Pins and Pistons: Gender and Patenting during the French Industrialization

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1 Introduction

1.1 Overview

In 1904, the American writer and business historian Ida Tarbell argued that "Women's needle and men's machine work" were equally important to industrial progress (Oldenziel, 1999). Her observation captured a fundamental problem in how we understand technological development. Women's labour underpinned production, but official statistics understated that labour, and their contributions to new technology were even more obscured, rarely acknowledged in records or narratives of invention. This dissertation investigates that hidden history by studying women's participation in patenting during France's industrialization between 1791 and 1900. More than 4,000 distinct women appear in French patent records during this period. Patents involving at least one woman account for 1.8 percent of all patents, a higher share than in Britain or the United States. Yet we know remarkably little about who these women were, how their inventive activity compared to men's, how collaboration shaped their work, or where they actually came from beyond the addresses listed on patent documents.

This dissertation addresses these gaps through four complementary papers. The first surveys the literature on gender and long-run economic development, examining how women's economic position changed as countries modernized and how those changes affected growth, with particular attention to education, fertility, and labor force participation. The second establishes the extent and characteristics of women's patenting across all sectors and the full nineteenth-century, examining how financial constraints, occupational backgrounds, and sectoral concentration shaped their participation. The third investigates how collaboration affected inventors' technological trajectories, productivity, and the novelty of their ideas, with particular attention to how their ties to others varied by gender. The fourth links more than 500 married women inventors to civil registration records to recover their demographic profiles, geographic origins, and life-course patterns. Together, these papers combine nearly 390,000 patents with civil vital records, machine learning methods for technology classification, text-based measures of novelty and influence, and large-scale record linkage to provide a comprehensive account of women's patenting activity during French industrialization.

The findings contribute to our understanding of both gender and patenting in economic development. They examine how collaboration functioned as a mechanism for knowledge access in an era before modern research institutions, the importance of family ties, and reveal how administrative structures can systematically distort the apparent geography of innovation. More broadly, they demonstrate that studying historical innovation requires methods that can identify inventors, classify their work, measure idea quality without modern citation data, and link patent records to demographic information, all of which this dissertation develops and validates for use in other historical settings. Most fundamentally, they document the diversity of women inventors and the barriers they faced, showing that women worked with both "pins and pistons" across traditionally feminine and masculine technology sectors alike.

1.2 Previous research: Gender, development and technology

Unified growth theory emphasizes human capital accumulation and technological change as engines of the transition from stagnation to sustained growth, but until recently said little about women's roles in these processes (Galor, 2011). More recent work places gender directly at the center, showing that women's education, labor force participation, and empowerment shaped fertility transitions, human capital investments, and growth trajectories (Diebolt and Perrin, 2013, 2019; Galor and Weil, 1996; Lagerlof, 2003). Theoretical models demonstrate that gender equality can accelerate development through multiple channels: by increasing educational investments in children, enabling demographic transitions, and expanding the productive workforce. Empirically, the evidence confirms that women's economic participation evolved alongside industrialization, though often following a U-shaped pattern as work shifted from home-based production to factories before rising again with service sector expansion (Boserup, 1970; Goldin, 1990). Yet historical statistics systematically underreported women's work, particularly for married women and home-based activities, obscuring the full extent of their economic contributions (Merouani and Perrin, 2022).

Understanding women's roles in economic development requires examining how technology itself was gendered during industrialization. As engineering professionalized in the late nineteenth-century, the definition of technology narrowed in the United States and other Western countries to emphasize mechanical and civil engineering, systematically marginalizing both the technologies and technical skills associated with women (Oldenziel, 1999). This involved creating an exclusive male professional identity through educational credentials and the cultivation of masculine ideals, while femininity was redefined as incompatible with technical pursuits (Wajcman, 2010). Yet redefining technology to include domestic equipment, textiles, and household production reveals extensive female technical activity that conventional definitions overlook (Cowan, 1976; Stanley, 1995). Historical research demonstrates that women's exclusion from technology was neither natural nor inevitable. During industrialization, men came to dominate skilled trades, with masculinity becoming embedded in industrial machinery itself (Bradley, 1992; Cockburn, 1983, 1988). Women's systematic absence from sites of technological decision-making shaped which problems received attention, which solutions were adopted, and whose needs were served (Cockburn and Ormrod, 1993).

Patent systems provide direct evidence of these dynamics because they document who invents and what counts as inventive activity. Across industrializing nations, women faced substantial barriers to patenting: married women's property rights were restricted in many jurisdictions, high patent fees excluded those with limited financial resources, women lacked access to formal scientific and technical education, and social norms often obscured women's contributions by attributing their inventions to male relatives (Khan, 2005, 2020). Patent system features shaped women's participation. Lower fees and recognition of the "first and true inventor" in the United States facilitated broader access, while high costs in Britain and France created significant financial barriers (Khan, 2005, 2016). Despite these obstacles, women managed to patent in meaningful numbers, often by navigating family networks, leveraging middle-class resources, or adapting to sectoral opportunities (Chanteux, 2009; Khan, 2016). Understanding how women overcame these barriers, what enabled or constrained their inventive activity, and how their innovations compared to men's provides crucial insight into the social organization of technological change during industrialization.

1.3 Context: French industrialization

Scholars initially viewed French industrialization as a failure. After the Second World War, historians emphasized slow growth and incomplete transformation (Crouzet, 2003). Clapham (1921) argued that France never experienced an industrial revolution comparable to Britain's, instead undergoing gradual change that lagged far behind Germany. American scholars attributed French weakness to poor entrepreneurship and economic Malthusianism, arguing that conservative businessmen avoided risk and restricted investment (Clough, 1946; Landes, 1949). This pessimistic interpretation dominated until the 1960s, when quantitative evidence forced a reassessment.

National income estimates challenged the stagnation thesis. Marczewski (1961) showed French

GDP per capita growing at rates similar to Britain and close to the Western European average between 1820 and 1913 (Maddison, 2001). Revisionist scholars argued that France followed a rational development path shaped by its endowments. High coal costs and skilled labor pushed French producers toward quality goods rather than mass production (Lévy-Leboyer, 1964; O'Brien and Keyder, 1978). Specialization in silks, fashion, and luxury products reflected comparative advantage, not backwardness. France achieved respectable per capita growth through adaptation rather than imitation.

The current consensus recognizes both achievements and constraints (Crouzet, 2003). France's early demographic transition limited aggregate growth even as living standards remained competitive. Population stagnation after the 1860s meant fewer workers and slower total output expansion. Agricultural employment dominated longer than in Britain or Germany, and the depression of the 1870s through 1890s brought severe disruption (Caron, 1995; Lévy-Leboyer et al., 1990). Yet these patterns reflected deliberate choices. Fertility control prevented Malthusian pressure. High savings rates funded substantial capital exports. The result was moderate but sustained per capita growth through quality-intensive production and gradual structural change (Asselain, 1984; Crouzet, 1972). Women's patenting activity emerged within this distinctive pattern of industrialization.

1.4 The French patent system

The modern French patent system emerged from the Revolution with laws enacted in January and May 1791 (Isoré, 1937). These laws established patents as a natural right of inventors rather than royal privileges, reflecting Enlightenment ideals about property and creation (Marchal, 2009). The system operated without preliminary examination of novelty or utility, since such oversight was seen as censorship reminiscent of the Ancien Régime (Galvez-Behar, 2019). Patent applicants paid fees based on duration: 300 livres tournois for five years, 800 for ten years, and 1,500 for fifteen years (Baudry, 2020). The government's role was limited to registration, with courts left to resolve disputes over validity and novelty. This registration-based approach kept administrative barriers low but created uncertainty about patent quality and led to frequent litigation (Galvez-Behar, 2019). The system also permitted patents for importation, which allowed anyone to patent foreign inventions newly introduced to France (Emptoz and Marchal, 2002). While this provision facilitated technology transfer (Nuvolari et al., 2023), it drew criticism for rewarding those who contributed nothing to the original invention (Galvez-Behar, 2019).

The 1844 Patent Act reformed the system while preserving its core philosophy. The reform abolished patents for importation, restricted protection to original inventions, and clarified what qualified as patentable: new industrial products, innovative processes, or novel applications of existing methods (Galvez-Behar, 2019). To make patents more accessible, the reform introduced installment payments for patent fees, effectively lowering the upfront cost and aligning with the US model, which deliberately kept fees low to encourage broader participation (Khan, 2005). The reform maintained the principle of issuing patents without government guarantee of validity, leaving disputes to specialized civil and criminal courts. Despite calls for preliminary examination, the French system continued to prioritize inventors' natural rights over administrative screening (Galvez-Behar, 2019).

1.5 Data and the application of machine learning to economic history

I develop four methods that collectively allow me to systematically analyze gender and innovation during this period. To study this, I needed to identify who invented, classify what they invented, track individuals across time, and measure idea quality without modern citation data. The approaches were developed to solve problems specific to the French case, but they provide templates for studying innovation in other patent systems and time periods where similar constraints exist.

Building the database required substantial work before analysis could begin. The starting point was digitized patent registries from the French National Institute of Intellectual Property (INPI), but the raw digitization contained the errors inevitable when manually transcribing historical documents at scale: discrepancies in dates, names, and categories that needed systematic correction. A combination of algorithmic detection methods and extensive manual review was used to identify and correct inconsistencies, cross-verified against original patent applications when discrepancies appeared, and every patent involving a woman inventor was individually reviewed to ensure accuracy. For the latter half of the century, where digitization remained incomplete, these records were supplemented with data extracted from the Bulletin des Lois using Optical Character Recognition, followed by machine structuring of text data and manual verification. Missing first names, which are crucial for identifying inventors across patents, required transcribing over 150,000 handwritten patent applications using an ensemble of vision-based language models, with manual quality assurance throughout. The resulting database contains nearly 390,000 patents spanning 1791 to 1900.

French naming conventions made identifying female-linked patents straightforward once the data had been cleaned. Patent records consistently include gender-specific honorifics like madame, mademoiselle, and veuve, which can be detected using rule-based methods that account for the various abbreviated forms appearing in different sources. This approach was validated against independent lists of known female-linked patents from the 1890s and correctly identified women with high reliability, missing only four cases out of thousands of patents. This systematic identification revealed over 6,800 female-linked patents, 1.8% of all patents, a substantially higher share than in Britain or the United States during the same period.

To enable consistent sectoral analysis at scale, all patents were reclassified. Rather than rely on the partial and shifting classifications in the original records, I trained machine learning models to map patent titles to INPI's 1904 technology classification system, which provides precise definitions for 20 main classes and 97 subclasses. Two advanced language models were combined in an ensemble that learns from nearly 40,000 expert-classified examples. This approach avoids reliance on simple keyword matching, which can badly misclassify patents, and instead learns to recognize the semantic content that expert classifiers use. The method performs well by standard metrics and produces classifications that make intuitive sense: a patent about parachutes for mine safety correctly falls under Mining Operations while one about air parachutes lands in the Aviation. Similar techniques were used to classify occupations according to the HISCO schema when occupation information was available.

Identifying inventors across time proved technically demanding because it required matching nearly 407,000 male inventor observations with inconsistency in the digitized recorded names and many inventors sharing common surnames. I developed a four-stage approach that begins with simple rules, adds probabilistic matching, incorporates semantic similarity measures from language models, applies supervised machine learning trained on labeled examples, and finally clusters the results while respecting realistic constraints like maximum career spans. This process yielded about 235,000 distinct male inventors from the nearly 407,000 observations, a ratio comparable to what manual linking achieved for the smaller sample of women inventors. This systematic identification enables tracking individual careers, documenting collaboration networks, and studying how inventors' behavior changes over time.

I also developed text-based measures of novelty and influence because nineteenth-century French patents lack the citations that modern innovation studies rely on. These measures aim to capture the same economic concepts using patent titles, building on recent work for contexts without citation data. Novelty is measured by how semantically distinct a patent's title is from the prior twenty years of patents, adjusted for the volume of available prior art. Influence is measured by how intensively subsequent patents draw on a given patent's language, scaled by how derivative that patent was at birth. Validating these measures against historically important patents like Pasteur's preservation method and the Lumière cinématographe shows that the influence measure correctly identifies famous inventions as more influential than ordinary ones substantially more often than chance alone would predict, performs well in out-of-time tests, and adds information beyond simple controls for time period and technology class.

Taken together, these approaches demonstrate what becomes possible when researchers combine machine learning with careful manual work to analyze historical archives at scale. The gender identification approach works wherever naming conventions signal demographic characteristics. The technology classification framework adapts to any patent system needing retrospective categorization. The inventor identification strategy addresses record linkage at scales where traditional methods become computationally infeasible. The novelty and influence measures offer tools for studying idea quality when citation networks are unavailable. Maintaining quality while working at this scale requires substantial investment in validation, cross-checking, and iterative refinement. Each method is documented in detail in the papers, with the goal of enabling other researchers to study historical innovation systematically in contexts where similar data constraints exist.

1.6 Summaries of papers

1.6.1 Paper I: A survey (with Faustine Perrin)

Paper 1 surveys the literature on gender and long-run economic development. It asks two questions: How did women's economic position change as countries modernized? And how did those changes affect growth? The paper reviews theoretical models, empirical evidence on education and fertility, studies of women's work and wages, and research on family systems and culture. Throughout, it emphasizes that women have always been central to human capital, fertility, and labor supply, but that standard data miss much of their contribution. The survey concludes with a research agenda focused on better data and better measures of women's economic roles across time.

Western Europe experienced a joint transformation: rising income per capita alongside falling fertility. Unified growth theory seeks to explain this pattern through a quantity-quality trade-off in children (Becker, 1960; Galor, 2011; Galor and Weil, 2000). Parents shifted from having many low-educated children to having fewer better-educated children. Technology made education more valuable, which triggered the demographic transition. But these models traditionally said little about women, even though women are central to fertility and schooling decisions. The models also struggle with France, where fertility fell before full industrialization (Perrin, 2013).

Later theory addresses this gap by putting gender at the center of long-run growth. Galor and Weil (1996) show that capital accumulation raises women's wages relative to men's, which lowers fertility and speeds up growth. Later work adds gender gaps in education (Lagerlof, 2003), distinguishes different dimensions of gender inequality and their effects on development (De La Croix and Vander Donckt, 2010), and builds empowerment directly into unified growth models (Diebolt and Perrin, 2013, 2019). In much of this literature the basic logic is similar: when women's opportunities improve, the opportunity cost of children rises, parents invest more in human capital, and economies move faster toward sustained growth. Prettner and Strulik (2017) offer another channel, showing that if women care more about child quality than quantity, empowering them helps the economy escape the Malthusian trap. Doepke and Tertilt (2019), however, provide a counterpoint. In their model with discrimination and gendered specialization, female empowerment can have only limited or even harmful effects on growth. The lesson is that gender matters, but the effect of greater equality depends on the mechanisms and the context.

The models imply a central role for women's education in fertility decline, and the empirical evidence gives strong support to this mechanism. Studies from England, Ireland, and Prussia show that families with fewer children invest more in schooling (Becker et al., 2010; Clark and Cummins, 2016; Fernihough, 2017). The French evidence is especially clear. Counties with more educated women had lower fertility and higher school enrollment for both boys and girls (Diebolt et al., 2017, 2021; Murphy, 2015). De la Croix and Perrin (2018) use a structural model and find that rational choices by parents explain a substantial share of the variation in fertility and most of the variation in schooling across French counties. Their counterfactuals show that mothers' education is the key driver of both school enrollment and fertility. Women's human capital mattered for the demographic transition, and the demographic transition mattered for growth.

If women's human capital was so important, this raises a natural question: how much did women actually work, and how did their labor force participation change as economies developed? The classic story says female participation followed a U-shaped curve (Boserup, 1970; Goldin, 1995). Women worked extensively in agriculture and home production when countries were poor. Participation fell during early industrialization as work moved from home to factory and as the male breadwinner ideal spread. Then participation rose again as education increased, fertility fell, and white-collar jobs expanded. The paper reviews evidence for each stage of this process, though it notes that scholars disagree about how universal or pronounced the U-shape really is.

The starting point for understanding this curve is the pre-industrial economy, where women worked extensively. They participated in agriculture, crafts, and family businesses, though their work was often recorded under men's names (Ågren, 2017; de Vries and van der Woude, 1997; Tilly and Scott, 1989; Whittle and Hailwood, 2020). Studies of court documents using verb-based approaches show that in Sweden and England women performed nearly all types of work, with the main exceptions being military service and hunting. Guilds and local institutions, not physical differences, restricted women's access to skilled and better-paid occupations (Ogilvie, 2003; Van Nederveen Meerkerk, 2010). The male breadwinner was not a universal pre-industrial norm.

Women did not just work, they also earned. Pre-industrial gender wage gaps varied dramatically across time and space. In Northern and Western Europe, especially for unskilled work, women sometimes earned two-thirds or more of men's wages (Gary, 2017; Humphries and Weisdorf, 2015; Molinder and Pihl, 2021). In Southern Europe and in some periods, women earned only half of men's wages (de Pleijt and van Zanden, 2021). Scholars debate whether the century after the Black Death was a golden age for women. Some argue that labor shortages raised women's opportunities and wages (van Zanden et al., 2019). Others stress that young women were pushed into poorly paid annual service contracts that restricted their freedom (Bennett, 2010; Humphries and Weisdorf, 2015). Gender wage gaps existed, changed over time and across regions, and reflected institutions and norms as much as productivity differences.

This relatively varied pre-industrial picture changed sharply with industrialization. Work moved from home to factory. Machinery changed the tasks people performed. The home and workplace became separate. Some scholars see this as progress for women, with new factory jobs and higher earnings, especially in textiles (de Vries, 2008; Pinchbeck, 1930). Others emphasize deteriorating conditions, technological unemployment, and the rise of the male breadwinner ideology that pushed women out of paid work (Berg, 1993; Horrell and Humphries, 1995, 1997).

Resolving this debate requires accurate wage data, but early estimates overstated the gender gap. They failed to adjust for hours worked, piece-rates, and payment in kind. Corrected estimates show smaller gaps, but gaps still existed and often widened during industrialization (Beneito and Garcia-Gómez, 2022; Burnette, 1997, 2004, 2019). Married women and mothers faced especially large penalties. Some industries, like Swedish tobacco, show much smaller gaps when workers were paid by output rather than time (Burnette and Stanfors, 2012; Stanfors et al., 2014). The experience varied by industry, region, and marital status, but discrimination and restricted opportunities were common.

If measuring wages is hard, measuring labor force participation is even harder. Census data systematically undercount women's work. Women working informally, without pay, or in family businesses often do not appear in official statistics. Studies using family budgets, autobiographies, and microdata paint a different picture. Men's wages alone were often too low to support a family. Women and children had to work (Horrell et al., 2022; Horrell and Humphries, 1997; Humphries, 2020). New estimates for Spain and the United States show participation rates far higher than official statistics suggest, and similar work for other countries points in the same direction (Chiswick and Robinson, 2021; Sarasua, 2019). Both supply-side factors, like domestic ideology and marriage norms, and demand-side factors, like local industry mix, determined whether women worked for pay (Boter, 2021; Pott-Buter, 1993; You, 2020). Industrialization often coincided with falling recorded participation, even though women kept working.

Data quality improved in the twentieth century, and the pattern becomes clearer. Better sources show rising female participation and a shift into clerical and service jobs. Women increasingly worked outside the home, while men increasingly shared home duties (Goldin, 1990; Stanfors and Goldscheider, 2017). Scholars still debate the strength and universality of the U-shape (Gaddis and Klasen, 2014), but the basic pattern of withdrawal during early industrialization followed by re-entry appears in many contexts.

Women's work patterns were shaped not just by industrialization but also by deeper institutions, particularly marriage and family systems. The European Marriage Pattern, identified by Hajnal (1965), features late female age at marriage, high celibacy, and nuclear households in Western Europe. Many scholars argue this gave women more agency, more time to acquire skills, and more control over fertility (De Moor and Van Zanden, 2010; Foreman-Peck and Zhou, 2018). Late marriage allowed women to work before childbearing, reduced fertility, and increased human capital investments in children, all of which helped Western Europe escape the Malthusian trap (van Zanden et al., 2019; Voigtländer and Voth, 2013).

But this view faces strong criticism. Dennison and Ogilvie (2014, 2016) show that late marriage was not uniquely linked to early industrialization. Some late-industrializing regions had later marriage than Britain. They argue that broader institutions, not marriage patterns alone, drove growth. Evidence from France complicates the story further. Fertility fell even as marriage age declined and celibacy dropped (Perrin, 2013, 2022b). Different regions used different strategies to control fertility: some through late marriage, others through limiting births within marriage. The European

Marriage Pattern mattered, but it was not the whole story.

If marriage patterns alone do not explain development, deeper cultural forces may. Traditional agriculture, for example, created persistent gender norms. Boserup (1970) argued that plough agriculture, which required male strength, generated a gendered division of labor that lasted long after the agricultural system changed. Empirical work supports this. Societies that used the plough historically have lower female labor force participation today (Alesina et al., 2013). Societies that transitioned to agriculture earlier show more conservative gender norms now (Hansen et al., 2015). The mechanisms are debated, but the persistence is clear.

Beyond agriculture, specific institutions also left lasting marks on gender equality. Beguinages in Belgium, which allowed women to remain single, raised gender equality in surrounding areas (Frigo and Roca Fernández, 2022). Protestantism's emphasis on Bible reading reduced gender gaps in basic education in nineteenth-century Prussia (Becker and Woessmann, 2008). Family structure mattered too. Nuclear families gave women more autonomy than extended, patriarchal families (Bertocchi and Bozzano, 2015; Dilli et al., 2015; Perrin, 2022a; Todd, 1996). Women in nuclear families enjoyed higher status and less segregated economic roles than women in extended family systems. These cultural and institutional forces were persistent, but they could also change as formal institutions strengthened and modernization expanded opportunities.

Understanding these patterns empirically requires good measures of gender inequality. Most studies use modern cross-country data. They consistently find that higher gender equality, especially in education and labor markets, is associated with faster growth (Klasen, 2002; Klasen and Lamanna, 2009; Stephan, 1999). The reverse direction, from growth to equality, is weaker and less robust. Historical studies have relied on single indicators like age at marriage or literacy gaps (Baten and de Pleijt, 2018; Carmichael et al., 2011), but these capture only one dimension of a multidimensional phenomenon.

Recent work builds composite indices that capture gender inequality more comprehensively. The Historical Gender Gap Index for France and Sweden covers education, labor markets, economic opportunities, and demographic outcomes (Perrin, 2014, 2022a; Perrin et al., 2023). The Historical Gender Equality Index covers 123 countries from 1950 to 2003 (Dilli et al., 2019). The Patriarchy Index uses household structure to capture male dominance, generational hierarchies, and son preference (Gruber and Szołtysek, 2014). These indices reveal that regions with higher historical gender equality tended to perform better economically. They also reveal how industrialization, the demographic transition, and family norms all interacted with gender relations.

Despite this progress, data remain the main constraint. Historical sources undercount women's labour, earnings, and human capital. They rarely capture unpaid work, and the definition of work itself shifts across time and space. The survey ends with a methodological agenda. It calls for better historical data on women's work, earnings, education, and fertility, and for measures that also include unpaid labour and care. It urges scholars to combine quantitative records with qualitative evidence from court documents, verb-based studies, and autobiographies. Digital technologies and machine learning, together with full-count censuses and linked longitudinal data, can turn scattered archives into large-scale datasets. With such data, economic historians can move from describing correlations to testing mechanisms. They can ask whether gender wage gaps reflect productivity differences or discrimination, whether women's empowerment raises growth or depends on context, whether new technologies favour gender equality, and whether changes in women's bargaining power alter investments in children and fertility choices.

In short, the survey argues that better historical measures of gender are a precondition for understanding how gender equality both shaped and was shaped by the long-run development process.

1.6.2 Paper II: Origins (with Faustine Perrin)

Paper 2 examines women's participation in patenting activities in nineteenth-century France to understand what underlies the persistent gender gap in innovation. Using an original database covering all French patents granted between 1791 and 1900, the paper documents the extent of women's patenting relative to men and analyzes differences in patent characteristics by gender. Despite the absence of formal scientific and technical education for women until late in the century and persistent institutional barriers, women played a notable and active role in patenting across all technology sectors. Although their overall patenting levels remained lower than men's, their growth rate closely mirrored that of their male counterparts. Yet the gender patenting gap remained extremely stable at approximately 1.8% from the 1840s onward. The paper finds that women's patenting was associated with financial constraints, limited access to education and employment, and concentration in particular sectors, while documenting surprising diversity in the socioeconomic backgrounds of women inventors.

The paper contributes to several strands of literature. It adds to work on women's role in long-run development (Boserup, 1970; Diebolt and Perrin, 2013; Goldin, 1990) and extends research on technical knowledge in driving industrialization (Mokyr, 2010; Squicciarini and Voigtländer, 2015). It engages with debates about whether patent systems functioned as democratic institutions or elitist mechanisms (Galvez-Behar, 2008, 2019; Khan, 2005, 2020), revealing that the French system facilitated innovation among diverse inventors and was more inclusive than previously suggested. Finally, it contributes to debates on French industrialization, supporting revisionist perspectives emphasizing quality over mass production (O'Brien and Keyder, 1978; Roehl, 1976) rather than narratives of slow development (Clapham, 1921; Landes, 1949; Landes, 1969).

What distinguishes this study is its quantitative analysis covering all patents and patentees across the entire nineteenth century. While Khan (2016) focuses on the first half of the century and middle-class women, and Chanteux (2023) adopts a historical, qualitative approach, this paper systematically compares women and men across all technology sectors, skill levels, and time periods using nearly 390,000 patents. The consistent inclusion of women's marital status in French patent records provides a significant advantage over other countries where identifying women requires inferring gender from first names. The database compiled information on nearly 390,000 patents, including 6,805 associated with at least one woman inventor, using the patent registry from the French National Institute of Intellectual Property (INPI) and the Bulletin des Lois. Women inventors were identified through gender-specific honorifics (madame, mademoiselle, veuve) with validation yielding very few missed patents. For technology classification, all patents were reclassified using a modern machine-learning approach based on INPI's 1904 technology class schema.

The results are consistent with financial constraints shaping women's patenting behavior, with the 1844 patent reform associated with a 0.7 percentage point increase in the probability of a patent being female-linked (a 40% increase relative to the 1.8% base rate). Probit models test whether the 1844 reform and lower-cost five-year patents increased women's relative patenting, whether women engaged more in co-patenting, whether women patented more in female-dominated sectors, and whether women lead inventors came from higher-skilled occupations given barriers they faced. Five-year patents show a 0.8 percentage point positive association (45.7% relative increase), confirming that lower costs facilitated women's participation. Collaboration mattered but remained uncommon: each additional inventor increases the probability of female involvement by 0.6 percentage points, yet the vast majority of both women and men patented as sole inventors (81% for women, 86% for men).

Women concentrated heavily in sectors where they had employment opportunities, particularly Clothing and Textiles. Women were significantly more likely to patent in Clothing (2.5 percentage points higher than average across all sectors, a 142% increase relative to the base rate), Textiles, Domestic Economy, Industrial Arts, Office Articles, Medicine and Hygiene, and Paris articles and Miscellaneous. They were less likely to patent in Agriculture, Railways, Machinery, Marine and Navigation, Construction, Mining, Road Transport, Weaponry, and Precision Instruments. This concentration aligns with labor market patterns: in 1860, women represented more than half of workers in Clothing and Textiles. The textile industry alone employed over 40% of industrial workers, and together with the food industry accounted for 62% of industrial production value.

The socioeconomic diversity of women inventors challenges narratives of elite-driven innovation. Among lead inventors with known occupations, women were less likely than men to belong to the highly skilled elite but more likely to come from white-collar professions and low-skilled backgrounds. Overall, 45% of women patentees belonged to higher social classes (including general managers, chemists, head teachers, and medical doctors), 31% were middle-class (concentrated in garment-related trades such as dressmakers, tailors, and milliners), and 25% came from low-skilled and unskilled backgrounds (including less skilled tailors, sewers, construction workers, and chemical processors). This contrasts sharply with findings from Sweden where patenting concentrated in a small industrial elite (Berger and Prawitz, 2024).

Widows were slightly overrepresented among women patentees, comprising 27.4% compared to their 10-20% population share, which is consistent with the idea that legal autonomy and the inheritance of family businesses may have facilitated their patenting. Among women patentees, 45.3% were married, 26.8% single, and 27.4% widows. Using multinomial logistic regression, the analysis finds no significant differences in financial constraints between married, single, and widowed women. However, team composition shows strong patterns: each additional inventor decreases the probability the lead inventor is married by 11.8 percentage points while increasing the probability for single women by 4.8 percentage points and widows by 7.0 percentage points.

Technology sectors strongly predict marital status. Single women were significantly more likely to patent in Clothing (7.6 percentage points higher than average) and Railways (14.8 percentage points). Widows were more likely to patent in Textiles (5.1 percentage points), Machinery (4.8 percentage points), and Paris articles and Miscellaneous (7.8 percentage points), but less likely in Clothing (10 percentage points lower). Married women showed higher likelihood in Construction and Road Transport (8.9 and 8.4 percentage points).

Women's patenting patterns reflected their life stages and employment circumstances in nineteenth-century France. Young single women often worked in clothing and textiles industries, and the proliferation of sewing machines after the 1860s enabled independent work from home or small workshops, facilitating collaboration in informal teams and giving single women advantage in Clothing patents. Widows often inherited family businesses, providing experience and financial imperatives to innovate; they accounted for the largest share of women general managers, confirming their prominent role in managing enterprises. Married women may have benefited from husbands' networks, financial support, and technical expertise in sectors like Construction and Road Transport, reducing their need for collaborative teams. Women developed diverse inventions across sectors: improvements in clothing and undergarments, Marie Breton's baby bottle for artificial breastfeeding, Louise Mulot's specialized tools for blind students' education, Louise Rose Gatteaux's coin-stamping machine, and Marie Redier's mechanisms for watches and clocks.

France showed higher women's participation in patenting than the United States or Britain, on average, throughout the nineteenth century. Women in France filed 1.8% of all patents, compared to 1% in Britain and under 0.5% in the US. Khan (2005, 2020) characterizes the American system as uniquely democratic while viewing French and British systems as oligarchic. Galvez-Behar (2008, 2019) challenges this by emphasizing Enlightenment principles underlying French laws. Despite higher costs than the US, France outstripped America in patents per capita during 1840-1860, and the occupational diversity of French women patentees, including 25% from lower-skilled backgrounds, challenges elite-driven innovation narratives. Direct international comparisons require caution because US inventors often needed multiple patents to cover what a single patent protected in France or Britain.

The persistent gender gap despite women's notable contributions reveals a glass ceiling of structural barriers beyond formal legal restrictions. The gap remained remarkably stable at 1.8% in the second half of the century despite growing educational opportunities and women's presence across all technology sectors. The diversity of women inventors across skill levels reveals that women's contributions to innovation were more extensive than traditionally recognized. The role of collaboration and sectoral employment highlights how institutional context shapes women's ability to participate, while differences by marital status show how life circumstances and legal constraints interacted with economic opportunities in complex ways. Women actively engaged in patenting across all sectors despite lacking formal scientific education and facing institutional barriers, but systemic obstacles including financial constraints, limited educational access, and concentration in less patent-intensive sectors prevented them from closing the gender gap. The French patent system enabled participation from a broader spectrum of inventors than previously understood, showing that patenting benefited from diverse inventors' creativity and resourcefulness rather than being exclusively elite-driven.

1.6.3 Paper III: Collaboration

Collaboration in nineteenth-century France changed which technology fields inventors worked in, not how much they produced or how original their ideas were. Using the full universe of French patents from 1791 to 1900 to reconstruct inventor careers, I focus on inventors who filed at least one solo patent before their first co-patent and track their behavior around that transition. For this group, moving from solo work to co-patenting coincided with roughly eleven percentage points of output being shifted to technology classes outside their historical home field: a large, immediate, and persistent reallocation. Yet collaboration showed no evidence of sustained productivity gains, no increase in novelty, and only a temporary bump in influence that faded within two years. Collaboration functioned primarily as a mechanism for crossing technological boundaries rather than for generating more productive or more original work.

The empirical strategy centers on within-inventor comparisons around each inventor's first collaboration. I identify all inventors who filed at least one solo patent before switching to teamwork and track their patenting behavior in the years before and after that switch. The analysis uses event-study designs that compare early solo-to-collaboration switchers to inventors who have not yet collaborated (including those who never do), controlling for inventor fixed effects and either calendar-year or pre-event technology-class-by-year fixed effects depending on the outcome. The Sun and Abraham (2021) stacked approach addresses staggered timing. Because different inventors switch to collaboration in different years, the stacked design compares each cohort of switchers only to inventors who have not yet switched, then aggregates the cohort-specific estimates.

To measure innovation without citation data, I develop text-based measures from patent titles using embedding-based semantic similarity. Unlike the bag-of-words approach in Kelly et al. (2021) and La Mela et al. (2024), my method converts titles into high-dimensional numerical representations that capture word meanings. Titles with similar concepts but different wording, like "process for vulcanizing rubber" and "method to harden caoutchouc", are recognized as similar. Novelty captures how semantically distinct a patent is from prior art, while influence measures how much future patents draw on its language. To validate the influence measure, I test whether it correctly ranks historically important patents above random ones: it does so 67-69 percent of the time, well above the 50 percent baseline of a coin flip.

Modern innovation is overwhelmingly collaborative, and the literature documents substantial gains from teamwork. Teams dominate the upper tail of scientific citations and produce the most technically complex work (Wuchty et al., 2007). As knowledge accumulates and individual scope narrows, collaboration rises to cover missing expertise (Jones, 2009). They mix diverse knowledge (Uzzi et al., 2013), generate refined recombinations, and depending on size either disrupt or deepen existing lines of inquiry (Wu et al., 2019). Collaboration in contemporary settings associates with rising knowledge complexity and narrow individual scope, and documented returns include higher citation counts, greater originality through atypical combinations (Uzzi et al., 2013), and improved access to non-redundant information by bridging gaps between disconnected groups (Burt, 2004; Fleming et al., 2007; Reagans and McEvily, 2003). Yet we know far less about how collaboration operated in earlier technological regimes, where knowledge was thinner, much technical expertise remained tacit rather than codified, and institutional constraints shaped who could work with whom. Nineteenth-century France offers a stark contrast: collaboration was rare, the co-inventor network consisted largely of inventors who worked entirely alone and small pairs who collaborated only with each other, and most inventors worked alone throughout their careers.

Collaboration showed no evidence of durable productivity gains. Annual patent output spiked mechanically in the year of first collaboration, rising by 0.87 patents, but this jump reflected the joint patent itself. Excluding the first collaborative patent removed the spike entirely. In years following first collaboration, output returned to baseline and remained flat. Pre-trends were violated, with negative pre-event coefficients suggesting inventors about to collaborate were already on different trajectories, one interpretation being that they were slowing down to prepare a joint project. Top-coding output at three patents per year left the pattern unchanged, and a more conservative specification using only switchers with technology-class-by-year fixed effects delivered a much smaller event-year effect of just 0.08 patents. The evidence shows no sustained increase in annual patenting after first collaboration. Output spikes mechanically in the event year because the joint patent itself appears in the count, but once that is removed, there is no lasting change in productivity.

Novelty showed no response to collaboration at any horizon. Event-study coefficients were small, mixed in sign, and statistically indistinguishable from zero at all event times. Patents filed during or after first collaboration were no more semantically distinct from prior art than patents filed before collaboration. This null result held when novelty was split into within-class and cross-class components, though the appendix shows some evidence that within-class novelty may be negatively associated with collaboration. The results provide no evidence that collaboration increased the semantic novelty of inventors' patents, at least as captured by title-based measures. If collaboration raises idea quality through better recombination or through access to diverse frames, that effect does not appear in the semantic distinctiveness of patent titles.

Influence rose modestly at first collaboration but faded quickly. Collaboration associated with a 0.04 standard deviation increase in influence in the year of first collaboration, peaking at 0.10 standard deviations one year later, then falling back to zero by year two. Pre-event coefficients were mixed and near zero, with no clear pre-trend. A placebo test randomly assigning first-collaboration years to inventors who never collaborate produced a flat path, confirming the pattern was not spurious. The effect was immediate, small, and short-lived, contrasting sharply with the large, persistent diversification across technology classes that emerged at the same moment.

Diversification across technology classes was collaboration's primary and most durable effect. At first collaboration, the share of an inventor's patents filed outside their pre-event modal technology class (the class where they filed the most patents before collaboration) jumped by 11.1 percentage points, remained large at 5.8 percentage points one year later and 6.3 percentage points two years later, then moderated to 2.6 percentage points for years three and beyond. Pre-event coefficients showed no significant trend. The outcome was detrended within inventor by calendar year to remove smooth career-age trends, since shares bounded between zero and one can drift with experience independently of any collaboration effect. This detrending ensures coefficients capture deviations from each inventor's smooth trajectory rather than general exploration over time. The specification used only not-yet-treated switchers as controls, excluding never-collaborators who may differ fundamentally in ways affecting technology-class choices independently of collaboration. In contrast, the productivity and novelty analyses retained the full sample of switchers and never-treated controls to maximize statistical power, since those outcomes do not mechanically depend on technology-class choice in the same way. Balanced-window restrictions requiring observable solo and collaborative patents on both sides of first collaboration delivered similar results: 12.1 percentage points at first collaboration, 6.0 one year later, 5.1 two years later. A placebo shuffling first-collaboration years among switchers produced a flat path with a tiny, insignificant effect. The diversification result was robust across specifications, samples, and placebo checks.

Collaboration in this setting was rare, fragmented, and confined to small teams. Of over 254,000 firm and individual inventors,[1] 69 percent worked entirely alone. Across all inventors, the median number of collaborators was zero, and the average was just 0.41; even at the 90th percentile the count was one, and at the 99th percentile only three. Network density was virtually zero. Inventors split into 209,470 separate components, disconnected groups within which inventors can reach each other through collaboration chains. The vast majority were isolated solo inventors (84 percent) or pairs collaborating only with each other (13 percent). The largest connected component contained just 76 inventors, though within that group the average distance between any two was only 4 steps. Where collaboration occurred, it concentrated in tightly knit teams: when patents involved three or more inventors, those groups almost always worked as complete units.

In cross-sectional network regressions that broaden the sample and redefine the comparison point as each inventor's entry class (their first patent's technology class), inventors diversified by partnering with collaborators from different fields and by repeating ties that had already crossed technological boundaries. Cross-class partner share was the single largest predictor: a one standard deviation increase associated with 12.1 percentage points more diversification. Inventors who bridged otherwise separate groups gained access to knowledge and problem-framing approaches invisible within existing circles, following structural holes logic that emphasizes informational advantages from bridging disconnected network parts (Burt, 2004). Repeated ties with prior joint boundary-crossing showed a 6 percentage point association with diversification per standard deviation increase. In contrast, repeated ties never leaving the home field showed small negative association. Repetition per se did not predict diversification; repetition with a partner who had already helped file outside the home class did. Trust and tacit knowledge develop through direct collaboration (Fleming et al., 2007; Reagans and McEvily, 2003), and once two inventors successfully ventured outside together, their shared experience eased subsequent boundary-crossing.

Peer exposure mattered little once direct partnership was accounted for. Simply observing that

[1] I estimate that during the full period (1791-1900), there are 12,315 firms, 3,242 family firms, 4,165 individual women, and 235,988 individual men.

one's collaborators patented in other fields, without actually working with them on such projects, showed a small, statistically marginal association with diversification. Watching was not the same as doing. Tacit knowledge appeared to transfer through joint work, not observation (Reagans and McEvily, 2003). Network controls behaved as expected: having collaborators who did not know each other positively predicted crossing (Burt, 2004), while the sheer count of collaborators, cumulative field reach, and family tie share negatively predicted it, possibly because inventors with many collaborators or kin-based networks remained anchored in their entry field due to accumulated obligations or specialization.

Women showed substantially larger diversification responses to cross-class and repeated outside partnerships than men did. The association between cross-class partners and diversification was roughly 9.2 percentage points larger for women, beyond what was observed for men. The association of repeated outside ties was similarly substantial at about 6.2 percentage points larger for women. In contrast, the peer exposure interaction for women was small and insignificant. Women were scarce in the patent system, making up 1.7 percent of inventors (Merouani and Perrin, 2026), and 76.5 percent of women worked entirely alone compared to 68.9 percent of men. Yet conditional on collaborating, women built networks at least as dense as men's, particularly in male-dominated technology classes like machinery, railways, and mining. Family ties provided the key entry point: 35.4 percent of women's ties were family links compared to 8.9 percent for men. When women obtained cross-class partners or repeated ties that had already crossed a boundary, the association with diversification was substantially larger than for men. This pattern aligns with research showing that women face higher thresholds of trust before gaining access to valuable connections (Ling et al., 2025; Meng, 2016). When barriers are high, the trusted partner from another field becomes especially valuable.

The findings connect to broader debates about the French patent system and the nature of collaboration in early industrialization. The dispersed network structure, with few brokers, no dominant hubs, and many small disconnected components, is more consistent with accounts of the French patent system as broadly open (Galvez-Behar, 2019; Merouani and Perrin, 2026) than with narratives of elite control (Khan, 2020). Women and men from medium-skill and even low-skill occupations obtained patents (Merouani and Perrin, 2026), and the observed collaboration structure suggests a relatively open, dispersed system rather than tight centralized control. The absence of productivity and novelty gains distinguishes nineteenth-century collaboration from modern teamwork, where knowledge is deep, codified, and widely shared, and where teams often matter because they allow specialization and support highly novel combinations (Jones, 2009; Uzzi et al., 2013; Wu et al., 2019). At the macro level, sustaining progress requires far more researchers as research productivity declines (Bloom et al., 2020). In nineteenth-century France, collaboration mainly changed where inventors applied their skills. It worked as a tool for crossing technological boundaries, especially when it linked inventors to partners from other fields and when women used scarce, trusted ties to enter new areas.

The results suggest that the returns to collaboration depend on context. In modern settings, teams associate with more citations, higher novelty, and greater impact because they pool specialized knowledge and navigate complex problem spaces (Jones, 2009; Uzzi et al., 2013; Wuchty et al., 2007). In nineteenth-century France, where knowledge was thinner and inventors operated in a fragmented network, collaboration was not associated with higher productivity or originality. Its durable association was with expanded technological scope, connecting inventors to partners from different fields and building repeated ties that reinforced boundary-crossing. For women, who faced higher barriers to entry and relied heavily on family ties, the returns from such connections were especially large. Collaboration in this setting was less about generating new ideas and more about accessing knowledge that already existed in other domains.

1.6.4 Paper IV: A demography

More than four thousand French women obtained patents between 1791 and 1900, but patent records tell us what they invented, not who they were. This paper links 545 married or widowed women inventors to French civil registration and genealogical records to address three questions: What happens to innovation geography when patent addresses are replaced with life-event locations? Which départements produced women inventors, and how do inventor rates relate to literacy, economic structure, and educational equality? When in the life course did married women enter the patent system, and how did marriage and childbearing shape this timing?

The analysis begins from the French patent database compiled by Merouani and Perrin (2026) and the inventor de-duplication of Merouani (2025), identifying 4,165 distinct women who appear on at least one patent between 1791 and 1900. The linking strategy exploits French naming conventions: married women typically appear in records with both their maiden name and marital surname. I construct targeted queries for the 1,212 women whose patents record complete names, using genealogical search interfaces aggregating millions of vital records. The linking algorithm uses probabilistic matching combining name similarity, spouse information, geographic consistency, source reliability, and temporal plausibility. Stratified validation against original civil records documents high reliability: 95 percent for birth years (average error 0.82 years), 97 percent for marriage years (average error 0.12 years), and 91 percent for death years (average error 0.41 years).

The analysis complements earlier work and clarifies a few aspects across the three themes. First, patent addresses make innovation appear overwhelmingly Parisian, but civil records reveal much more dispersed origins. Patent records show 81 percent of women listing Paris addresses, yet only 43 percent married in the capital. Among 260 inventors who married outside Paris, 169 (65 percent) have patent addresses in Paris, with a median distance of 210 kilometers between marriage location and patent address. Death records distinguish genuine migrants from administrative address users: among 96 Paris-Address Non-Parisians with observed deaths, 51 died in Paris while 45 died outside Paris. These 45 women married outside Paris, listed Paris addresses on patents, but died outside Paris, suggesting they may not have permanently relocated to the capital. This represents 8.3 percent of the sample. Patent agents are strongly associated with this pattern: among inventors married outside Paris, 77.9 percent with listed agents have Paris addresses, compared to 50.8 percent without agents. The institutional context supports this: French patent applications were filed in a central Paris office, often through agents whose addresses appeared in records (Galvez-Behar, 2019). Civil records reveal geographic dispersion that patent addresses hide: birth and marriage locations show substantial clustering beyond Paris in Lyon, Bordeaux, and other cities.

To examine which départements produced women inventors, I construct inventor intensity: women inventors per 100,000 female residents in each département. Regressions excluding Seine (Paris) show higher female literacy positively associates with women's inventor rates. A ten percentage point increase in female literacy associates with 0.25 additional women inventors per 100,000 women ($p = 0.011$). The share of women employed in agriculture shows a negative coefficient: a ten percentage point increase associates with 0.37 fewer inventors per 100,000 women ($p = 0.050$). The Education Gender Gap Index, measuring relative gender parity in primary education, shows no additional explanatory power once absolute educational levels and economic structure are controlled. Railroad infrastructure and urban population share show no significant associations when Seine is excluded.

Second, married women entered the patent system in mid-life, not youth. Among 471 linked inventors with birth years and patent dates, the median age at first patent was 41 (mean 42.5). Among 449 women with observed marriages, mean age at marriage was 23.9 years (median 22). The first patent arrives a median of 16 years after marriage (mean 18.6), with remarkable stability across sectors and decades. Only 4.2 percent of women patent before marrying. Serial inventors differ sharply: one-time patentees file their first patent at average age 43.0, while serial patentees enter at 30.8 years, a gap of 12.3 years. This early start translates into longer potential careers: one-time patentees live about 25 years after their first invention, while women with two or more patents live roughly 37 years after entry. Sectoral variation shows modest differences, with Clothing (median age 40) showing younger entry than Chemistry (median 45) and Medicine & Hygiene (median 43).

Third, family formation strongly influenced timing. Among 344 women for whom the timing of births is observed, 95.3 percent filed their first patent after their first child; 83.1 percent patented after their last child. The typical mother gave birth to her last child at age 30-31 and filed her first patent at age 42, with a median gap of 10 years. This resonates with modern work showing mothers' scientific productivity often peaks in their early forties (Kim and Moser, 2025). Despite this long gap, there is no detectable relationship between family size and patent productivity: childless women filed 1.46 patents on average, mothers of small families 1.06, and mothers of large families 1.17 ($p = 0.12$).

Women with five or six children filed their first patents at roughly the same age as women with one or two children. The posible explnation lies in the gap between last birth and first patent, which shows a significant negative association with family size. Each additional child is associated with about 1.5 years reduction in the post-childbearing wait time. Women with one child waited about 13 years after that birth before patenting, while women with five or more children waited only about 8 years. Women with larger families effectively caught up to the typical patenting age of early forties by transitioning faster from childbearing to invention.

The findings carry important limitations. The sample represents only successfully linked, married women with complete names, just 545 of 4,165 identified women inventors. Death dates exist for only 56 percent. Marriage location imperfectly proxies for patent-time residence given the roughly 20-year median gap between events.

Yet the study makes three contributions. First, methodologically, it demonstrates that large-scale linkage between historical patent records and genealogical metadata is feasible and accurate. Second, it shows centralized administrative arrangements systematically distorted innovation geography: patent addresses suggest 81 percent Paris concentration, but civil records reveal only about 43 percent married there, with at least 8.3 percent clearly using Paris addresses without evidence of permanent residence there, and a speculative upper bound of about 14.5 percent if the missing-death cases resemble the observed ones. Départements with higher literacy and less female agricultural employment produced more women inventors. Third, it reveals that for married women inventors, patenting was a mid-life activity shaped by family formation: women entered at median age 41, roughly 18 years after marriage, with 83 percent of mothers patenting only after their last childbirth. Women with varying family sizes converged on the same mid-life entry point through faster post-childbearing transitions for larger families.

The 545 women successfully linked were not the Parisian entrepreneurs patent addresses suggest. They were middle-aged women from across France who entered the patent system after decades of marriage and motherhood, their origins outside the capital obscured by administrative centralization.

1.7 Conclusion

French women patented more than their British or American counterparts, yet their 1.8 percent share remained remarkably stable across the century. Financial constraints mattered: lower patent fees after 1844 raised women's participation, and cheaper five-year patents attracted them disproportionately. Women concentrated in sectors where they worked, particularly clothing and textiles, though they invented across all fields from baby bottles to coin-stamping machines. Their socioeconomic backgrounds were surprisingly diverse, with a quarter coming from low-skilled occupations rather than just the elite. Collaboration changed what inventors did, not how much they produced. Moving from solo work to teamwork shifted inventors toward new technology fields but showed no sustained gains in productivity or novelty. Women relied more heavily on family ties than men, with 35 percent of their collaborative links being family connections compared to just 9 percent for men. In male-dominated sectors like machinery, railways, and mining, women worked with more collaborators than in other fields, suggesting they needed broader networks to access knowledge in areas where they faced higher barriers. For women facing higher barriers, trusted cross-class partnerships generated especially large diversification returns. Patent addresses made innovation appear overwhelmingly Parisian, but civil records reveal that only 43 percent of married women inventors actually married in the capital. Women entered the patent system in mid-life, at median age 41, roughly 18 years after marriage and typically after childbearing ended. Départements with higher female literacy and less agricultural employment produced more women inventors per capita.

The findings come with clear limitations. The linked demographic sample covers only 13 percent of identified women inventors, all married or widowed with complete names. Patent addresses may reflect administrative convenience rather than true residence, and marriage locations imperfectly proxy for later residence given the long time gaps. The collaboration analysis cannot distinguish whether partnerships caused diversification or whether inventors planning to enter new fields sought partners for that purpose. Future work should extend these methods to longer time periods, and countries, to test whether the patterns generalize. Better understanding of how family networks and education systems shaped women's innovative capacity would help explain the persistent gender gap. Linking more inventors to census and civil records would reveal how occupational paths, migration, and life events influenced both men's and women's participation in technological change. The central challenge remains building data infrastructure that can connect scattered historical sources at the scale needed to study patenting activity and innovation systematically.

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