Women Inventors:

The Legacy of Medieval Guilds *

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23 December 2024

Abstract

This paper studies whether the innovation gender-gap is historically rooted, using evidence from social norms formed in the Italian Medieval guilds. We employ a unique dataset that matches Italian administrative employer-employee records to patent data from the European Patent Office (1987-2005) and municipality-level information on medieval guilds. We show that women's low propensity to patent can be explained by the share of women in guild founders from the Middle Ages. 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.

*We thank Federico Barbiellini Amidei, Graziella Bertocchi, Federico Cingano, Marta De Philippis, Kathy Grady, Sauro Mocetti, Giovanni Pica and Eliana Viviano for their precious comments, and the participants at the World Economic History Conference (Paris; July 25-29, 2022), the Bank of Italy's Gender Economics Workshop (Rome; June 23, 2023), the Associazione Italiana Economia del Lavoro (Genoa; September 8-9, 2023), the European Association of Labor Economists (Bergen; September 5-7, 2024). We express our gratitude to the Paris-Dauphine Foundation for generously funding this project. The views expressed herein are those of the authors and not necessarily those of the Bank of Italy.

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1 Introduction

During the last few decades, the share of women in the labor force has increased substantially in most Western European countries. However, large geographical differences in female labor force participation persist, across and within Europe (Ortiz-Ospina et al., 2024). In 2022 the lowest female participation rate among EU countries was recorded in Italy (Carta et al., 2023), where geographical differences in gender disparities are highly pronounced: the gender differentials in employment rates was 14.5 percentage points in the North and 24.8 in the South. The gender gap in women's patenting activity is even greater: in 2010-2019, the women inventor rate (WIR) was just 14.3 in Italy, against 16.6 and 23.2 percent in France and Spain, respectively (although in Germany it was only 10 percent; EPO 2022).[1] Although the gender gap in patenting is gradually closing up, the pace at which this occurs remains slow. 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 in 1940-1980).

Social norms and attitudes in a conservative society may prevent women from entertaining professional aspirations: women may negatively select into the labor market, and more specifically, into the innovative sectors. The negative selection could occur at an earlier stage: fewer female students may enroll in a STEM (Science, Technology, Engineering, and Math) university, which 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 females among college graduates is above the European average (60 percent in 2021). Still, the percentage of female graduates in a STEM major is just 40, lowering to 27 in ICT and engineering (Bovini et al., 2024). Not surprisingly, the percentage of women in R&D personnel and researchers is around 30 (in 2010-19; EPO, 2022). Most 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: 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.

This paper investigates whether the innovation gender-gap is historically rooted, using evidence from social norms formed in the Italian Medieval municipalities. More specifically, we collect novel information on the gender of the founders of the main eight

[1] WIR measures the percentage of women inventors among all inventors listed in patent applications in a year; a woman is an inventor if she has applied for at least one patent during her career.

Medieval guilds in Italian municipalities to create a new indicator of gender-egalitarian norms. 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.[2] Several historical records indicate that women in the Middle Ages gained substantial decision-making and economic power through these institutions (Bellavitis, 2002).

We hypothesize that the cities that experienced higher female participation in the labor market since the Middle Ages developed a more gender-egalitarian culture that was transmitted over centuries and generations and that today shapes women's education and labor supply decisions. In the context of this paper, the "culture" of a city is the collection of norms, values, and beliefs associated with female role models, regarding, for instance, whether women are expected to be housewives or work in the labor market, or whether they can freely choose their field of study. In a study on stereotypes conducted on the web, Nosek et al. (2002) obtain that science and career are commonly associated with men, while liberal arts and family are with women. Thus, girls' academic self-concept, their choice of a scientific field of study, and consequently the likelihood of working as an inventor depend on the culture into which they were born and raised. To empirically verify this hypothesis, we construct an indicator classifying Italian municipalities according to their share of women in Medieval guilds' founders and test its impact on the current female propensity to invent (proxied by patent applications like for instance, Akcigit et al., 2023) and other female outcomes.

For our analysis to be causal, the municipalities with higher values of women's participation in guild foundations today should exhibit a larger number of female inventors *only because* of women's involvement in the Medieval labor market, after conditioning on the observable characteristics. We thus control for historical and geographical characteristics that increase the validity of this exclusion restriction. A first possible concern is that results are driven by municipalities' geographical characteristics that favored both women in guilds and long-term women's outcomes (the "geography hypothesis"). Even though the geography hypothesis seems unlikely, given that the distribution of the corporations and of the women who participated in their foundation was rather uniform over the Italian territory (see Figure 1), we also control for time-invariant municipality characteristics,

[2]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). 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).

such as altitude, land area, and a dummy for whether the city is located near the coast. A second concern may be that results are driven by other historical pre-existent characteristics that may have favored female participation in guilds and current female outcomes (the "history hypothesis"). To take into consideration this concern we also control for the presence of a local University founded before the XIII century and for whether the town was close to a commercial route in the Middle Ages, as in these cities merchants' wives acquired reading and writing abilities that were necessary for substituting they husbands during their trade trips (Bertocchi and Bozzano, 2016). Finally, our indicator of women's participation in guilds is computed on information restricted to the Middle Ages: before this historical period guilds did not exist and restrictions to female participation in guilds' activity began to arise later (in the XV century; Bellavitis, 2002 and Rescigno, 2016).[3] Conditional on the observable geographical and historical municipality characteristics, the identifying assumption of our empirical strategy rests on the idea that the proportion of women among guild founders is unrelated to other features that could affect the long-term proportion of women inventors.

Before examining 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 education and female labor market outcomes. We find that the women living in the cities that in the past had a higher intensity of female participation in guilds today exhibit higher chances of graduating, especially from a STEM faculty, a higher chance to join the labor force participation, and a lower probability of being housewives. These results suggest that the diffusion of cultural norms over centuries can affect current female education and labor outcomes.

We then turn to analyze inventors, 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 are able to compute the Middle Ages effect based on the inventors' municipality of birth to test whether the culture women were raised into matters regardless of where they are living as adults. We find that cities with more intense female participation in Medieval guilds exhibit a 0.8 percentage points higher share of female inventors today. In these cities, women are more likely to submit patent applications to the EPO than elsewhere, both on a yearly basis

[3]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.

and over their lives. In particular, 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 find no gender differentials in the patent application quality correlated to the intensity of female participation in guilds.

This paper contributes to three strands of the literature. First, we contribute to an increasing body of work studying which background characteristics, especially education, determine individual propensity to innovate. 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. Kim and Moser (2021) find that female scientists are more likely to hold a Ph.D. than their male counterparts, while Jensen et al. (2018) show that the acceptance rate of patents submitted by women is lower than that of men. In the context of Italy, Bianchi and Giorcelli (2020) document that university-level scientific education changes the direction of innovation, while Di Addario et al. (2024) show the importance of inventors' coworker networks for firms' innovation. Finally, recently some literature on historical patents has emerged, using evidence from female inventors in Italy (Martinez, 2024), France (Merouani and Perrin, 2024), and from local exhibitors in Germany during the Industrial Revolution (Cinnirella et al., 2022). We contribute to this literature by studying to what extent historical and cultural exposure to women inventors in the past can affect women's probability of patenting today.

Second, this paper adds to the literature on the legacy of culture and history on current economic performance. The literature on persistence dates back to Putnam (1993)'s seminal work, which argued that the current efficacy of local governments in Italy depends on the degree of local civic commitment that originated from the political regime prevailing in the Middle Ages. Along these lines, Guiso et al. (2016) show that the higher level of social capital developed in the Medieval communes persists today and was transmitted to the population through a more pervasive sense of self-efficacy. Based on these findings, a few papers analyze the effect of social capital on economic performance, under the hypothesis that the Medieval political regime shaped today's degree of local civicness without having other direct effects on current outcomes (for instance, de Blasio and Nuzzo, 2009). 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 another outcome to this literature: the propensity to innovate, stemming from the historical roots of the inventors' municipality of birth.

Finally, we contribute to the literature on gender norms and persistence. Alesina et al. (2013) show that the agricultural system prevailing in the pre-industrial period determined a production specialization along gender lines that affects contemporary views about gender roles and female labor force participation in present days. Boelmann et al. (2024) analyze the effect of the cultural norms acquired during childhood and those deriving from the adulthood environment on women's labor supply decisions after childbirth, and find that the East German more egalitarian gender norms (due to socialism) are persistent whereas the more traditional West German ones are not. While it has been shown that gender bias affects women's social and economic outcomes through the labor market (see, among others, also 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 and 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 within the same country, which allows more precise comparisons as regions have more similar institutions and cultural norms than different countries.

The rest of the paper is structured as follows. Section 2 presents the data and the variables, Section 3 the descriptive statistics, and Section 4 the empirical strategy and results. Finally, Section 5 concludes.

2 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.

2.1 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. 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).

2.2 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 Di Addario (2014) used the release of April 2009; we drop the years 2006-2009 because, in the last period, 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, and the date the patent was granted (if it was). 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 names of inventors, applicants, and locations, and assigned VAT codes to firms and Istat codes to municipalities.

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 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) 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 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 could 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 could 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 submitted by firms to the EPO individually or as a coauthor, regardless of whether the application was eventually granted.

2.3 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 and to provide protection and mutual aid. Guilds were prolific throughout Europe between the 11th and 17th centuries as both business and social organizations.

We leverage the fact that the foundation of a guild required a statute indicating 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 (the *Fondi Carte Medievali*, buste 112-129). We use this information to reconstruct the gender of the founding members for the eight major guilds in various Italian municipalities: wool, silk, spices, furs, goldsmiths, dyers, blacksmiths, and shoemakers.

City borders in the Middle Ages differed from those at present. Using GIS to geolocate the ancient city of guilds, we overlapped the maps of Medieval municipalities collected from the Historical Archives with 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.[4]

Since all female inventors in our sample were born in municipalities with all eight guilds, we do not distinguish between guild types. We construct indicators at the municipality level for the number of guilds that existed in the Middle Ages and for the share of women in total founders joining any of the guilds.

[4]Namely, $7,904$ municipalities, with the only exceptions of Cermes (Bolzano) and Misiliscemi (Trapani). Note that if a municipality's current area spans multiple Medieval cities, we impute the sum of all their guild members to the current municipality. If, on the contrary, one Medieval municipality corresponds to more than one current city, we attribute the guild members to each of today's cities by dividing them equally among each of them.

3 Descriptive Statistics

In the period 1987-2005, INPS-PatStat comprises more than $16,000$ inventors (including about $1,400$ women). After disregarding the 600 individuals born abroad, we are able to associate all the remaining inventors to at least one Medieval guild by their municipality of birth. Our final sample comprehends more than $15,400$ inventors, 9 percent of whom are women.

Women are a minority among inventors in Italy and worldwide, although the gap is slowly reducing: the share of female inventors in our sample increased from 4 percent in 1987 to 10 percent in 2005. However, when examining the yearly share of applications in the number of inventors, we do not find much difference between men and women. Thus, on average, women are not less innovative than men, although the gap enlarges when we focus only on the applications that will eventually be granted.

Table 1 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: 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, are less (more) likely to be blue (white-)-collar workers, equally likely to be managers, and less likely to work full-time. Among the people who provided information on the type of contract (just about half of the sample), the majority have an open-ended contract irrespective of gender.

When examining the distribution of inventors by the municipality of birth, we observe that the totality of female inventors in the sample was 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 1 reports the share of women in total guild members in the Middle Ages: the map does not exhibit any specific territorial pattern.

Finally, when looking at the distribution of male and female inventors according to the intensity of women's participation in guilds in the Middle Ages, we find that while men are equally distributed among the quartiles of the distribution, female inventors are more concentrated in the cities with a higher female presence 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 persist today.

4 Empirical Strategy and Results

This paper hypothesizes that the cities in which women had a more active labor market role in the Middle Ages (i.e. participated in founding guilds to a greater extent than elsewhere) developed a more gender-egalitarian culture that over the centuries "legitimized" women to study longer, graduate in scientific subjects, undertake careers as inventors, and, more generally, work outside the home.

Our variable of interest, the fraction of women in total guilds' members (FWG_c) in municipality c, exploits 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 collected from the National Archive of State:

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

We link FWG_c to INPS-PatStat data by inventors' municipality of birth (Sections 4.2-4.3). The extent to which the place of birth can be considered exogenous (once parents have chosen their location), we can interpret FWG_c as the causal effect of being born in a city with more intense female participation in Medieval guilds on the probability of being a female inventor in municipality c. The mechanism would operate through the acquisition of more gender-egalitarian cultural norms through childhood, regardless of whether the person moved elsewhere later.

In contrast, for the analysis on the course of studies and participation in the labor market, place of birth is not available in the data and we can link our variable of interest only to individuals' municipality of residence (Section 4.1). We are aware that basing our analysis on the city of residence may introduce endogeneity issues since people can choose where to live; thus, we take the results of Section 4.1 as descriptive.

Another threat to our identification strategy is the presence of geographic or preexisting historical features correlated both to women's involvement in Medieval guilds and the propensity of studying longer or being in the labor market. To reduce the possibility that female participation in guild foundation is related to other characteristics that can affect the long-term proportion of women inventors, we always control for additional geographical (altitude, land area, and a dummy variable for whether the city is on the coast) and historical city characteristics (the presence of a University founded before the XIII century and proximity to a Medieval trade route). Indeed, it might be the case that the presence of a local University in the Middle Ages affected women's propensity to be active in guilds. Thus, we always control for whether cities hosted one of the 15 universities

that had been founded before the XIII century. In addition, 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 and forced their wives to take charge of their business while 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. Thus, we control for whether the individual's municipality was a commercial center in the Middle Ages, to avoid biased and inconsistent estimates in case the higher female literacy rates in the Medieval commercial routes were positively correlated to the share of female college graduates, STEM students, and inventors today.

Our analysis documents that the municipalities that developed more gender-egalitarian social norms since the Middle Ages, today exhibit a higher probability that women graduate from college, enroll in STEM majors, become inventors, and submit patent applications. It also shows that these cities are characterized by a higher female labor force participation and a lower share of women choosing to be housewives.

4.1 Women in Guilds and Current Female Outcomes in Italian Municipalities

The main objective of this paper is the analysis of the specific labor market of inventors, who are highly specialized workers. It is useful to first examine whether the social norms that originated 800 years ago induce women to study longer. In this section, we investigate whether the girls living in the cities with higher female participation in Medieval guilds' foundations are also more likely to obtain a college degree and, in particular, a degree from a STEM faculty. Moreover, we study the correlation between living in those cities and the current women's likelihood of joining the labor market or being housewives.

We use quarterly individual data from the LFS, the primary source of information on working conditions at the individual level in Italy. We estimate the following equation in the sample of working-age women and report the results in Table 2:

$$Y_{ict} = \beta_1 FWG_{c(i)} + \beta_2 X_{ict} + \beta_3 Z_c + \phi_{LLM} + \gamma_t + \epsilon_{ct}, \tag{2}$$

where the outcome variables are (alternatively) being a college graduate (columns (2.1)-(2.2)), having graduated from a STEM faculty (specifications (2.3)-(2.4)), being in

the labor force ((2.5)-(2.6)), or being a housewife ((2.7)-(2.8)) in municipality c at time t. X is a quadratic form of individuals' age; ϕ_{LLM} represents LLM-fixed effects,[5] and γ_t contains the year-, the quarter-fixed effects, and their interaction with time. The variable of interest, $FWG_{c(i)}$, is linked to LFS by women's municipality of residence. The second specification for each dependent variable reported in Table 2 includes Z, the historical and geographical characteristics of the municipality of residence described in the previous section. Standard errors are always clustered at the municipality level.

Results indicate that a one percentage point increase in Medieval guilds' female ratio is associated with a 0.8 percentage points higher probability that a female student graduates from college (at the 1 percent statistical level; column (2.2)). In terms of standard deviations, the increase is very large: it amounts to 2.8. Moreover, female students are 0.2 percentage points more likely to graduate 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 (column (2.4)). In terms of standard deviations, the increase is 0.9.

Table 2 also reports the results on the labor market outcomes. Results show that a one percentage point increase in Medieval guilds' female ratio is associated with a 0.4 percentage points higher female labor force participation today (at the 5 percent statistical level; column (2.6)). An increase of one standard deviation in Medieval guilds' female ratio corresponds to a 0.7 percentage point increase in current female labor force participation. Finally, a one percentage point increase in the share of women in municipality c's guild members 800 years ago is associated with a 0.9 percentage point lower chance of being a housewife in the same city (at the 1 percent level; (2.8)), or a 1.9 reduction in terms of standard deviation, 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.

4.2 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. The extent to which the place of birth can be considered exogenous (once parents have chosen their location), we can interpret the FWG_c coefficient as the causal effect of being born in a city with more intense female

[5] In 2001 Italy counted 686 LLMs, partitioning the entire country. They are "self-contained" labor markets: ISTAT singles them out based on workers' daily commuting flows from place of residence to place of work (Istat, 2005).

participation in Medieval guilds on the current share of female inventors in municipality c. More specifically, we estimate the following equation in the sample of inventors:

$$Y_{ict} = \beta_1 FWG_{c(i)} + \beta_2 X_{ict} + \beta_3 Z_{c(i)} + \phi_{LLM} + \gamma_t + \epsilon_{ct}, \quad (3)$$

where Y_{ict} is a dummy variable equal to one if the inventor is a woman. We also control for workers' age, work status, type of contract, and firm size (X_{ict}); ϕ_{LLM} represents LLM-fixed effects and γ_t year fixed-effect. 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 cities' geographical and historical features ($Z_{c(i)}$). Observations are weighted by municipality size (measured by the number of workers) and standard errors are clustered at the municipality level.

Results indicate a positive impact of cities' gender-egalitarian rules on the share of women inventors today (Table 3). Column (3.1), reporting the outcomes obtained after controlling for the individual characteristics and for year-fixed effects, shows that a one percentage point increase in 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. After controlling for LLM-fixed effects, the estimated coefficient of interest almost halves (column 3.2), while adding the geographical and historical variables at the municipality level stabilizes the impact at 0.8 percentage points (column 3.3). In terms of standard deviations, this increase is very large (2.8).

4.3 Women in Guilds and Current Patent Applications of Female Inventors

We now examine whether the positive effect of a more gender-egalitarian culture in Medieval cities on the current share of women inventors translates into a more intense patent activity by the female inventors in these municipalities. In this section, we thus focus on inventors' "productivity" in terms of patent applications and we estimate the following OLS model (in the sample of inventors):

$$Patent_{ijt} = \beta_1 Female_i + \beta_2 FWG_{c(i)} + \beta_3 Female * FWG_{c(i)} + \beta_4 X_{it} + \beta_5 Z_{c(i)} + \delta_j + \gamma_t + \epsilon_{ijt}, \quad (4)$$

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 will

eventually be granted in our observational period. To raise the estimates' precision, we add a vector of individual observable characteristics (X_{it}), such as age, work status, a dummy for a full-time contract, and a dummy for an open-ended contract. We also control for the number of patent-coauthors, year dummies γ_t, the geographical and historical municipality characteristics $Z_{c(i)}$, and firm-fixed effects δ_j, because in our context the decision to apply for a 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 in equation (4) patents can also be submitted by men, our variable of interest is now the interaction between the $Female$ dummy and $FWG_{c(i)}$ ($Female * FWG_{c(i)}$ from now on), after controlling for gender and $FWG_{c(i)}$. In this case, the coefficient of interest β_3 represents the marginal effect of applying for a patent for a woman born in a municipality that experienced higher female participation in Medieval guilds.

We first estimate equation (4) using the number of yearly patent submissions as the dependent variable. As it is apparent from the first column of Table 4, Panel A, controlling for the covariates at the worker-, firm- and year-level, on average each year women apply for patents less intensively than men; 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 0.7 percentage points (at the 10 percent level). Adding all the covariates raises the effect of interest to 1.1 percentage points (at the 1 percent statistical significance level), which corresponds to a 1.5 percent increase in terms of standard deviations.

We now examine whether these results are confirmed in terms of quality. To this aim, we run the same regressions reported in Panel A 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 $27,000$ applications presented overall in our sample have been granted between 1987 and 2009. Results are reported in Table 4's Panel B. The coefficient of our variable of interest $Female * FWG_c$ is significant only in the first specification: when we control for firm fixed-effects it loses significance. These results suggest that higher female participation in Medieval economic life favored the development of gender norms that currently enable women to undertake scientific careers and to contribute to patent applications more often than elsewhere. However, while these norms affect female behavior they do not have an impact on the probability of being granted a patent, which does not statistically differ from men's once we take into account unobserved firm characteristics.

5 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 experienced higher participation of women in guilds in the Middle Ages developed a more gender-egalitarian culture that persists today and encourages women to innovate.

Our results align with the hypothesis that social norms on the role of women in society are, at least partly, historically rooted, and are persistent over centuries. Policies should thus aim at targeting female students to enroll in STEM faculties and at encouraging female participation in innovation, especially in the areas more permeated by traditional social norms.

Figure 1: **FWG: Female share in Medieval guild members.** Source: Our elaboration on data from the Central Archive of the State in Rome. Notes: The darker red means that in the Middle Ages the city (at current Italian borders) 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: **Descriptive statistics on inventors**

	Men		Women		Whole sample	
	Mean	Std. Dv.	Mean	Std. Dv.	Mean	Std. Dv.
			Individual-level variables			
Age	39.631	9.506	34.854	7.178	39.270	9.437
Full-time	0.995	0.069	0.959	0.198	0.993	0.086
Blue-collar	0.052	0.221	0.016	0.124	0.049	0.216
White-collar	0.612	0.487	0.726	0.446	0.620	0.485
Manager	0.003	0.057	0.003	0.057	0.003	0.057
Other work status	0.333	0.471	0.255	0.436	0.327	0.469
Seasonal contract	0.018	0.132	0.053	0.224	0.020	0.141
Open-end contract	0.430	0.495	0.499	0.500	0.435	0.496
Patent's no. of authors	0.372	1.111	0.616	1.642	0.390	1.160
No. of patent applications per year	0.210	0.735	0.227	0.694	0.211	0.732
Overall no. of patent applications	4.030	7.266	3.686	5.337	4.005	7.142
No. of patent grants per year	0.069	0.380	0.064	0.326	0.069	0.376
Overall no. of patent grants	2.232	4.930	1.860	3.291	2.205	4.829
			Firm characteristics			
Industry	0.942	0.234	0.912	0.283	0.940	0.238
Services	0.002	0.046	0.002	0.046	0.002	0.046
Public	0.020	0.141	0.034	0.181	0.021	0.144
Handcraft	0.007	0.085	0.002	0.046	0.007	0.083
Agriculture and Fishing	0.001	0.030	0.001	0.026	0.001	0.029
Credits and Insurance	0.000	0.017	0.001	0.025	0.000	0.017
Retail	0.027	0.163	0.048	0.214	0.029	0.168
Firm-size (log)	5.921	2.235	6.296	2.054	5.941	2.224
			Municipality-level variables			
FWG_c	0.049	0.054	0.054	0.015	0.050	0.016
Altitude	160.765	172.839	138.590	148.471	160.765	172.839
Coastal dummy	0.817	0.386	0.757	0.429	0.812	0.390
Municipality size (km^2)	147.036	239.861	198.737	307.923	150.847	245.894
Medieval trade route dummy	0.609	0.487	0.666	0.472	0.613	0.487
Pre-XIII century university dummy	0.162	0.368	0.152	0.359	0.161	0.36

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

Table 2: **Female participation in Medieval guilds and current female outcomes**

	College			STEM			LFP			% of housewives		
	(2.1)		(2.2)	(2.3)		(2.4)	(2.5)		(2.6)	(2.7)		(2.8)
FWG_c	1.2890	***	0.7891 ***	0.2987	***	0.1714 ***	0.8122	***	0.3703 **	-1.1734	***	-0.8737 ***
	(.1203)		(.1166)	(.0567)		(.0543)	(.1915)		(.1724)	(.2389)		(.2447)
No. obs.	497,267			220,931			489,945			293,716		
Mean of dep. var.	.087			.040			.481			.313		
Std. dev. of dep. var.	.281			.197			.500			.464		

Source: Labor Force Survey, years 2002-2003, quarterly data. Note: additional control variables include: age, age squared, LLM fixed-effects, year, quarter fixed-effects, and quarters x year. The control variables at the municipality level are the city's altitude and surface, a dummy for being near the coast, a dummy for whether the city was located near a Medieval trade route (i.e., Novara (Vercelli), Turin, Genoa, Bergamo, Brescia, Como, Cremona, Milan, Pavia, Padua, Udine, Venice, Bologna, Ferrara, Modena, Parma, Piacenza, Arezzo, Florence, Pisa, Siena, Rome, Perugia, Naples, Salerno, Bari, Lecce, Catanzaro, Messina, Siracusa, Palermo, and Sassari), and a dummy for the presence of a University before the XIII century (i.e., Bologna, Salerno, Modena, Reggio Emilia, Parma, Pavia, Ivrea, Turin, Cremona, Firenze, Fermo, Verona, Vicenza, Forli, and Lucca). STEM faculties include engineering, mathematics, physics, chemistry, and biology. ***[**](*) denotes significance at the 1[5](10)% confidence level.

Table 3: **Female participation in Medieval guilds and share of women inventors**

	Share of female inventors		
	(5.1)	(5.2)	(5.3)
FWG_c	1.536 ***	0.797 ***	0.784 ***
	(0.272)	(0.207)	(0.221)
Obs.	15,423	15,423	15,423
Worker- and firm-level covariates	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes
LMM fixed-effects	No	Yes	Yes
Municipality-level covariates	No	No	Yes
Mean of dep. var.	.089	.089	.089
Std. dev. of dep. var.	.284	.284	.284

Source: European Patent Office; INPS. Note: Worker- and firm-level covariates include worker's age, work status, type of contract, a full-time dummy, the log of firm size, the log of firm average wage, and industry dummies. The control variables at the municipality level are the city's altitude and surface, a dummy for being near the coast, a dummy for whether the city was located near a Medieval trade route (i.e., Novara (Vercelli), Turin, Genoa, Bergamo, Brescia, Como, Cremona, Milan, Pavia, Padua, Udine, Venice, Bologna, Ferrara, Modena, Parma, Piacenza, Arezzo, Florence, Pisa, Siena, Rome, Perugia, Naples, Salerno, Bari, Lecce, Catanzaro, Messina, Siracusa, Palermo, and Sassari), and a dummy for the presence of a University before the XIII century (i.e., Bologna, Salerno, Modena, Reggio Emilia, Parma, Pavia, Ivrea, Turin, Cremona, Firenze, Fermo, Verona, Vicenza, Forli, and Lucca). ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size (measured by the number of employees). Standard errors, in parentheses, are clustered at the municipality level.

Table 4: **Yearly number of patent applications and grants**

Panel A: Yearly number of patent applications								
	(6.1)		(6.2)		(6.3)		(6.4)	
Female x FWG_c	0.708	*	1.036	***	1.127	***	1.124	***
	(0.392)		(0.360)		(0.322)		(0.321)	
FWG_c	-0.840	*	-0.828	*	0.254		0.183	
	(0.474)		(0.451)		(0.201)		(0.346)	
Female	-0.098	***	-0.098	***	-0.105	***	-0.104	***
	(0.030)		(0.030)		(0.028)		(0.028)	
Mean of dep. variable	.211		.213		.213		.213	
Std. dev. of dep. variable	.731		.736		.736		.736	
Panel B: Yearly number of patent grants								
	(6.5)		(6.6)		(6.7)		(6.8)	
Female x FWG_c	0.425	***	-0.159		-0.131		-0.130	
	(0.123)		(0.183)		(0.182)		(0.183)	
FWG_c	0.342		-0.105		0.101		0.271	**
	(0.340)		(0.175)		(0.128)		(0.142)	
Female	-0.026	***	-0.013		-0.015		-0.015	
	(0.008)		(0.011)		(0.011)		(0.011)	
Mean of dep. variable	.069		.069		.069		.069	
Std. dev. of dep. variable	.376		.378		.378		.378	
No. obs.	214,074		211,065		211,065		211,065	
Worker- and firm-level covariates	Yes		Yes		Yes		Yes	
Year fixed-effects	Yes		Yes		Yes		Yes	
Firm fixed-effects	No		Yes		Yes		Yes	
LMM fixed-effects	No		No		Yes		Yes	
Municipality-level covariates	No		No		No		Yes	

Source: European Patent Office; INPS. Note: Worker- and firm-level covariates include the worker's age, work status, type of contract, a full-time dummy, number of patent coauthors, the log of firm size, the log of firm average wage, and industry dummies. The control variables at the municipality level are the city's altitude and surface, a dummy for being near the coast, a dummy for whether the city was located near a Medieval trade route (i.e., Novara (Vercelli), Turin, Genoa, Bergamo, Brescia, Como, Cremona, Milan, Pavia, Padua, Udine, Venice, Bologna, Ferrara, Modena, Parma, Piacenza, Arezzo, Florence, Pisa, Siena, Rome, Perugia, Naples, Salerno, Bari, Lecce, Catanzaro, Messina, Siracusa, Palermo, and Sassari), and a dummy for the presence of a University before the XIII century (i.e., Bologna, Salerno, Modena, Reggio Emilia, Parma, Pavia, Ivrea, Turin, Cremona, Firenze, Fermo, Verona, Vicenza, Forli, and Lucca). ***[**](*) denotes significance at the 1[5](10)% confidence level. Observations are weighted by municipality size (measured by the number of employees). Standard errors, in parentheses, are clustered at the municipality level.

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