{75} coefficient is now significant at the 10 percent level (in contrast, in Table 6 it was non-significant).

[11] Note that we cannot replicate the results of Table 8 because workers might move various times over the course of their lives, which makes tracking the source of cultural bias over the entire life more challenging.

8 Conclusions

Our work sheds new light on the determinants of the gender gap in innovation. Innovation is widely viewed as a central driver of economic growth and many countries use a variety of policy measures to spur it. A crucial aspect for these policies to be successful is to understand who becomes an inventor.

Our paper focuses on the specific channel of a historically transmitted gender bias that may encourage women to patent. In particular, we test whether the municipalities that in the Middle Ages experienced higher participation of women in guilds developed a more gender-egalitarian culture that persists today and that encourages women to work outside the home and to innovate. We are able to single out the cultural effect because we trace its origin to a historical period whose formal political and economic institutions have long disappeared.

We find that female participation in market-based economic activities persists over time across Italian municipalities. A one percentage point higher share of women in guilds is associated with a 0.5 percentage points higher female labor force participation today, a 0.8 percentage points lower probability of being a housewife, and a 0.8 percentage point higher probability of being an employee (versus being self-employed) in the private sector. Moreover, the cities with more intense participation of women in guilds today exhibit a higher share of women with a college degree, especially from STEM faculties. Finally, a more gender-egalitarian culture increases the share of female inventors and their propensity to submit patent applications to the EPO. We find that the higher intensity of patent applications over the course of a woman inventor's life also leads to more granted patents. Our findings are robust to controlling for three main potential confounding factors: the political regime prevailing in the Middle Ages, proximity to a Medieval trade route, and the presence of a University founded before the XIII century, making the "geography hypothesis" lose ground.

Our results are in line with the hypothesis that social norms on the role of women in society are, at least partly, historically rooted, and are persistent over centuries. Moreover, our findings suggest that female innovation is more influenced by other women's models than by men's, and in particular by the activities that women used to undertake historically in their city. Our conclusions are thus in line with Bell et al. (2019), who obtained that the gender gap in innovation would halve if girls were as exposed to female inventors as boys are to male inventors. Thus, innovation policies targeted to raise women's exposure to scientific subjects and innovation would both help to close up the inventor gender gap and speed up countries' innovation process.

Figure 1: **Distribution of guilds in the Middle Ages.** Source: Our elaboration on data from Central Archive of the State in Rome. Notes: The darkest blue means that in the current municipal territory were present all the guilds considered in this paper: wool, silk, spices, furs, goldsmiths, dyers, blacksmiths, and shoemakers. The lightest shade means that just one of them was present.

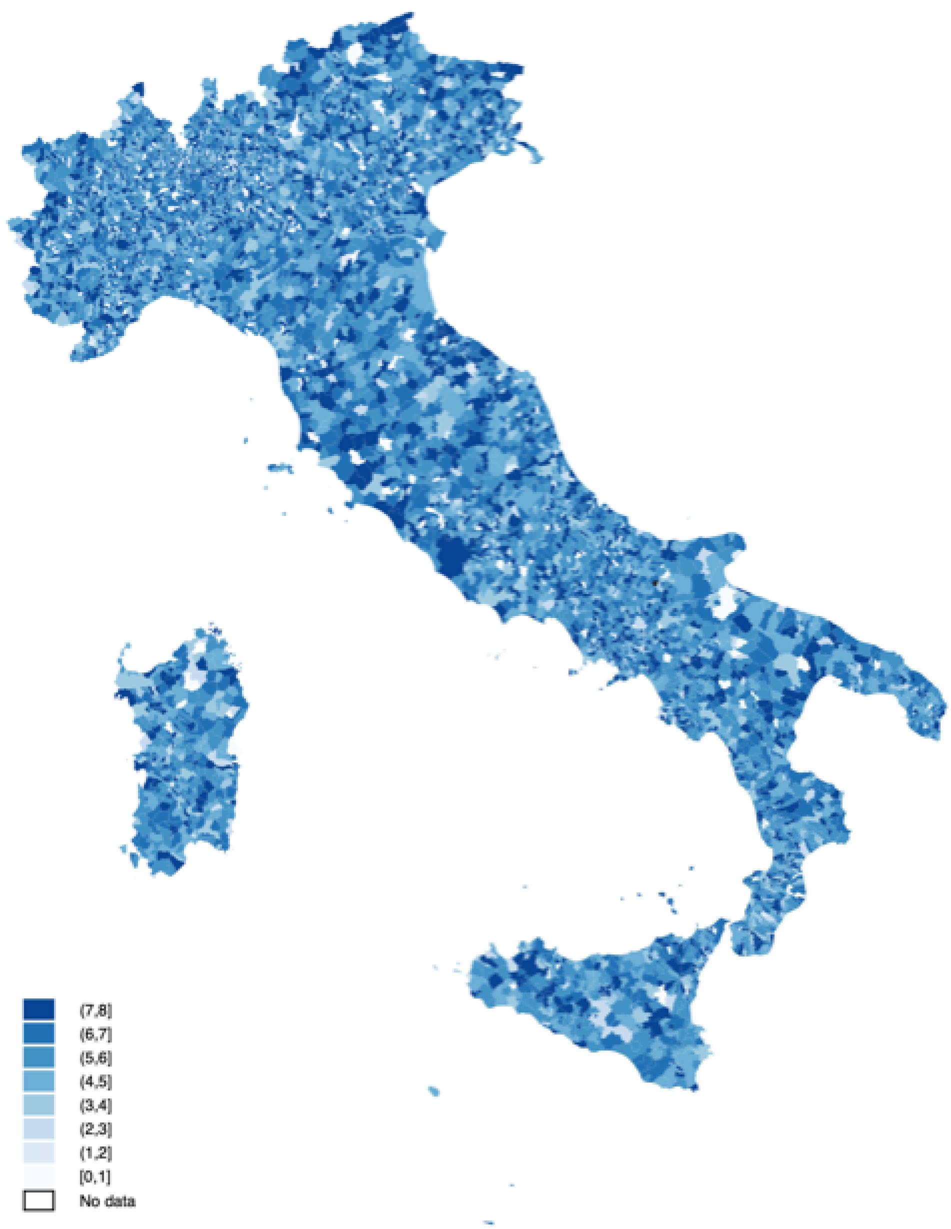

Figure 2: **Women share in Medieval guild members.** Source: Our elaboration on data from Central Archive of the State in Rome. Notes: The darkest red means that current Italian municipalities in the Middle Ages exhibited a higher share of women in any of the 8 guilds considered in this paper (wool, silk, spices, furs, goldsmiths, dyers, blacksmiths, and shoemakers).

Table 1: **Distribution of patent applications and grants by gender and year**

	% Female inventors	No. applications/no. inventors		No. grants/no. inventors	
Sample:	Total	Women	Men	Women	Men
1987	4.4	14.0	15.1	11.7	12.3
1988	4.7	14.1	15.9	12.9	12.7
1989	5.2	15.9	15.7	14.7	12.7
1990	5.7	18.3	19.1	14.5	15.0
1991	5.9	19.9	16.5	16.7	13.8
1992	6.2	22.3	19.1	14.4	14.6
1993	6.3	19.2	17.2	17.2	13.7
1994	6.5	19.9	16.7	13.3	13.7
1995	6.8	18.2	17.1	13.7	13.3
1996	6.9	17.6	18.6	12.9	14.7
1997	7.2	19.0	19.5	15.3	15.7
1998	7.6	20.1	19.3	13.0	15.9
1999	8.0	20.3	21.0	14.0	15.6
2000	8.6	19.9	21.5	14.4	16.2
2001	9.0	22.8	24.2	13.3	16.2
2002	9.3	28.5	27.2	16.3	16.4
2003	9.4	31.7	28.8	14.7	16.0
2004	9.7	32.2	31.0	10.5	15.1
2005	10.0	31.2	30.6	7.5	11.7

Source: European Patent Office, years 1987–2005.

Table 2: **Descriptive statistics on inventors**

	Men		Women		Whole sample	
	mean	sd	mean	sd	mean	sd
FWG_c	.04914	.054278	.054278	.015445	.0495191	.0160271
FWG_c^{75}	.242739	.42874	.342244	.474476	.2500747	.4330568
Municipality size	147.016	239.8404	198.795	308.013	150.8332	245.8848
Municipality altitude	160.769	172.8222	138.582	148.455	159.1335	171.2423
Coastal municipality	.18328	.3868966	.243301	.429089	.1877043	.3904768
Age	39.6311	9.506	34.8543	7.17764	39.27	9.437
Full time	.995176	.0692899	.959144	.197964	.9925195	.0861661
Blue-collar	.05155	.2211181	.015709	.124352	.0489083	.2156768
White-collar	.61193	.4873118	.726421	.44581	.6203702	.4852959
Manager	.003262	.0570173	.003231	.056747	.0032593	.0569974
Other Work Status	.333258	.471379	.25464	.435672	.3274622	.4692886
Open-Ended Contract	.42974	.4950401	.498892	.500015	.4348372	.4957368
Seasonal Contract	.017674	.1317644	.053018	.224077	.0202796	.1409555
Industry	.94175	.2342162	.912206	.283004	.9395721	.2382785
Services	.002132	.0461287	.002154	.046359	.002134	.0461456
Public	.020296	.1410096	.034079	.181437	.0213116	.1444212
Handcraft	.007239	.0847742	.002154	.046359	.0068642	.0825656
Agriculture and Fishing	.000872	.0295187	.000697	.026388	.0008592	.0292994
Credit and Insurance	.000277	.0166489	.000633	.025161	.0003035	.0174191
Retail	.027434	.163344	.048078	.213937	.0289555	.167682
Firm size	3244.11	1127.319	2461.8	6816.58	3186.444	1100.83
Number of authors	.372261	1.111271	.61595	1.64179	.3902249	1.160445
No applications per year	.209876	.73454	.2272123	.6935838	.2111545	.7316114
Overall no. applications	4.03	7.26573	3.685627	5.337268	4.004613	7.141925
No. of grants per year	.068967	.379716	.0644201	.326176	.0686322	.3760302
Overall no. of grants	2.23192	4.92973	1.860138	3.29075	2.204514	4.828912

Source: INPS-Patstat, years 1987–2005. Note: FWG_c is the fraction of women in total guilds' founders; FWG_c^{75} is a dummy variable equal to 1 if city *c* is in the top-25 percentile of the FWG_c distribution.

Table 3: **Distribution of male and female inventors by FWG_c quartiles**

	Male inventors	Female inventors
1st quartile	25.55	17.42
2nd quartile	24.89	22.38
3rd quartile	24.68	27.48
4th quartile	24.88	32.73

Source: INPS-Patstat, years 1987–2005. Note: FWG_c is the fraction of women in total guilds' founders.

Table 4: **Female participation in Medieval guilds and current female labor outcomes**

	Women					
	LFP	% of housewives	% of employees	LFP	% of housewives	% of employees
	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)	(4.6)
FWG_c	0.4862 ***	-0.7754 ***	0.8471 ***			
	(.1652)	(.2096)	(.1764)			
FWG_c^{75}				0.2055 ***	-0.0289 ***	0.0380 ***
				(.0055)	(.0072)	(.0059)
No. obs.	489,949	293,714	203,546	489,949	293,714	203,546
Mean of dep. var.	.481	.313	.780	.481	.313	.780

Source: Labor Force Survey, years 2002-2003, quarterly data. Note: additional control variables include: age, age squared, province fixed-effects, year, quarter fixed-effects, and quarters x year. Note: ***[**](*) denotes significance at the 1[5](10)% confidence level.

Table 5: **Female participation in Medieval guilds and current female college education**

	College	STEM	College	STEM
	(5.1)	(5.2)	(5.3)	(5.4)
FWG_c	1.1867 ***	0.0974 ***		
	(.1067)	(.0282)		
FWG_c^{75}			0.0412 ***	0.0033 ***
			(.0034)	(.0009)
No. obs.	497,260	220,923	497,260	220,923
Mean of dep. var.	.087	.018	.087	.018

Source: Labor Force Survey, years 2002-2003, quarterly data. Note: additional control variables include: age, age squared, province fixed-effects, year, quarter fixed-effects, quarter x year. ***[**](*) denotes significance at the 1[5](10)% confidence level.

Table 6: **Female participation in Medieval guilds and share of women inventors**

	Share of women inventors							
	(6.1)		(6.2)		(6.3)		(6.4)	
FWG_c	1.477	***	0.867	**				
	(0.124)		(0.442)					
FWG_c^{75}					0.046	***	0.022	
					(0.004)		(0.014)	
Obs.	15,431		15,431		15,433		15,433	
Controls	Yes		Yes		Yes		Yes	
Region fixed-effects	No		Yes		No		Yes	
Year fixed-effects	Yes		Yes		Yes		Yes	
Mean of dep. var.	.089		.089		.089		.089	

Source: European Patent Office; INPS. Note: All the regressions include controls for the city's altitude and surface, a dummy for a coastal municipality, worker's age, work status, type of contract, and firm size. ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size, measured by the number of workers. Standard errors, in parentheses, are clustered at the municipality level.

Table 7: **Yearly number of applications and grants**

	Yearly number of applications				Yearly number of patent grants			
	(7.1)		(7.2)		(7.3)		(7.4)	
Female x FWG_c	1.120	***			-0.151			
	(0.324)				(0.184)			
FWG_c	-0.541	**			0.019			
	(0.240)				(0.154)			
Female	-0.104	***	-0.043	***	-0.014		-0.020	***
	(0.028)		(0.010)		(0.011)		(0.002)	
Female x FWG_c^{75}			0.023	***			-0.006	
			(0.009)				(0.005)	
FWG_c^{75}			-0.010				-0.001	
			(0.009)				(0.005)	
Controls:	Yes		Yes		Yes		Yes	
Year fixed-effects:	Yes		Yes		Yes		Yes	
Region fixed-effects:	Yes		Yes		Yes		Yes	
Firm fixed-effects:	Yes		Yes		Yes		Yes	
Mean of dep. variable	.213		.213		.069		.069	
No. obs.	211,107		211,141		211,107		211,141	

Source: European Patent Office; INPS. Note: All the regressions include controls for the city's altitude and surface, a dummy for a coastal municipality, worker's age, work status, type of contract, and number of patent coauthors. ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size, measured by the number of workers. Standard errors, in parentheses, are clustered at the municipality level.

Table 8: **Overall number of applications and grants**

	Number of applications				Number of patent grants			
	(8.1)		(8.2)		(8.3)		(8.4)	
Female x FWG_c	16.560	***			6.255	***		
	(5.098)				(2.050)			
FWG_c	-13.749				-7.334			
	(8.448)				(6.419)			
Female	-1.199	***	-0.355	**	-0.532	***	-0.196	***
	(0.443)		(0.173)		(0.122)		(0.039)	
Female xFWG_c^{75}			0.436	***			0.131	***
			(0.130)				(0.048)	
FWG_c^{75}			-0.350				-0.180	
			(0.248)				(0.182)	
Controls:	Yes		Yes		Yes		Yes	
Year fixed-effects:	Yes		Yes		Yes		Yes	
Region fixed-effects:	Yes		Yes		Yes		Yes	
Firm fixed-effects:	No		No		No		No	
Mean of dep. variable	3.80		3.80		2.03		2.03	
No. obs.	15,431		15,433		15,431		15,433	

Source: European Patent Office; INPS. Note: All the regressions include controls for the city's altitude and surface, a dummy for a coastal municipality, worker's age, work status, type of contract, number of patent coauthors, and firm size. ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size, measured by the number of workers. Standard errors, in parentheses, are clustered at the municipality level.

Table 9: **Robustness checks on the share of women inventors**

Panel A: Medieval Free City-State		
	(9.1)	(9.2)
FWG_c	0.881 *	
	(.462)	
FWG_c^{75}		0.0238 *
		(.0143)
No. obs.	15,431	15,433

Panel B: Medieval Trade route		
	(9.3)	(9.4)
FWG_c	0.909 **	
	(.459)	
FWG_c^{75}		0.024 *
		(.014)
No. obs.	15,431	15,433

Panel C: Pre-XIII century University		
	(9.5)	(9.6)
FWG_c	0.853 **	
	(.348)	
FWG_c^{75}		0.022 *
		(.013)
No. obs.	15,431	15,433

Panel D: City of arrival		
	(9.7)	(9.8)
FWG_c (city of residence)	1.899 ***	
	(.384)	
FWG_c^{75} (city of residence)		0.046 *
		(.024)
No. obs.	15,960	15,960

Source: European Patent Office; INPS. Note: All the regressions include controls for workers' age, work status, type of contract, and firm size; geographical characteristics of the city (altitude, surface, a dummy if on the coast); region fixed-effects and year fixed-effects. ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size, measured by the number of workers. Standard errors, in parentheses, are clustered at the municipality level.

Table 10: Robustness check on the yearly number of applications and grants

Panel A: Medieval Free City-State								
	Yearly number of applications				Yearly number of patent grants			
	(10.1)		(10.2)		(10.3)		(10.4)	
Female x FWG_c	1.121	***			-0.151			
	(0.324)				(0.184)			
FWG_c	-0.549	**			0.016			
	(0.239)				(0.154)			
Female	-0.104	***	-0.043	***	-0.014		-0.020	***
	(0.028)		(0.010)		(0.011)		(0.002)	
Female x FWG_c^{75}			0.023	***			-0.006	
			(0.009)				(0.005)	
FWG_c^{75}			-0.009				-0.001	
			(0.008)				(0.005)	
No. obs.	211,107		211,141		211,107		211,141	

Panel B: Medieval Trade route								
	Yearly number of applications				Yearly number of patent grants			
	(10.5)		(10.6)		(10.7)		(10.8)	
Female x FWG_c	1.121	***			-0.151			
	(0.324)				(0.184)			
FWG_c	-0.553	**			0.013			
	(0.234)				(0.150)			
Female	-0.104	***	-0.043	***	-0.014		-0.020	***
	(0.028)		(0.010)		(0.011)		(0.002)	
Female x FWG_c^{75}			0.023	***			-0.006	
			(0.009)				(0.005)	
FWG_c^{75}			-0.010				-0.001	
			(0.008)				(0.005)	
No. obs.	211,107		211,141		211,107		211,141	

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Panel C: Pre-XIII century University								
	Yearly number of applications				Yearly number of patent grants			
	(10.9)		(10.10)		(10.11)		(10.12)	
Female x FWG_c	1.120	***			-0.150			
	(0.322)				(0.185)			
FWG_c	-0.540	**			0.012			
	(0.242)				(0.153)			
Female	-0.104	***	-0.043	***	-0.014		-0.020	***
	(0.028)		(0.010)		(0.011)		(0.002)	
Female x FWG_c^{75}			0.023	***			-0.006	
			(0.009)				(0.005)	
FWG_c^{75}			-0.010				-0.001	
			(0.009)				(0.005)	
No. obs.	211,107		211,141		211,107		211,141	

Panel D: City of arrival								
	Yearly number of applications				Yearly number of patent grants			
	(10.13)		(10.14)		(10.15)		(10.16)	
Female x FWG_c	1.107	**			-0.273			
	(0.475)				(0.170)			
FWG_c (city of residence)	-0.446	*			-0.267	**		
	(0.231)				(0.122)			
Female	-0.122	***	-0.064	***	-0.012		-0.029	***
	(0.040)		(0.016)		(0.012)		(0.005)	
Female x FWG_c^{75}			0.030	**			-0.003	
			(0.015)				(0.007)	
FWG_c^{75} (city of residence)			-0.043	***			-0.011	*
			(0.013)				(0.006)	
No. obs.	214,132		214,132		214,132		214,132	

Source: European Patent Office; INPS. Note: All the regressions include controls for workers' age, work status, type of contract, number of patent coauthors, and geographical characteristics of the city (altitude, surface, a dummy if on the coast); region fixed-effects, firm fixed-effects, and year fixed-effects. ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size, measured by the number of workers. Standard errors, in parentheses, are clustered at the municipality level.

Table 11: Robustness check on the overall number of applications and grants

Panel A: Medieval Free City-State								
	Number of applications				Number of patent grants			
	(11.1)		(11.2)		(11.3)		(11.4)	
Female x FWG_c	16.622	***			6.361	***		
	(5.108)				(2.060)			
FWG_c	-14.062	*			-7.864			
	(8.530)				(6.444)			
Female	-1.204	***	-0.356	**	-0.540	***	-0.198	***
	(0.443)		(0.174)		(0.123)		(0.039)	
Female x FWG_c^{75}			0.436	***			0.132	***
			(0.130)				(0.048)	
FWG_c^{75}			-0.352				-0.186	
			(0.248)				(0.182)	
No. obs.	15,431		15,433		15,431		15,433	

Panel B: Medieval Trade route								
	Number of applications				Number of patent grants			
	(11.5)		(11.6)		(11.7)		(11.8)	
Female x FWG_c	16.756	***			6.381	***		
	(5.136)				(2.037)			
FWG_c	-14.189	*			-7.617			
	(8.293)				(6.328)			
Female	-1.213	***	-0.358	**	-0.541	***	-0.198	***
	(0.445)		(0.173)		(0.122)		(0.039)	
Female x FWG_c^{75}			0.438	***			0.133	***
			(0.130)				(0.048)	
FWG_c^{75}			-0.353				-0.181	
			(0.244)				(0.179)	
No. obs.	15,431		15,433		15,431		15,433	

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	Panel C: Pre-XIII century University			
	Number of applications		Number of patent grants	
	(11.9)	(11.10)	(11.11)	(11.12)
Female x FWG_c	16.654 ***		6.320 ***	
	(4.879)		(2.199)	
FWG_c	-13.175 *		-6.939	
	(7.486)		(5.550)	
Female inventor	-1.205 ***	-0.356 **	-0.536 ***	-0.197 ***
	(0.430)	(0.171)	(0.129)	(0.038)
Female x FWG_c^{75}		0.439 ***		0.133 ***
		(0.127)		(0.050)
FWG_c^{75}		-0.317		-0.157
		(0.210)		(0.147)
No. obs.	15,431	15,433	15,431	15,433

Source: European Patent Office; INPS. Note: All the regressions include controls for workers' age, work status, type of contract, number of patent coauthors, and firm size; geographical characteristics of the city (altitude, surface, a dummy if on the coast); region fixed-effects and year fixed-effects. ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size, measured by the number of workers. Standard errors, in parentheses, are clustered at the municipality level.

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