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Women inventors: The legacy of Medieval guilds

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Women inventors:

The legacy of Medieval guilds *

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Abstract

The share of female inventors remains significantly lower than that of men in both developed and developing countries. This paper studies 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 guild founders from the Middle Ages. The 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

Despite the increase in the share of women in the labor force over the last decades, 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 the EU countries was recorded in Italy (Carta et al., 2023), where geographical differences in gender disparities are highly pronounced: the gender gap 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 the period 2010-2019, the women inventor rate was just 14.3 in Italy, against 16.6 and 23.2 percent in France and Spain, respectively (although in Germany it was only 10.0 percent; EPO (2022))[1]. 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 1987 the women inventor rate in Italy was just 4 percent; Figure 1), the pace at which this occurs 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: 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 girls 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)).

This is one of the first papers to investigate whether the innovation gender-gap is historically rooted, originating from social norms formed in the Italian Medieval municipalities and transmitted across generations in Italy. Most papers on social norms study

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

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 a 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 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] Female participation in guilds was more intense in sectors protected by corporations and 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 par-

[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). 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).

ticipation 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 Figures 2 and 3), we also control for time-invariant municipality characteristics, 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, note that 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]

Thus, 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

[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.

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 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.

The paper structure is the following: the next section highlights our contribution to the literature, Section 3 presents the data and the variables, Section 4 the descriptive statistics, and Section 5 the empirical strategy and results. Finally, the last section concludes.

2 Contribution to the literature

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 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. 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 was transmitted to the population through a more pervasive sense of 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, under the hypothesis 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. 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.

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 men and women without children. Jensen et al. (2018) show that the acceptance rate of patents submitted by women is lower than that of men. Finally, recently some literature on historical patents has emerged: Martinez (2024) describes the activity of female inventors in Italy during

the 1861-1939 period; Merouani and Perrin (2024) focus on French women in 1791-1900. 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 thickness of local exhibitors at the 1873 Vienna World's Fair increased with the local density of the members of the economic societies founded between 1764 and 1800. We contribute to this field by studying to what extent historical cultural biases affect women's probability of patenting today.

Finally, we contribute to the literature on gender norms and persistence. 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. 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 (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.[4] 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 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, 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.,

[4] We use the 2002-2003 waves because the information on individuals' municipality of residence is only available in these years (in contrast, place of birth is unavailable).

of inventors, applicants, and locations), assigned VAT codes to firms and Istat codes to municipalities.[5]

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 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 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.

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 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.[6] We use this information to reconstruct the gender of the founding mem-

[5]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.

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

bers 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 geo-locate 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.[7]

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. Figure 2 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.[8]

4 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 (for whom we do not have information on the existence of guilds), 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.

Although the gap is slowly reducing, women are a minority among inventors in Italy and worldwide. In 2019 the percentage of female 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 Figure 1's Panel A shows, 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, and in some years the gap is even in favor of the latter (Figure 1, Panel B). Thus, on average, women are not less innovative than men; however, the gap enlarges when we focus only on the applications that will eventually be granted (Figure 1, Panel C).

[7] 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.

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

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 (Table 1): 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.[9] Among the people who provided information on the type of contract (just about half of the sample), the majority has an open-ended contract irrespective of gender. Finally, male inventors tend to work full-time more 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 3 reports the share of women in total guild members in the Middle Ages:[10] the map does not exhibit any specific territorial pattern.

Finally, Table 2 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 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.

5 Empirical Strategy and results

This paper hypothesizes 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 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.

[9] Note that we respect to the average employee in INPS data, inventors are more likely to be white-collar workers, and are less likely to be blue-collar workers and have a temporary contract (Di Addario and Wu, 2024).

[10] This share ranges from 0 to 12 percent. The percentiles of the FWG distribution across municipalities are: 0.030 (Q1); 0.039 (Q2); 0.049 (Q3); and 0.074 (Q4)

The data we collected from the National Archive of State enable 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:

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

We link FWG_c to INPS-PatStat data by inventors' municipality of birth (Sections 5.2-5.3). 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 (note that linking FWG_c by the municipality of work does not substantially change the results).

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 5.1). We are aware that basing our analysis on the city of residence may introduce endogeneity issues since people can choose where to live. For instance, the women who want to work in the labor market may move to the cities with historically more intense female participation in guild founding precisely because these locations are the most emancipated and favorable to female work. Thus, we take the results of Section 5.1 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 and historical city characteristics. More specifically, to exclude the "geography hypothesis" we control for altitude, land area, and a dummy variable for whether the city is located on a coast, while to exclude "history hypothesis" we control for the presence of a University founded before the XIII century and for 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.[11] 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,[12] 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.

To show the efficacy of our geographical and historical control variables, we undertake an empirical test. We compute the unconditional correlation between FWG and two non-female specific factors at the municipality level: the total employment rate and the proportion of male graduates in the male population 15-64 (from the LFS). The unconditional correlations are, respectively, 0.455 (significant at 5%) and 0.310 (significant at 1%). However, once we control for LLM fixed-effects and for the city's geographical and historical characteristics none of these correlations remains significant. This test provides support to the exclusion restriction of our identifying assumption.

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.

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

[12] According to the authors the towns on trade routes were: 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.

5.1 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 thus 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 (i.e. engineering, mathematics, physics, chemistry, biology). Moreover, we study the correlation between living in those cities and the current women's likelihood of joining the labor market, being employees, or 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:

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

where the outcome variables are (alternatively) being a college graduate, having graduated from a STEM faculty, being in the labor force, being a housewife, or a private-sector employee in municipality c at time t. X is a quadratic form of individuals' age, which is important because education or labor supply decisions have changed across cohorts over time; Z includes the geographical and historical variables described in the previous section; ϕ_{LLM} represents LLM-fixed effects,[13] and γ_t contains the year-, the quarter-fixed effects, and their interaction with time, to increase the precision of our estimates. The variable of interest, $FWG_{c(i)}$, is linked to LFS by women's municipality of residence. Standard errors are always clustered at the municipality level.

Table 3 exhibits the results. In the first two columns, the dependent variable is the college dummy, while in the last two, it is the STEM dummy. Results in (3.1) indicate that a one percentage point increase in Medieval guilds' female ratio is associated with a 1.3 percentage points higher probability that a female student graduates from college (at the 1 percent statistical level). When adding the historical and geographical characteristics of the municipality of residence (specification (3.2)), the probability lowers to 0.8 but remains positive and statistically significant at the 1 percent level. In terms of standard deviations, the increase is very large: it amounts to 2.8. Moreover, female students are

[13] In 2001 Italy counted 686 LLMs, partitioning the entire country; they are "self-contained" labor markets since the National Institute of Statistics singles them out based on workers' daily commuting flows from place of residence to place of work (Istat, 2005).

0.3 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. When controlling for city characteristics (column (3.4)) the coefficient slightly lowers (to 0.2); in terms of standard deviations, the increase is 0.9.

Table 4 reports the results on the labor market outcomes. In the first two columns, the dependent variable is a dummy equal to 1 if the woman works or is unemployed in municipality c at time t, zero otherwise. Our preferred specification's results, including the geographical and historical variables, indicate 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 (3.2)). 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. In columns (3.3)-(3.4) 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 guild members 800 years ago is associated with a 0.9 percentage points lower chance of being a housewife in the same city (statistically significant at the 1 percent level), 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. In contrast, specification (3.4) shows that a one percentage point higher share of female guild members is associated with a 0.5 percentage points greater share of the city's female employees in total employed women (at the 1 percent statistical level), but this result is no longer significant once we add the geographical and historical city characteristics (in the last column).

5.2 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.[14] 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 participation in Medieval guilds on the current share of female inventors in municipality

[14]Matching our variable of interest to individuals' municipality of work does not change the results (available upon request) substantially.

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. To increase th precision of our estimates, we also control for X_{ict}, including workers' age, work status, and type of contract; for firm size, since large companies tend to employ more inventors and also more women, which could be correlated with FWG; ϕ_{LLM} represents LLM-fixed effects and γ_t year fixed-effect, capturing the average probability to observe a female inventor in year t. 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 5). Column (5.1) reports the outcomes obtained after controlling for the individual characteristics and for year-fixed effects, while specification (5.2) adds LLM fixed-effects, and column (5.3) includes the geographical and historical characteristics at the municipality level. We obtain 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 (column (5.1)). After controlling for LLM-fixed effects, the estimated coefficient of interest almost halves (column 5.2), while adding the geographical and historical variables at the municipality level stabilizes the impact at 0.8 percentage points (column 5.3). In terms of standard deviations this increase is very large (2.8).

5.3 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 estimates' precision, we add a vector of individual observable characteristics (X_{it}), 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 (capturing the average yearly variation in patenting activity among all the inventors), the geographical and historical municipality characteristics $Z_{c(i)}$, and for 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 the Medieval intensity of women's participation in guilds in inventor i's municipality of birth. 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. Panel A of Table 6 reports the results. As it is apparent from the first column, 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 (the effect is significant 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 6's Panel B (columns (6.5)-(6.8)). 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 a 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.

Finally, in Table 7 we test three other sets of specifications, 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 (7.1)-(7.3)), or, alternatively, in terms of the sum of granted patents that they ever obtain (columns (7.4)-(7.6)). The number of observations drops from over $210,000$ to about $15,400$ 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 is positive and significant only after we control for the LLM fixed effect. More importantly, our variable of interest, $Female * FWG_c$, has always a large, positive, and highly significant effect on the number of applications. In contrast, there are no gender differences in the number of granted patents.

6 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 encourages women to work outside the home and innovate. We are able to single out the cultural effect by tracing 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 higher share of women in guilds in the Middle Ages in one's city today is associated with a higher percentage of women with a college degree, especially from STEM faculties. Moreover, the cities with more intense participation of women in guilds today exhibit a greater female labor force participation and a lower share of housewives. Finally, a more gender-egalitarian culture increases the share of female inventors and their propensity to submit patent applications to the EPO. However, more gender-egalitarian norms affect women's behavior but not the acceptance rate of their patent applications, which does not differ from that of observationally equivalent men. Our findings are robust to controlling for geographical city characteristics and two alternative historical variables that could in principle be relevant (i.e. proximity to a Medieval trade route, and the presence of a University founded before the XIII century), making the geography and alternative history hypotheses lose ground.

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 enrol in STEM faculties and at encouraging female participation to innovation, especially in the areas more permeated by traditional social norms.

Figure 1: **Women Inventor Rates, patent applications and granted patents by gender** Source: European Patent Office, years 1987–2005. Notes: The Women Inventor Rate measures the percentage of women inventors among all inventors listed in all patent applications in a given year.

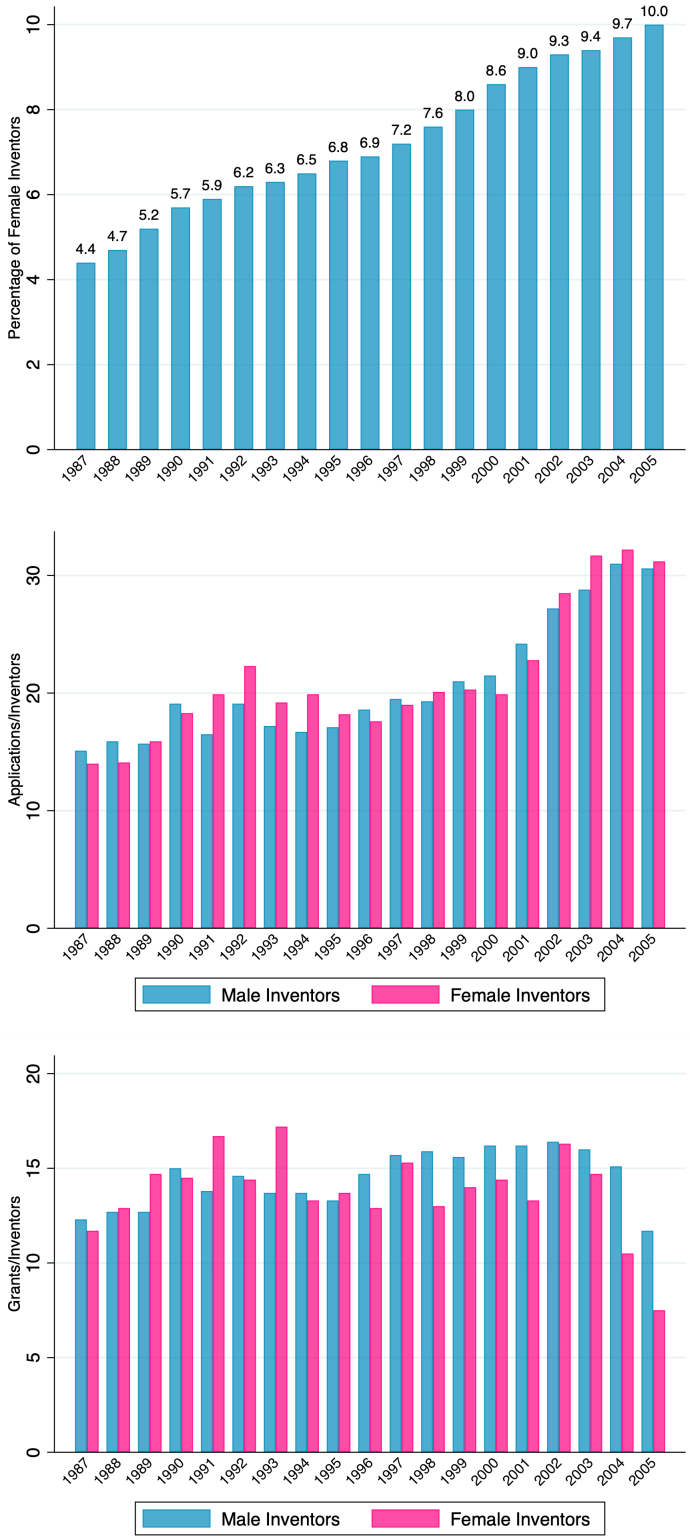

Figure 2: **Distribution of guilds in the Middle Ages.** Source: Our elaboration on data from the Central Archive of the State in Rome. Notes: The darkest blue means that all the Medieval guilds considered in this paper (wool, silk, spices, furs, goldsmiths, dyers, blacksmiths, and shoemakers) are present in the current municipal territory. The lightest shade means that no guilds (for two municipalities) or just one of them was present.

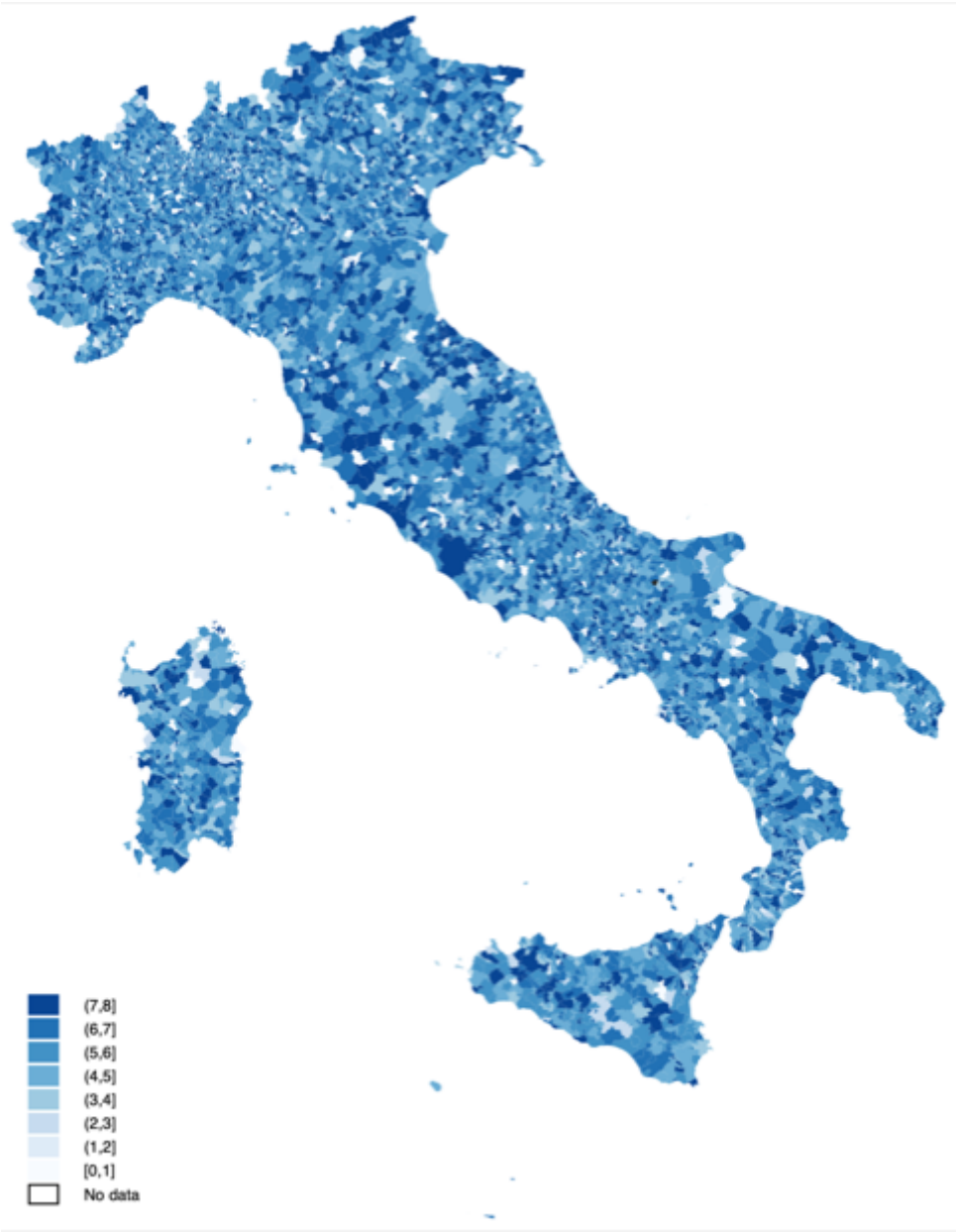

Figure 3: **FWG: Female share in Medieval guild members.** Source: Our elaboration on data from the Central Archive of the State in Rome. Notes: The darker red means that in the Middle Ages the city (at current Italian borders) exhibited a higher share of women in any of the 8 guilds considered in this 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: **Distribution of male and female inventors by FWG_c quartiles**

	Male inventors	Female inventors	FWG_c
1st quartile	25.55	17.42	0.037
2nd quartile	24.89	22.38	0.050
3rd quartile	24.68	27.48	0.059
4th quartile	24.88	32.73	0.077

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

Table 3: **Female participation in Medieval guilds and current female study outcomes**

	College				STEM			
	(3.1)		(3.2)		(3.3)		(3.4)	
FWG_c	1.2890	***	0.7891	***	0.2987	***	0.1714	***
	(.1203)		(.1166)		(.0567)		(.0543)	
No. obs.	497,267				220,931			
Mean of dep. var.	.087				.040			
Std. dev. of dep. var.	.281				.197			

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, and a dummy for the presence of a University before the XIII century. Note: ***[**](*) denotes significance at the 1[5](10)% confidence level.

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

	LFP		% of housewives		% of employees	
	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)	(4.5)
FWG_c	0.8122 ***	0.3703 **	-1.1734 ***	-0.8737 ***	0.5112 ***	0.1596
	(.1915)	(.1724)	(.2389)	(.2447)	(.1660)	(.1718)
No. obs.	489,945		293,716		203,545	
Mean of dep. var.	.481		.313		.780	
Std. dev. of dep. var.	.500		.464		.414	

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, and a dummy for the presence of a University before the XIII century. Note: ***[**](*) denotes significance at the 1[5](10)% confidence level.

Table 5: **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, and a dummy for the presence of a University before the XIII century. ***[**](*) 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 6: **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 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, and a dummy for the presence of a University before the XIII century. ***[**](*) 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 7: **Overall number of patent applications and grants**

Panel A: Overall number of patent applications						
	(7.1)		(7.2)		(7.3)	
Female x FWG_c	18.213	***	13.969	***	13.947	***
	(4.574)		(4.352)		(4.347)	
FWG_c	-0.298		3.717		14.152	**
	(15.249)		(6.464)		(6.214)	
female	-1.265	***	-1.013	**	-1.011	**
	(0.373)		(0.400)		(0.400)	
Obs.	15423		15423		15423	
Mean of dep. variable	3.80		3.80		3.80	
Std. dev. of dep. variable	4.52		4.52		4.52	
Panel B: Overall number of patent grants						
	(7.4)		(7.5)		(7.6)	
Female x FWG_c	6.976	*	4.274		4.252	
	(3.940)		(3.015)		(3.021)	
FWG_c	1.191		4.229		7.845	**
	(9.746)		(3.156)		(3.550)	
Female	-0.581	***	-0.415	***	-0.413	***
	(0.213)		(0.159)		(0.159)	
Mean of dep. variable	2.03		2.03		2.03	
Std. dev. of dep. variable	6.69		6.69		6.69	
No. obs.	15,423		15,423		15423	
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	

Source: European Patent Office; INPS. Note: Worker- and firm-level covariates include 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, and a dummy for the presence of a University before the XIII century. ***[**](*) 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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