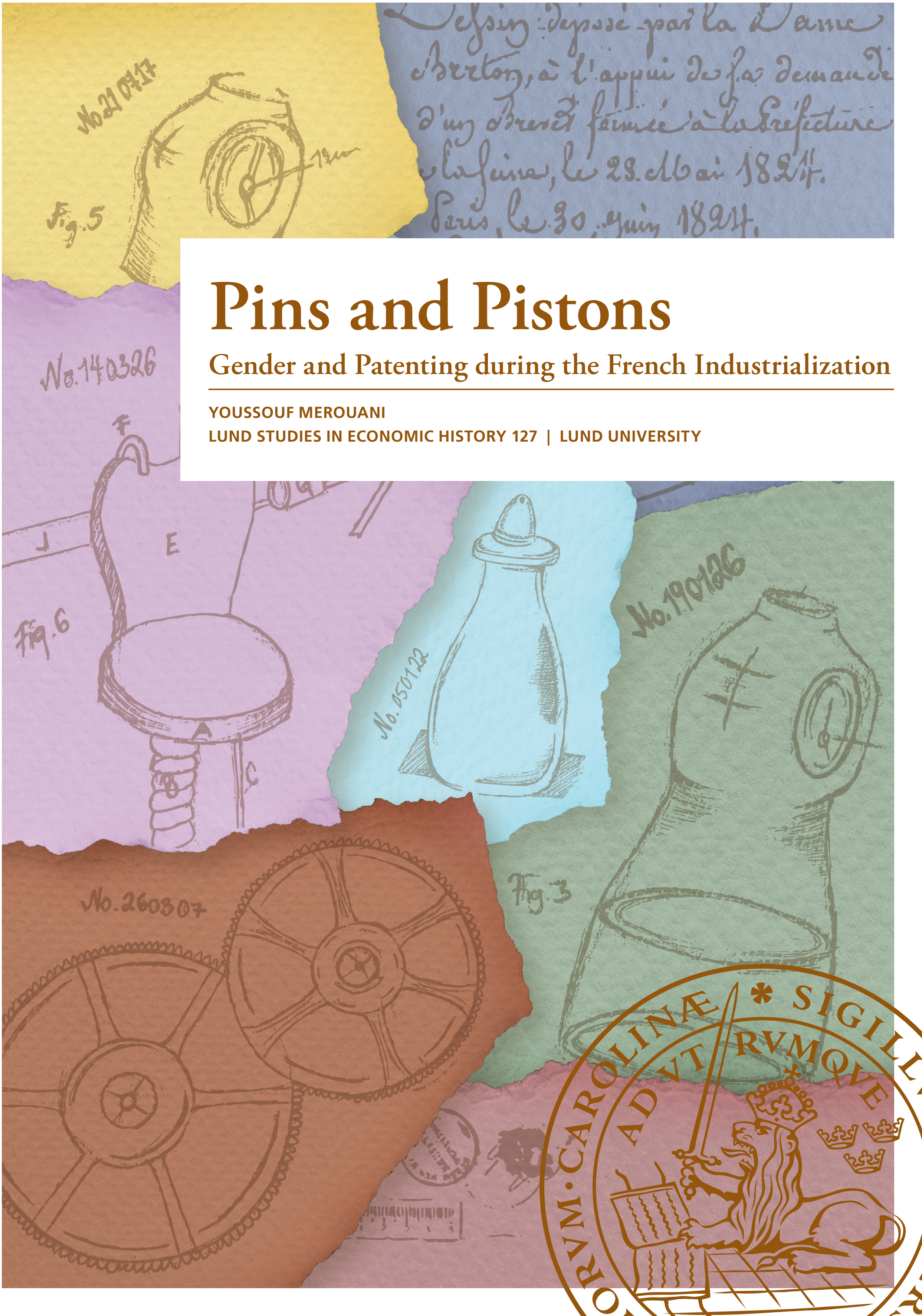
Pins and Pistons

Gender and Patenting during the French Industrialization

Merouani, Youssouf

2026



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Gender and Patenting during the French Industrialization

YOUSSOUF MEROUANI

LUND STUDIES IN ECONOMIC HISTORY 127 | LUND UNIVERSITY

Pins and Pistons

The feeding bottle on the cover of this thesis was patented in 1824 by a Parisian midwife named Marie Madeleine Adélaïde Breton. She sold it from her shop, shipped it by mail with endorsements from the Royal Academy of Medicine, and went to court when rivals copied her design. She rarely appears in the histories of French industrialization. Neither do the 4,164 other women who filed French patents between 1791 and 1900.

Pins and Pistons recovers them. Working from the complete universe of French patents, rebuilt from government gazettes, handwritten applications, and civil registers, the thesis follows women inventors across every one of the twenty technology classes the patent office recognized. They patented in all of them, from pins to pistons: from clothing, textiles, and household articles to machinery and precision instruments. Patents involving at least one woman account for 1.75 percent of the French record, a higher share than in Britain or the United States. For more than a thousand of these women, civil records restore what patent documents omit: birth years, marriages, children, deaths, and the arc of a working life.

The thesis challenges the longstanding view of French invention as a Parisian elite preserve. Women and men patented across the social spectrum, and while Napoleon's Civil Code denied married women the right to their own earnings, the patent office was open to anyone who wished to file. The gender gap persisted anyway, and the thesis locates it elsewhere. Not at the patent office, but earlier: in the work that channelled women into certain sectors, in the collaborations they struggled to enter, and in the years of marriage and childbearing that left little time to invent.

Bringing together advanced text analysis, network reconstruction, and large-scale record linkage, *Pins and Pistons* is the first systematic account of who these women were, how they invented, and why the gender gap was made long before any patent application was ever written.

Department of Economic History
School of Economics and Management

Lund Studies in Economic History 127
ISBN 978-91-989643-8-7
ISSN 1400-4860

Printed by Media-Tryck, Lund 2025 NORDIC SWAN ECOLABEL 3041 0903

9 789198 964387

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Gender and Patenting during the French Industrialization

by Youssouf Merouani

Thesis for the degree of Doctor of Philosophy
Thesis advisors: Faustine Perrin, Josef Taalbi
Faculty opponent: Benjamin Schneider

To be presented, with the permission of the Lund University School of Economics and Management of Lund University, for public criticism in the *Holger Crafoords Ekonomicentrum* (EC3:211) at the Department of Economic History on Wednesday, the 3rd of June 2026 at 09:15.

Organization
LUND UNIVERSITY
Department of Economic History
Box 7083
SE–220 07 LUND
Sweden

Document name
DOCTORAL DISSERTATION

Date of disputation
2026-06-03

Sponsoring organization

Author(s)
Youssouf Merouani

Title and subtitle
Pins and Pistons: Gender and Patenting during the French Industrialization

Abstract
Studying the full universe of nearly 390,000 French patents filed between 1791 and 1900, I show that the nineteenth-century gender patenting gap arose less at the patent office than through unequal access to practical knowledge, collaborators, and time across the life course. I identify 4,165 women inventors using gender-specific honorifics, classify patents with machine learning, reconstruct the full co-inventor network, and link 1,076 women to civil vital records.

Patents involving at least one woman made up 1.75 percent of the French record, higher than in Britain or the United States, and women from a broad social range patented across all twenty technology classes. What produced the gap lay before the application was filed.

Three mechanisms shape it. Direction: within each inventor's birth department, the female employment share predicts her patent sector about twice as strongly as industry size. Women patented where women worked. Scope: at first collaboration, the share of output outside an inventor's home technology class rose by 35 percentage points and persisted. Women were more likely than men to remain outside the network (76.5 versus 68.8 percent isolates), and family ties made up 35.8 percent of women's collaborative links versus 8.8 percent of men's. Timing: married women filed their first patent at a median age of 41.5, compared with 30 for women unmarried at first patent; 83 percent of mothers patented only after their last recorded child was born. Later cohorts filed their first patent about four years earlier, as access costs fell with the 1844 reform and women's legal and educational opportunities expanded.

Key words
patents, gender, France, industrialization, women inventors

Classification system and/or index terms (if any)

Supplementary bibliographical information

Language
English

ISSN and key title
ISSN: 1400-4860 Lund Studies in Economic History 127

ISBN
978-91-989643-8-7 (print)
978-91-989643-9-4 (pdf)

Recipient's notes

Number of pages
366

Price

Security classification

Signature ____________________ Date 2026-04-22

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Lund University

A doctoral thesis at a university in Sweden takes either the form of a single, cohesive research study (monograph) or a summary of research papers (compilation thesis), which the doctoral student has written alone or together with one or several other author(s).

In the latter case the thesis consists of two parts. An introductory text puts the research work into context and summarizes the main points of the papers. Then, the research publications themselves are reproduced, together with a description of the individual contributions of the authors. The research papers may either have been already published or are manuscripts at various stages (in press, submitted, or in draft).

Cover illustration: Cover art by Claudia Schmiedtova and Simona Suržinová. Hand-drawn illustrations by Claudia Schmiedtova; digital artwork by Simona Suržinová.

Funding information: The thesis work was financially supported by the Jan Wallander and Tom Hedelius Foundation (P21-0168).

Lund University School of Economics and Management, Department of Economic History

ISBN: 978-91-989643-8-7 (print)
ISBN: 978-91-989643-9-4 (pdf)
ISSN: 1400-4860 Lund Studies in Economic History 127

Printed in Sweden by Media-Tryck, Lund University, Lund 2026

Printed matter
3041 0903

Media-Tryck is a Nordic Swan Ecolabel certified provider of printed material. Read more about our environmental work at www.mediatryck.lu.se

MADE IN SWEDEN

To Mehdi and Elias Zakaria

Contents

List of publications

This thesis is based on the following publications, referred to by their Roman numerals:

I **Gender and the Long-Run Development Process. A Survey of the Literature**

Youssouf Merouani, Faustine Perrin
Published in *European Review of Economic History*, 26(4), 2022, pp. 612–641

II **Women Inventors: On the Origins of the Gender Patenting Gap**

Youssouf Merouani, Faustine Perrin
Accepted for publication in *Journal of Economic History*

III **What Happens When Inventors Collaborate? Evidence from 19th-Century French Patents**
Youssouf Merouani
Unpublished manuscript

IV **What Shaped Women's Invention during Industrialization?**

Youssouf Merouani
Unpublished manuscript

RELATED PAPERS

"Myths and Biases: An Exploration of Women's Historical Patenting Activities"

Youssouf Merouani, Faustine Perrin

Chapter in C. Le Chapelain (ed.) *Nineteenth Century Businesswomen*. Cham: Springer Nature Switzerland (Frontiers in Economic History), 2024, pp. 253–276.

"Pioneering Women: The Determinants of Women's Inventive Productivity"

Youssouf Merouani, Faustine Perrin

Under review, 2026.

Acknowledgements

I am grateful to many, for little things and big things, and all the things in between. I will name some of you. But know that even those of you I do not name are not forgotten. Here are my thanks.

Faustine Perrin, my supervisor. For all the support, of course. For your incredible mentorship, and for instilling in me the courage to follow my academic curiosity, even when only based on hunches. For being happy when things went according to plan and supportive when not. But also for your friendship, and for introducing Claudia and me to dear Rémi.

Josef Taalbi, my co-supervisor. For the comments, the encouragement, and the exciting discussions on all kinds of topics: from networks to Algeria. Tobias Karlsson, my co-supervisor at the start of this journey. For the fulfilling discussions and for always asking how things are going.

Marcus Box, Paulina Rytkönen, and Tommy Larsson Segerlind, my mentors from Södertörn University. For setting me on this journey well prepared and supporting me through it.

Mats Olsson, Ellen Hillbom, Anders Larsson, Seán Kenny, Anneli Nilsson Ahlm, Tina Wueggertz, my PhD colleagues on both sides of "the little kitchen", and many others. For creating the supportive and inspiring environment of our department. Kerstin Enflo, for your constant encouragement. Olof Ejermo, for the many discussions and the sharing of literature. Anna Tegunimataka, for your guidance.

Maria Stanfors and Alessandro Nuvolari. For your insightful and constructive discussion. Ben Schneider and Marco Martinez, for being an inspiration. Fredrik Tell, for your questions and comments. Matti La Mela, for the open discussions. Claude Diebolt, for always sharing your energy and wisdom. Jochen Streb, for your questions and invitation. Finni Jo Erdmann and Sophia Rishyna, for making all those conferences more enjoyable.

Jonas Kreutzer, for sharing the office and a rock by Västra Hamnen, and, together with Emmie Wahlström, for always including us. Jonathan Jayes and Anton Svensson, for being welcoming and often sharing food. Bram Hilkens and Tancredi Buscemi, for your friendship and for bringing renewed energy to the "downstairs" during your stay.

Alexandra Cermeño and Kathryn Gary. For your warmth and for opening the doors to your homes for Claudia and me. Anabela Stan, for reminding me that there are more important things in life.

Felicia Frennesson, my von Kofeldt sister and dear friend, for your help and for extending our family with yours. Oussama and Amine, for the adventure of a lifetime. Daniel, for your friendship. Ikram, Mariam, and Jasmina, for being our extended family. Simona, for sharing your talent. *Tata* Ouiza, for your unwavering help. Sulaman and Humera, for your warmth and for welcoming Claudia and me into the fold of your family.

My family in Algeria. Aunties, uncles, and cousins, for all the restful summers. My family and friends in Slovakia, for your welcoming kindness. Deniska, for your love of life. Janka, for your attentive care.

Mani, for always caring and taking pride in your work and family. Yemma, for your care and all the visits to Cherchell. Djeddou and Baba Sidou, for the examples you set. Mama and Papa, for life, for wisdom, for love, and more. Mehdi, for the fond memories. Amina, for your knowledge. Yasmine, for your strength. Younes, for your joy. Elias Zakaria, for bringing us all even closer.

Claudia. For your love, your patience, and your care. What would life be without you?

Popular summary in English

The feeding bottle on the cover of this thesis was patented in 1824 by a Parisian midwife named Marie Madeleine Adélaïde Breton. She sold it from her shop, shipped it by mail, secured endorsements from the Royal Academy of Medicine, and went to court when rivals copied her design. Fifty years later, Madeleine Brès, daughter of a village wheelwright and the first woman to earn a French medical degree, patented her own feeding bottle in three age-calibrated sizes.

Neither woman appears in the standard histories of French industrialization. Until recently, most women inventors appeared only as names on patent documents, when they appeared at all.

This thesis recovers them. Between 1791 and 1900, 4,165 individual women filed patents in France. They worked in every one of the twenty technology classes the patent office recognized, from clothing and textiles to machinery and precision instruments. Patents involving at least one woman made up 1.75 percent of the French record, a higher share than in Britain or the United States. Others had traced some of these women case by case. What was missing was a systematic picture across the full century, and the lives behind the names.

The French patent office used gender-specific honorifics: *Madame*, *Mademoiselle*, *Veuve*. British and American records did not. I built on digitization work by the French national patent institute, adding 14,500 pages of government gazettes and 150,000 handwritten applications. I developed machine learning to do much of the work at scale: reading faded print, classifying technology, linking inventors across decades of name changes. Flore Félicité Prophète, a seamstress, appears on her early patents as Mademoiselle Prophète, then Madame Bresson after marriage, then Veuve Bresson after her husband's death. One person, three names. For 1,076 of them, I traced birth, marriage, and death records through French civil registers, so we now know when they were born, whom they married, where they came from, how many children they had, and when they died.

The openness of the patent office is a paradox. Under Napoleon's *Code civil*, a married woman could not easily sign a commercial contract, take a job, or keep her own earnings without her husband's permission. The patent office was the exception. The 1844 law allowed access to "whoever wishes to obtain a patent," and the administration did not check. A wife could file without her husband's knowledge. The country with Europe's most restrictive marriage law also ran one of its most accessible patent systems. Women made the most of it. Marie Virginie Decroisette, a village seamstress from the Somme, patented a padding material made from plant fibers in 1844 and was selling it in Paris under her own name.

Three patterns came out of the data.

Women patented where women worked. Compare two women born a few hundred kilometers apart. Marie Massart, from Haut-Rhin in Alsace, patented a textile innovation, and Haut-Rhin was a textile region where women filled the mills. Marie Louise Trouilhas, from Bouches-du-Rhône, patented a chemical process, and Bouches-du-Rhône was soap country, where women handled industrial chemistry every day. Comparing sectors within each woman's birth department, the share of local women employed in a sector predicts her patents about twice as strongly as the size of the sector. Invention was not separate from economic life. It grew out of it.

Collaboration widened what inventors could do. When an inventor first worked with a partner, the share of her output outside her usual field jumped by about 35 percentage points, and stayed there. Knowledge moved along specific ties: once someone worked with a machinist, her later solo patents began appearing in the machinist's field. Women faced a sharp barrier to entering these partnerships. Three in four never collaborated with anyone. Among those who did, family made up 36 percent of their partners, against 9 percent for men. Sisters, husbands, fathers, sons: the household was where many women found their way into wider networks. Once inside, they diversified their work more broadly than men.

Timing was the third constraint, and the hardest to see without the civil records. Married women filed their first patent at a median age of 41.5. Women who were still single when they first patented were 30. Among mothers, 83 percent patented only after their last recorded child was born, with a median gap of eleven years between the last birth and the first patent. Children and family consumed time, but the practical knowledge women had picked up earlier in life did not vanish because of it. They kept it.

A policy change in 1844 mattered. The French state let inventors pay for patents in annual installments instead of one large sum. The probability of a patent being filed by a woman rose by 40 percent. Mothers who came of age around the reform patented about four years sooner than the cohort before them. Cheaper access, combined with a slow widening of women's legal rights from the 1880s onward, changed when women could act on the knowledge they had built up.

Put the three patterns together and the argument follows. The gender gap was not made at the patent office. The office was, by the standards of its time, remarkably open. The gap was made earlier: in the work that sorted women into certain sectors, in the partnerships women struggled to enter, and in the marriage and childbearing years that left little time to invent.

Pins and pistons came from the same economy. It took centuries to see it.

Populärvetenskaplig sammanfattning på svenska

Nappflaskan på omslaget till denna avhandling patenterades 1824 av den parisiska barnmorskan Marie Madeleine Adélaïde Breton. Hon sålde den i sin butik, skickade den med post, fick rekommendationer från Académie royale de médecine och gick till domstol när konkurrenter kopierade hennes modell. Ett halvt sekel senare patenterade Madeleine Brès, dotter till en hjulmakare i en fransk by och den första kvinnan att ta en fransk medicinsk examen, sin egen nappflaska i tre storlekar anpassade till olika åldrar.

Ingen av dem har någon självklar plats i standardskildringarna av Frankrikes industrialisering. Fram till helt nyligen syntes de flesta kvinnliga uppfinnare bara som namn på patenthandlingar, om de syntes alls.

Den här avhandlingen gör dem synliga. Mellan 1791 och 1900 lämnade 4 165 olika kvinnor in patent i Frankrike. De patenterade i alla de tjugo teknikklasser som patentverket använde, från kläder och textilier till maskiner och precisionsinstrument. Patent där minst en kvinna medverkade stod för 1,75 procent av alla franska patent, en högre andel än i Storbritannien och USA. Andra forskare har följt några av dessa kvinnor, fall för fall. Det som saknades var en systematisk bild av hela seklet, och av liven bakom namnen.

Det franska patentverket använde könsspecifika titlar: *Madame*, *Mademoiselle*, *Veuve*. De brittiska och amerikanska registren gjorde det inte. Jag byggde vidare på det digitaliseringsarbete som det franska nationella patentinstitutet bedrivit, och tillförde 14 500 sidor officiella franska kungörelsetidningar och 150 000 handskrivna ansökningar. Jag utvecklade maskininlärningsmetoder som gjorde det möjligt att i stor skala läsa bleknad trycktext, klassificera teknik och knyta ihop samma uppfinnare trots namnbyten över flera decennier. Flore Félicité Prophète, en sömmerska, förekommer på sina tidiga patent som Mademoiselle Prophète, därefter som Madame Bresson efter giftermålet och slutligen som Veuve Bresson efter makens död. En person, tre namn. För 1 076 av kvinnorna har jag dessutom kunnat följa födelse-, vigsel- och dödsuppgifter i franska civilregister. Därmed vet vi när de föddes, vem de gifte sig med, varifrån de kom, hur många barn de hade och när de dog.

Patentverkets öppenhet är en paradox. Under Napoleons *Code civil* kunde en gift kvinna inte utan vidare ingå kommersiella avtal, ta arbete eller fritt förfoga över sina egna inkomster utan makens tillstånd. Patentverket var undantaget. 1844 års lag öppnade systemet för "var och en som vill få patent", och myndigheten kontrollerade inte sökandens civila behörighet. En gift kvinna kunde alltså lämna in en ansökan utan att behöva visa upp något medgivande från sin man. Landet med Europas mest restriktiva äktenskapslagstiftning hade samtidigt ett av Europas mest tillgängliga patentsystem. Kvinnor tog vara på den möjligheten. Marie Virginie Decroisette, en sömmerska från Somme, patenterade 1844 ett vadderingsmaterial av växtfibrer och sålde det i Paris under eget namn.

Tre mönster träder fram ur materialet.

Kvinnor patenterade inom de områden där kvinnor arbetade. Låt oss jämföra två kvinnor, födda några hundra kilometer från varandra. Marie Massart, från Haut-Rhin i Alsace, patenterade en textilinnovation, och Haut-Rhin var en textilregion där många kvinnor arbetade i industrin. Marie Louise Trouilhas, från Bouches-du-Rhône, patenterade en kemisk process, och Bouches-du-Rhône var ett centrum för tvålindustrin, där kvinnor dagligen arbetade med industriell kemi. När jag jämför sektorer inom varje kvinnas födelsedepartement förklarar andelen kvinnor i den lokala arbetskraften hennes patentområde ungefär dubbelt så starkt som sektorns storlek. Uppfinnande var inte skilt från det ekonomiska livet. Det växte fram ur det.

Samarbete vidgade vad uppfinnare kunde göra. När en uppfinnare för första gången arbetade tillsammans med någon annan ökade andelen patent utanför hennes vanliga område med omkring 35 procentenheter, och låg sedan kvar på den nivån. Kunskap följde konkreta samarbetsband: när någon hade arbetat med en mekaniker började hennes senare patent på egen hand att dyka upp inom mekanikerns område. Kvinnor mötte ett tydligt hinder för att komma in i sådana samarbeten. Tre av fyra samarbetade aldrig med någon annan. Bland dem som gjorde det stod familjen för 36 procent av samarbetspartnerna, jämfört med 9 procent för män. Systrar, makar, fäder, söner: hushållet blev för många kvinnor vägen in i bredare nätverk. När de väl kom in kunde samarbetet kraftigt vidga deras tekniska räckvidd.

Livsfasen var den tredje begränsningen, och den svåraste att se utan civilregistren. Gifta kvinnor tog sitt första patent vid medianåldern 41,5 år. För kvinnor som fortfarande var ogifta när de patenterade första gången var medianåldern 30 år. Bland mödrar togs 83 procent av de första patenten först efter att det sista registrerade barnet hade fötts, med en median på elva år mellan den sista födseln och det första patentet. Barn och familj tog tid, men den praktiska kunskap kvinnorna hade samlat på sig tidigare i livet försvann inte. Den fanns kvar.

En reform 1844 spelade roll. Den franska staten lät uppfinnare betala patentavgifterna i årliga delbetalningar i stället för i en enda stor summa. Sannolikheten att ett patent involverade en kvinna ökade med 40 procent. Mödrar i de kohorter som blev vuxna kring reformen patenterade ungefär fyra år tidigare än kohorten före dem. Lägre kostnader, tillsammans med en gradvis utvidgning av kvinnors rättigheter från 1880-talet och framåt, förändrade när kvinnor kunde omsätta sin kunskap i patent.

Sätter man samman de tre mönstren följer slutsatsen. Könsgapet i patentering uppstod inte främst vid patentverket. Verket var, med sin tids mått mätt, anmärkningsvärt öppet. Gapet skapades tidigare: i det arbete som styrde in kvinnor i vissa sektorer, i de samarbeten som var svåra för kvinnor att få tillgång till, och i de år av familjebildning som lämnade liten tid att uppfinna.

Knappnålar och kolvar växte fram ur samma ekonomi. Det tog århundraden att se det.

Résumé de vulgarisation en français

Le biberon figurant sur la couverture de cette thèse a été breveté en 1824 par une sage-femme parisienne, Marie Madeleine Adélaïde Breton. Elle le vendait dans sa boutique, l'expédiait par la poste, obtint des recommandations de l'Académie royale de médecine et porta l'affaire en justice lorsque des concurrents copièrent son modèle. Cinquante ans plus tard, Madeleine Brès, fille d'un charron de village et première femme à obtenir un diplôme français de médecine, breveta à son tour un biberon décliné en trois tailles adaptées à l'âge des enfants.

Ni l'une ni l'autre n'occupent une place de choix dans les récits classiques de l'industrialisation française. Jusqu'à une date récente, la plupart des femmes inventrices n'apparaissaient guère que comme des noms sur des brevets, quand elles apparaissaient.

Cette thèse les fait réapparaître. Entre 1791 et 1900, 4 165 femmes distinctes ont déposé des brevets en France. Elles ont breveté dans chacune des vingt classes technologiques reconnues par l'administration, de l'habillement et du textile aux machines et aux instruments de précision. Les brevets impliquant au moins une femme représentent 1,75 pour cent de l'ensemble des brevets français, soit, sur la même période, une part plus élevée qu'en Grande-Bretagne ou aux États-Unis. D'autres chercheuses et chercheurs avaient déjà retrouvé certaines de ces femmes, au cas par cas. Ce qui manquait, c'était une vue d'ensemble sur tout le siècle et sur les vies cachées derrière les noms.

L'administration française des brevets utilisait des titres explicitement genrés : *Madame*, *Mademoiselle*, *Veuve*. Les registres britanniques et américains ne le faisaient pas. Je me suis appuyé sur le travail de numérisation mené par l'Institut national de la propriété industrielle, que j'ai complété par 14 500 pages de bulletins officiels et 150 000 demandes manuscrites. J'ai développé des méthodes d'apprentissage automatique capables de déchiffrer des imprimés estompés, de classer les inventions par domaine technique et de retrouver une même personne derrière plusieurs noms au fil des décennies. Flore Félicité Prophète, couturière, apparaît d'abord sur ses premiers brevets comme *Mademoiselle Prophète*, puis comme *Madame Bresson* après son mariage, et enfin comme *Veuve Bresson* après la mort de son mari. Une seule personne, trois noms. Pour 1 076 de ces femmes, j'ai en outre retrouvé les actes de naissance, de mariage et de décès dans les registres d'état civil français. Nous savons donc désormais quand elles sont nées, qui elles ont épousé, d'où elles venaient, combien elles ont eu d'enfants et quand elles sont mortes.

L'ouverture du système des brevets constitue un paradoxe. Sous le *Code civil* napoléonien, une femme mariée ne pouvait pas aisément conclure un contrat commercial, exercer un métier ou disposer librement de ses revenus sans l'autorisation de son mari. Le brevet faisait exception. La loi de 1844 ouvrait l'accès à « quiconque voudra obtenir un brevet », et l'administration ne vérifiait pas la capacité civile des demandeurs. Une femme mariée pouvait donc déposer une demande sans avoir besoin de l'autorisation de son mari. Le pays dont le droit matrimonial était l'un des plus restrictifs d'Europe avait en même

temps l'un de ses systèmes de brevets les plus accessibles. Certaines femmes en ont pleinement profité. Marie Virginie Decroisette, couturière originaire de la Somme, breveta en 1844 un matériau de rembourrage à base de fibres végétales et le vendait bientôt à Paris sous son propre nom.

Trois grands résultats ressortent de l'enquête.

D'abord, les femmes déposaient des brevets dans les secteurs où elles étaient présentes sur le marché du travail. Comparons deux inventrices nées à quelques centaines de kilomètres l'une de l'autre. Marie Massart, originaire du Haut-Rhin en Alsace, breveta une invention textile ; or le Haut-Rhin était une région textile où les femmes occupaient une place importante dans l'industrie. Marie Louise Trouilhas, née dans les Bouches-du-Rhône, breveta un procédé chimique ; les Bouches-du-Rhône étaient alors un centre de l'industrie du savon, où les femmes manipulaient quotidiennement des substances et des procédés relevant de la chimie industrielle. Lorsqu l'on compare les secteurs au sein du département de naissance de chaque inventrice, la part des femmes dans l'emploi local d'un secteur constitue un facteur environ deux fois plus déterminant que la taille même de ce secteur pour prédire son domaine de brevet. L'invention n'était pas séparée de la vie économique. Elle en était issue.

Ensuite, la collaboration élargissait le champ des possibles. Lorsqu'un inventeur ou une inventrice collaborait pour la première fois avec un partenaire, la part de ses brevets déposés hors de son domaine habituel augmentait d'environ 35 points de pourcentage, puis s'y maintenait. La transmission des connaissances s'effectuait par le biais de relations spécifiques : après avoir travaillé avec un mécanicien, une inventrice voyait ses brevets ultérieurs apparaître dans le domaine de la mécanique. Les femmes, toutefois, se heurtaient à une forte barrière d'entrée dans ces collaborations. Trois sur quatre ne collaboraient jamais avec personne. Parmi celles qui le faisaient, la famille représentait 36 pour cent des partenaires, contre 9 pour cent chez les hommes. Sœurs, maris, pères, fils : pour beaucoup de femmes, le foyer fut la porte d'entrée vers des réseaux plus larges. Une fois ce seuil franchi, la collaboration pouvait élargir fortement leur horizon technique.

Le troisième facteur tenait au moment du cycle de vie ; c'était le plus difficile à identifier sans les registres d'état civil. Les femmes mariées déposaient leur premier brevet à un âge médian de 41,5 ans. Pour celles qui étaient encore célibataires au moment de leur premier brevet, l'âge médian n'était que de 30 ans. Parmi les mères, 83 pour cent ne déposaient leur premier brevet qu'après la naissance de leur dernier enfant recensé, avec un écart médian de onze ans entre cette naissance et le premier brevet. Les enfants et la vie familiale prenaient du temps ; le savoir pratique accumulé plus tôt, lui, ne disparaissait pas. Il demeurait disponible.

Une réforme adoptée en 1844 a aussi compté. L'État français permit désormais de payer les brevets par annuités, au lieu d'exiger une forte somme d'un seul coup. La probabilité qu'un brevet implique une femme augmenta de 40 pour cent. Les mères qui atteignirent l'âge adulte autour de cette réforme brevetèrent environ quatre ans plus tôt que la cohorte précédente. Un accès moins coûteux, combiné à l'élargissement progressif des droits des femmes à partir des années 1880, modifia le moment où elles purent transformer en brevet les connaissances qu'elles avaient accumulées.

Si l'on réunit ces trois résultats, la conclusion s'impose. L'écart entre les femmes et les hommes en matière de brevet ne s'est pas formé d'abord au guichet de l'administration. À l'échelle de son temps, celle-ci était remarquablement ouverte. L'écart se construisait en amont : dans les processus qui assignaient les femmes à certains secteurs, dans les partenariats auxquels elles avaient difficilement accès, ainsi que durant les années de mariage et de maternité, qui limitaient fortement le temps disponible pour l'activité inventive.

Les épingles et les pistons relevaient d'une même économie. Il a fallu des siècles pour le voir.

Pins and Pistons: Gender and Patenting during the French Industrialization

1 Introduction

1.1 Aim

In 1887, the 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 labor underpinned production, but official statistics understated that labor, and their contributions to new technology were even more obscured, rarely acknowledged in records or narratives of invention. This thesis investigates that hidden history by studying women's participation in patenting during French industrialization between 1791 and 1900. In total, 4,165 distinct individual women appear in French patent records during this period. Patents involving at least one woman account for 1.75 percent of all patents, a higher share than in Britain or the United States. These women patented across every one of the twenty technology classes, from pins to pistons. Yet beyond the patents themselves, these women remain largely unknown.

Women's contributions were obscured by overlapping forces that operated across countries and centuries. Censuses systematically undercounted women's work (Goldin 1990). Adjusted figures for the United States suggest that married women's labor force participation was five times the official rate. If we cannot accurately count how many women worked, we cannot count how many invented. The rise of the male breadwinner model reclassified working women as dependents (Humphries and Sarasúa 2012), and women who had always worked disappeared from official records. As engineering consolidated as a profession in the late nineteenth century, the meaning of "technology" narrowed to heavy machinery, excluding the domains where women had always worked: clothing, food, and the household (Oldenziel 1999). Together, these forces made women's economic contributions invisible, and their contributions to invention even more so.

Yet in France, some of the evidence survived. French patent records use gender-specific honorifics, making women inventors identifiable at a scale British and American records do not allow. French departments differed in industrialization, female labor force participation, and demographic structure, providing within-country variation that a more homogeneous setting would not (Perrin 2014). The distinctive path of French industrialization, centered on small workshops, artisanal manufacturing, and household-based production rather than the factory system that dominated Britain (Roehl 1976; Tilly and Scott 1989), may have preserved the conditions under which women accumulated sector-specific knowledge longer. Many women were in the record. The question was always whether anyone would look.

Without systematic evidence, we know remarkably little about who these women were, what determined where they patented, how collaboration shaped their work, or when in their lives they invented. The most influential characterization of the French patent system, which frames how we interpret women's presence in it, rests on a sample ending in the mid-nineteenth century (Khan 2020). Chanteux (2023) provides rich qualitative evidence on individual women's strategies and networks but does not model the determinants of women's patenting across the full century. No study has combined the complete universe of French patents with the tools needed to trace women inventors across technology sectors, networks, and life courses. If we mischaracterize the institutions women worked within, we misunderstand their absence and the system that produced it.

This thesis has two aims: to recover the women who invented in France between 1791 and 1900, and to explain what shaped their inventive activity. It is about women inventors: who they were, what they invented, what shaped their participation. Gender comparisons appear throughout to identify what was distinctive about women's experience, but the central subjects are the women themselves. The overarching question is: what shaped women's inventive activity during French industrialization? The four papers answer this question by moving from the literature, to the patent universe, to inventor networks, and finally to individual lives. Paper I (with Faustine Perrin) surveys the literature on gender and long-run economic development, identifying what is known and what tools are needed to move forward. Paper II (with Faustine Perrin) asks who patented, in what sectors, and under what institutional conditions, using the full population of French patents. Paper III examines how collaboration and networks shaped what inventors worked on and whether these mechanisms operated differently for women. Paper IV traces individual women across their life courses to ask when they invented, where they came from, and what role work and family played. Across the empirical papers, I combine French patent records with machine learning methods for technology classification, text-based measures of novelty and influence, and large-scale record linkage; Paper IV additionally links the patent record to civil vital records. Taken together, the four papers form the first systematic study to link the patent record to the women who filed it.

This thesis argues that the persistent gender patenting gap in nineteenth-century France did not arise mainly at the point of patent application. It arose earlier, in the unequal distribution of practical knowledge, collaborators, and time across the life course. Women's access to sector-specific practical knowledge shaped the direction of invention; collaboration shaped its scope; family formation shaped the timing of first patents.

The thesis then proceeds from broad context to individual lives. Section 2 develops the mechanisms linking women's work, collaboration, and family life to invention. Section 3 describes the sources and the machine learning pipeline used to turn them into a linked inventor-level database. Section 4 explains how each empirical design speaks to one part of the overarching question. Section 5 shows how the four papers fit together.

1.2 Research questions

This thesis is organized around one central question: what shaped women's inventive activity during French industrialization? Paper I provides the intellectual foundation; Papers II, III, and IV each address one part of this question, using the full population of French patents filed between 1791 and 1900.

Paper I (with Faustine Perrin) synthesizes the state of the art on gender and long-run economic development. The survey maps what is known about women's changing economic roles across development stages and identifies where the evidence runs out. From this synthesis, the survey concludes that resolving these gaps requires a shift from aggregate indicators to micro-level data: individual-level databases, machine learning methods for processing historical documents, and record linkage techniques that can trace women across their lifetimes. Papers II, III, and IV develop and apply exactly these tools.

How extensively did women participate in the patent system, and how did their activity compare to men's? The accessibility of the French patent system remains disputed. Khan (2020) characterizes it as administered and elitist, drawing on a sample that ends in the mid-nineteenth century. Galvez-Behar (2019) counters that the 1791 laws constituted a genuine institutional break from the *Ancien Régime* and that the 1844 reform promoted a democratization of patenting. Nuvolari et al. (2023), working from the full 1791–1844 patent population, find that French patent fees were about half the British level and that the social composition of patentees was broader than Khan's mid-century sample suggested. The debate remains unresolved because no study has compared women's and men's patenting across the full population of patents and the full century. Chanteux (2023, 2024) reconstructs the profiles of French women patentees through qualitative and archival analysis, but does not bring men into the comparison. If the system was elitist, the few women who patented were exceptional. If it was broadly accessible, the persistent gender gap points to barriers beyond the patent office. Paper II (with Faustine Perrin) addresses this debate by comparing women's and men's patenting across the complete universe of nearly 390,000 French patents between 1791 and 1900.

What happened when inventors worked together, and did collaboration operate differently for women and men? Modern evidence shows that teams dominate the upper tail of high-impact scientific and technological production (Wuchty et al. 2007), but these findings come from settings with corporate labs, universities, and formal intellectual property systems. In this earlier setting, most inventors worked alone, technical knowledge was largely tacit and transmitted through practice rather than codification (Mokyr 2005), and the network was sparse. Whether collaboration worked similarly under these conditions remained sparsely documented. Co-patenting was rare: about 90 percent of patents in comparable European systems were filed by single applicants, and no giant component, a single dominant cluster connecting most participants, connected the network (Andersson et al. 2019). Women faced sharper barriers to entering the network. Burt (1998) argues that outsiders cannot build social capital through their own networks but must borrow it through a strong tie to an established sponsor; Meng (2016) shows that women access knowledge through channels requiring trust and direct collaboration rather than the weak ties available to men. If family ties were an important route into collaboration for women, then whom they worked with determined what knowledge they could access and in which technology classes they could invent. Paper III reconstructs the full French patent collaboration network and develops text-based measures of novelty and influence for an era without citations.

When in their lives did women invent, where did they come from, and what role did work and family play? Patent records list an inventor's name, an address, and sometimes an occupation, but not their age, number of children, or place of birth. Chanteux (2023, 2024) identifies the absence of such biographical data as a gap in the study of French women's invention. If occupational knowledge drove invention, then what women invented should depend on what they and women around them worked on: in 1881 England, You (2020) shows that the industry mix of a woman's parish mattered more for her employment than her family circumstances; in the modern United States, Bell et al. (2019) find that girls who grew up near female inventors were more likely to become inventors themselves, while exposure to male inventors had no detectable effect on girls. If family formation shaped timing, then the timing of their patents should depend on how their family lives unfolded. But these predictions could not be tested because the data did not exist. Paper IV creates these data by linking women inventors to genealogical records drawn primarily from civil vital registers, producing the first historical demographic profiles to include birth years, marriage timing, geographic origins, children, and death years.

I return to these questions in Section 6.

1.3 Contributions

This thesis makes three main contributions.

First, I build data infrastructure that makes it possible to study patenting in nineteenth-century France at full-population scale, and women's patenting at a depth that did not previously exist. Previous quantitative work on the French patent system either relied on samples or stopped before the second half of the century, and no study has combined a systematic quantitative comparison of women's and men's patenting across the full century with the tools to trace inventors as individuals. Recent qualitative work on women inventors has richly reconstructed individual strategies without modeling women's patenting comparatively across the full population. I combine the complete universe of nearly 390,000 patents with systematic gender identification, machine learning classification of technology into 20 main classes and 97 subclasses, text-based measures of novelty and influence calibrated for an era without citations, deduplication of about 448,000 inventor-observations into distinct identities, and genealogical linkage of women inventors using records drawn primarily from civil vital registers. The full infrastructure supports the comparisons of women and men in Papers II and III. The women-specific identification and deduplication procedures identify 4,165 distinct individual women inventors across the period; the genealogical extension reconstructs life histories for 1,076 of them. For about a quarter of these women, we now know when they were born, whom they married, where they came from, how many children they had, and when they died. These are not aggregate statistics; they are individual life courses reconstructed from patent and civil records. The tools can be applied wherever similar data constraints exist.

Second, I join the debate on whether the French patent system was democratic or elitist. Khan (2005, 2020) distinguishes between market-oriented systems, exemplified by the United States with its low fees and first-true-inventor rule, and administered systems, which she identifies in both France and Britain. In her account, the democratic rhetoric of the French Republic masked an elitist reality: high fees, concentrated Parisian institutions, and elite-adjacent bodies whose discretionary rewards favored well-connected inventors. In her work on French women inventors, Khan finds that some middle-class wives and widows reached the patent office through manufacturing family firms (Khan 2016). Galvez-Behar (2019) counters that the 1791 laws constituted a genuine institutional break from the *Ancien Régime* and that the 1844 reform produced a democratization of patents, even if short-lived patents proliferated and litigation increased as a consequence.

I provide new evidence on both sides of the debate using the full population of patents rather than selected samples. In the patent-level Paper II sample, 25 percent of female-lead patents with known lead-inventor occupations were filed by women from lower-skilled backgrounds and 31 percent by women in medium-skilled trades, a breadth that challenges Khan's elitist characterization. The patent collaboration network was dispersed rather than controlled by a small elite. Women entered it less often than men, but those who did were more likely to form ties across technology-class boundaries than men starting from the same home technology class. If the system was broadly accessible, then the persistently low share of patents involving women must be explained less by exclusion at the patent office than by barriers embedded in work, family, and the organization of knowledge before an application was ever filed.

Third, I show that women's inventions were tied to their work and their lives through three mechanisms: direction, scope, and timing. A large literature documents that women's labor force participation depended on the occupational structure around them (You 2020; Boter and Woltjer 2020), and that occupational knowledge was acquired through sustained engagement with production rather than formal education (Mokyr 2005). If work generated the practical knowledge that made invention possible, then the female employment share of local industries should predict the sectors in which women patented. The direction of women's patents matched this pattern. The female employment share of local industry was the dominant predictor of patent sector.

Collaboration shaped scope. Women who worked with other inventors patented in technology classes they had not entered alone, and family ties provided a key entry point into collaboration for many women. Family formation shaped timing. Married women filed their first patent at a median age of 41.5, compared with 30 for women who were unmarried at the time of first patent, and most mothers patented only after their last child was born. But timing also shifted across cohorts. Among mothers observable through age 50, the generation that came of age around the 1844 patent reform patented about four years sooner than earlier cohorts, a shift that coincided with falling age at first marriage across the nineteenth century (Perrin 2022b) and with institutional changes that followed the 1844 reform (Galvez-Behar 2019). The individual timing pattern, in which marriage and childbearing delayed the onset of inventive activity, foreshadows, two centuries earlier, what Kleven et al. (2019) measure as the child penalty in Danish earnings and Kim and Moser (2025) document in American scientific output. The thesis does not claim to have measured the child penalty in the modern sense; it documents that the relationship between family formation and productive timing was already present in an era long before modern labor markets or welfare states existed. Taken together, these mechanisms show that invention was not separate from women's economic lives but an extension of them. Women's inventive activity was shaped by where they acquired practical knowledge, whether collaboration widened their technological range, and when in their lives they had the time to act on what they knew.

1.4 Limitations

This thesis studies patenting in France between 1791 and 1900. Before the revolutionary patent laws, inventors could obtain exclusive royal privileges for inventions (Isoré 1937; Galvez-Behar 2019), but I do not study this earlier period. I do not study women's inventive activity after 1900 or outside France. Cross-national comparisons with Britain and the United States appear in Paper II to contextualize France's higher female patenting share, but I do not conduct parallel analyses for those countries. The choice of France is deliberate. The quantitative literature on historical patenting has developed primarily around British and American data (Khan 2005; Moser 2005), leaving France less thoroughly studied despite the richness of its patent records.

This thesis studies invention, not innovation. The two concepts are routinely distinguished in the literature. Invention is the first occurrence of an idea for a new product or process; innovation is the first attempt to carry it out into practice (Fagerberg et al. 2013, ch. 1). Patents reflect invention more directly than innovation, but they remain the most widely used proxy for innovation activity. For the nineteenth century, Moser (2005) shows that only 11 percent of British and 14 percent of American innovations exhibited at the 1851 Crystal Palace were patented. Mokyr (1990) adds that not all patents were inventions, and not all inventions were patented. Recent work extends this evidence with modern data. Taalbi (2025) estimates both the share of innovations that are patented and how well patent indicators identify innovations. About 44 percent of Swedish innovations between 1970 and 2015 were patented, and international patent data capture about 15 percent of the information about these innovations. Patents remain an indispensable but incomplete record of innovation.

Studying invention rather than innovation is a substantive choice. Mokyr (1990) treats invention and innovation as complementary but distinct: invention generates new knowledge, and innovation carries it into economic use through institutions and markets. For women in nineteenth-century France, the distance between these two steps was widened by specific legal and social constraints: the *Code civil*'s restrictions on married women's property and commercial capacity (discussed in Section 2.3), and limited access to capital. A study of successful innovation would count only the women who crossed that gap. By studying invention instead, this thesis includes some of those who did the inventive work even when bringing it to market was blocked. Women who improved production methods without filing, who contributed to inventions patented under a husband's name, or whose work never reached market still escape these records. But for the inventive activity that did leave a patent trace, the patent record is the best available evidence, despite the critique of its use as a proxy for innovation (Mokyr 1990; Taalbi 2025).

Co-patenting is a conservative proxy for collaboration. Most knowledge sharing in the nineteenth century was informal and left no patent trail (Bessen and Nuvolari 2016; Moser 2016). The linked demographic sample covers 1,076 of 4,165 distinct individual women inventors, about a quarter. These women were linked because their names were traceable in genealogical records, primarily derived from civil vital registers, not because they were randomly selected. Despite this selection, the linking process did not detectably distort the sectoral composition of either the married or single samples. Each empirical paper discusses its specific identification challenges; the thesis as a whole should be read as evidence of robust associations rather than clean causal effects.

This thesis draws on the feminist technology studies tradition (Oldenziel 1999; Wajcman 2010) in Section 2 to frame the problem of women's invisible contributions in technology. That tradition argues that what counts as "technology" has been narrowed historically in ways that hid women's work, and I build on that insight. But the question this thesis asks is empirical rather than interpretive: who invented, in what sectors, with which collaborators, and at which points in the life course. The evidence is patent records and civil registers rather than language, representation, or material culture, and the methods are quantitative rather than archival or ethnographic. My linked data provide demographic profiles, but not the narrative depth or archival immersion that the prosopographical tradition requires (Pilato 2000; MacLeod and Nuvolari 2006).

1.5 Thesis outline

Figure 1 illustrates the roadmap of the thesis. The four papers move through three scales of analysis, from the aggregate to the individual, which I label macro, meso, and micro (Dopfer et al. 2004). The macro here covers the aggregate literature and theory of gender and long-run development. The meso covers the universe of French patents and the inventors who filed them. The micro covers individual life courses.

Paper I (with Faustine Perrin), "Gender and the Long-Run Development Process," works at the macro scale. It synthesizes the state of the art on gender and long-run development and argues for a shift from aggregate indicators to micro-level data. Paper II (with Faustine Perrin), "Women Inventors: On the Origins of the Gender Patenting Gap," works at the meso scale. It studies the universe of nearly 390,000 French patents filed between 1791 and 1900, with a focus on the 6,805 patents that involved at least one woman. Paper III, "What Happens When Inventors Collaborate?" sits between meso and micro. It reconstructs the co-inventor network from the full patent universe and asks how collaboration shaped the technological range of inventors. A gender analysis at the heart of the paper shows that women faced a sharp access barrier to the collaboration network, that family ties mattered disproportionately as an entry point into it, and that those who entered diversified more broadly than men. Paper IV, "What Shaped Women's Invention during Industrialization?" works at the micro scale. It narrows to individual women inventors, follows the life courses of 1,076 of them linked to French civil registration records, and asks when they invented and why.

The order reflects both the scale of analysis and the data work that each paper requires. Paper III builds on Paper II: the co-inventor network is reconstructed from the cleaned

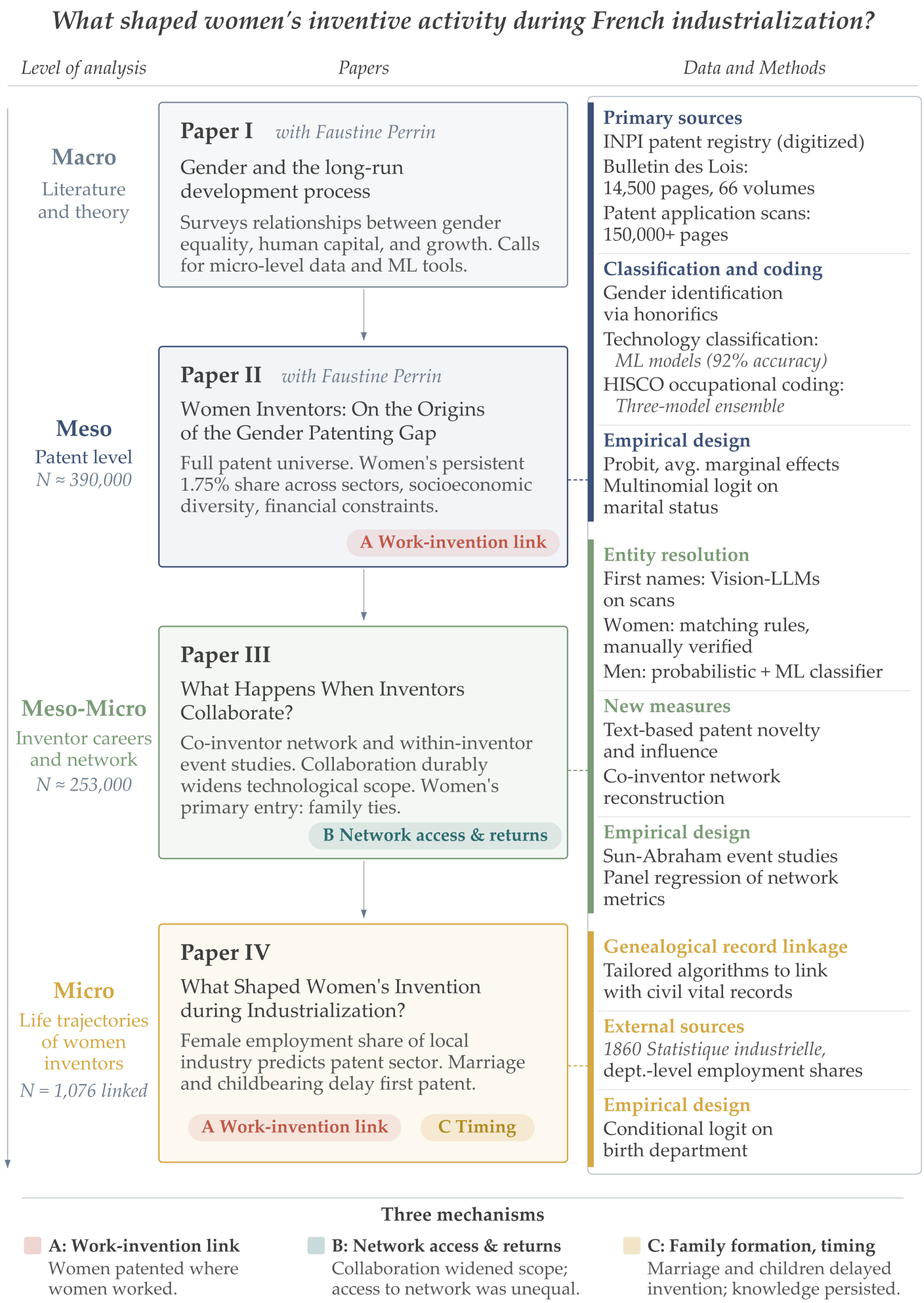

Figure 1 Structure of the thesis. Four papers move from the macro level (theory and literature) down to the life trajectories of individual women inventors. The left column shows the level of analysis, the right column summarizes sources and methods, and the three mechanisms (A, B, C) appear at the bottom.

and gender-identified patent universe that Paper II delivers. Paper IV builds on Paper III: the genealogical linkage runs on the deduplicated inventor identities produced in Paper III. Each step narrows the object of analysis. The 6,805 female-linked patents of Paper II are resolved by Paper III's deduplication into 4,295 distinct entities, which include both individual women and female-linked firms. Paper IV restricts to the 4,165 individual women and links 1,076 of them to genealogical records.

Section 5 presents an executive summary of each paper.

2 Theory, previous research, and historical context

A large literature asks why pre-existing gender gaps in economic life persisted, and often widened, during the transition to industrialization. One tradition, drawing on human capital theory, explains the gap through women's allocation of time between market work and family: women earned less because they accumulated less market experience, and the gap should narrow as their skills converged with men's (e.g., Goldin 1990, 2006). A second, institutional tradition emphasizes legal constraints, occupational segregation, and restricted access to resources and autonomy, and argues that human capital itself is shaped by those constraints rather than freely chosen (e.g., England 1982; Humphries and Weisdorf 2015). This thesis enters that debate through invention. If practical knowledge came from work, then women's patenting should reflect what they worked on, the resources and collaborative ties they could draw on, and the way marriage, childbearing, and changing institutional conditions shaped when they patented. The sections that follow develop those dimensions.

The argument proceeds in three steps. The first two sections explain why women's contributions became difficult to see and how practical knowledge was tied to gendered work. The next three sections describe the French setting and the patent system in which that knowledge could, or could not, become a patent. The final two sections turn to the timing and scope of inventive activity: when in their lives women could patent, and what collaboration made possible for those who entered it.

2.1 The problem: women's invisible contributions

Women have always worked. In nineteenth-century France, married women participated in the labor force at rates far higher than in Britain (about 40 percent in the 1860s, compared to 25 percent in England in 1851), though the comparison is imprecise because French and British censuses defined "work" differently (Tilly and Scott 1989). They spun, wove, traded, and managed farms and workshops alongside their husbands and children (Tilly and Scott 1989). Yet for most of the twentieth century, these contributions were invisible in economic history. Three processes, operating at different times, produced this erasure.

The first was statistical. Census practices across Europe and the United States systematically undercounted women's work (Humphries and Sarasúa 2012). French enumerators listed dependents as employed only if they worked outside the household (Grantham and Grimard 2010). Zijdeman et al. (2014), using marriage records from 95 French departments, find that about 60 percent of brides reported an occupation, with persistent regional differences. Even these figures understate the true level. Internationally, the pattern repeats. In the United States, Goldin (1990) adjusts the 1890 census for boardinghouse keepers, unpaid family farm workers, and manufacturing workers in homes and in factories, and finds that the participation rate of married white women rises from 2.5 percent to 12.5 percent, five times the official figure. For 1860, Chiswick and Robinson (2021), using microdata to identify unreported family workers, find that 57 percent of free adult women were in the labor force, against a census figure of 16 percent. Both adjustments recover women whose work the census treated as non-employment. In Spain, Sarasua (2019) finds a different mechanism: eighteenth-century tax surveys failed to record women's work because subsistence wages fell below the taxable threshold, and married women in particular disappeared from the historical record. But Burnette (2021) sees a deeper problem. She argues that the very idea of labor force participation is ill-suited to historical women's work, because definitions of productive work were fluid, employment was not permanent, and the boundary between full-time and part-time did not exist.

The second process was the rise of the male breadwinner model, but it operated differently across countries. In Britain, the mechanization of spinning destroyed a sector that had employed eight percent of the population, almost all of them women and children (Schneider 2026). The destruction consolidated the male breadwinner family as a standard (Humphries and Schneider 2021). As women's industrial employment collapsed, households became increasingly dependent on men's earnings (Horrell and Humphries 1995, 1997). Humphries and Weisdorf (2015) show that the gender wage gap in England widened specifically when industrialization shifted work from flexible, home-based arrangements to rigid schedules that demanded continuous hours outside the home.

In France, the path was different. Small-scale agriculture and manufacturing preserved the family economy far longer. French married women could more easily combine productive and reproductive work because so much of it was located at home, on the family farm, or in a small family workshop (Tilly and Scott 1989). Coffin (1994) shows that French linen drapers and seamstresses in eighteenth-century Paris had their own female guilds; the linen drapers' statutes specifically forbade husbands from participating in their business. The same household-based organization extended into rural France. Grantham and Grimard (2010), studying 127 rural communes in northern France using the 1851 census, show that spinning and weaving were carried out in households as commercialized production coordinated by merchants. Evidence from other European countries also challenges the breadwinner assumption. Gary and Olsson (2020) show that in pre-industrial southern Sweden, even with an extended working year, a man alone could not support a family at a respectable consumption level, a pattern that studies of other European countries have also found (Tilly and Scott 1989; Horrell and Humphries 1997). The breadwinner model was a product of a specific British path of industrialization. In France, where household production persisted and married women's labor force participation remained high, the breadwinner model may fit less well.

A third process, operating later, compounded the first two. In the late nineteenth and early twentieth centuries, the professionalization of engineering in Britain and the United States narrowed the meaning of "technology." Oldenziel (1999) shows how the broad category of the "useful arts," which had included spinning, needlework, food preservation, and agriculture alongside mining and metalwork, was replaced by a definition centered on heavy machinery. The steam engine and the Bessemer converter became emblems of the new discipline, while corsets, bonnets, and fabrics were excluded from what engineers counted as technology. Cockburn (1988) documents the shop-floor version. Employers divided tasks into "engineering," which meant understanding how a machine worked, and "operating," which meant pushing its buttons, with male trade unions guarding the first as their monopoly. As engineering consolidated as a profession, technical competence became culturally seen as masculine, and femininity was reinterpreted as incompatible with technological pursuits (Wajcman 2010). Historians working in this tradition rarely counted women's patenting in clothing, domestic equipment, or food processing as technological activity (Oldenziel 1999).

Even so, the French patent record keeps these domains visible. The INPI classification, developed between 1853 and 1904 (Emptoz and Marchal 2002) and applied consistently to all patents in the database, includes Clothing and Domestic Economy as main technology classes on equal footing with Machinery, Mining, and Construction. Subclass 16.1 covers, among others, haberdashery, gloves, corsets, and pins. Subclass 9.1 covers household articles and kitchen equipment. Cowan (1976) showed that treating household appliances as real technology revealed the home as a site of continuous technological change, where women worked 53 to 80 hours per week even with modern conveniences. The question that remains is what enabled these women to invent in the first place.

2.2 Work, knowledge, and the capacity to invent

Formal technical education was largely closed to women for most of the nineteenth century in France. The Camille Sée law of 1880 established secondary girls' schools, but it did not allow women to take the *baccalauréat*, the credential needed for university entry or higher technical training (Canel 2000). Universities began to admit women in the closing decades of the century, but their numbers remained small: by 1907, 1,317 women were registered at the Sorbonne, of whom 829 were foreigners (Canel 2000). Equal secondary education for girls came only in 1924, and the traditional *grandes écoles* stayed closed even longer: the École des Ponts et Chaussées opened to women in 1959, the École des Mines in 1970, and the École Polytechnique in 1972 (Canel 2000). Yet women patented across all sectors, from textiles and clothing to chemistry and machinery. If formal technical education was largely closed to them, where did the knowledge come from?

Arrow (1962) proposed that production itself generates knowledge. Workers encounter problems and develop solutions through repeated practice. Mokyr (2005) distinguishes between two kinds of technical knowledge: the epistemic base, which is the scientific understanding of why a technique works, and competence, which is the practical ability to execute it. Most practitioners in the nineteenth century needed only competence, and competence came from sustained engagement with production, not from formal schooling. Formal schooling was not the main route for male inventors either. Mokyr notes that John Mercer, one of Lancashire's most successful colorists and dye specialists, was entirely self-taught, and that Eaton Hodgkinson became an engineer the same way. In Britain, public lectures, informal scientific societies, and technical apprenticeship did the work that formal institutions did not. I extend this logic to women. A woman who spent years in a workshop understood the properties of the materials, the behavior of the tools, and the points where the process broke down. She did not need formal training to identify a patentable improvement. If this is right, then what women knew depended on what they worked on, and what they worked on depended on the occupational structure around them.

The occupational structure of pre-industrial and industrializing Europe was sharply gendered, but the pattern was institutional, not biological. Ågren (2017) and Whittle and Hailwood (2020), studying court records from Sweden and England respectively, both find that women participated in all main areas of the economy. But access was uneven: craft work showed a sharp gendered division, agriculture was flexible, and commerce showed much smaller differences between men and women (Whittle and Hailwood 2020). At the level of specific tasks, however, strict divisions existed. Men drove and freighted, while women carried and fetched (Ågren 2017). The sharpest evidence comes from Ogilvie (2003), who assembled 2,828 observations of men's and women's work from church-court minutes in the Württemberg Black Forest. Ogilvie shows that guilds reserved light, sedentary indoor tasks for male weavers while forcing unmarried women into stages involving heavier physical exertion. When women worked illegally as weavers, their output was of high enough quality to pass guild inspections. Ogilvie concludes that the industrial division of labor was shaped more by institutional rules than by physical differences between the sexes.

Wage evidence addresses the same question. Gary (2017) finds a consistent pattern in Swedish construction between 1550 and 1759: where women made up a larger share of the labor force, the gender wage gap was small. Burnette (1997) gives a different mechanism for British wage gaps. She argues that in competitive markets like agriculture, wage gaps reflected genuine productivity differences from physical strength. She does identify institutional barriers, but elsewhere: occupational crowding prevented women from entering skilled occupations like mule-spinning and medicine, and educational discrimination limited their access to skills. But the institutional conclusion is the same. Whether the market was fair or not, what determined women's knowledge was the set of occupations they were allowed to enter.

In France, local industry shaped what women worked on. Grantham and Grimard (2010), using 1851 census records for 127 communes across six northern French departments, show that married women's participation was high across multiple sectors: 70 percent of farmers' wives worked, rising to 78 percent among cloth manufacturers and 86 percent among spinners. Zijdeman et al. (2014) extend the finding across France: using marriage records from 95 French departments, they show that spikes in female occupational reporting in Ardèche and Loire were tied directly to the local silk industry, which hired mainly women. Perrin (2022a) confirms the point at the aggregate: her gender gap index for 86 French departments in the 1850s shows that departments with higher shares of women in industry displayed significantly greater gender equality.

The mechanism holds beyond France. You (2020), using the full 1881 census of England and Wales (about 26 million records), tests the demand side against the supply side directly: the industry mix of a woman's parish mattered more for whether she worked than her family circumstances. Married women in cotton districts worked at seven times the rate of those in agricultural areas, and even among women in the same life stage whose husbands held the same occupation, participation differed sharply between cotton and mining parishes. Boter and Woltjer (2020) add the temporal dimension: for the Netherlands between 1812 and 1929, shifting sectoral employment shares account for about half of the decline in unmarried women's participation. The empirical prediction follows: within a local economy, sectors with higher female employment shares should be the sectors in which women patented.

The distinctive path of French industrialization may have shaped these mechanisms. France relied more heavily than Britain on artisanal manufacturing, small workshops, and household-based production, a contrast that Section 2.3 develops in detail. In Britain, the mechanization of spinning destroyed home-based hand-spinning on a massive scale (Schneider 2026; Humphries and Schneider 2019). In France, Grantham and Grimard (2010) show that rural textile production remained household-based and commercially oriented. Coffin (1994) documents the institutional basis of women's autonomy in the French garment trades: exclusively female guilds that forbade husbands from participating. This slower, more workshop-based path may have preserved the conditions under which women accumulated sector-specific knowledge longer.

A modern parallel supports this reasoning. Bell et al. (2019) find that girls who grew up in neighborhoods with more female inventors were themselves more likely to become inventors, while men's patent rates had no statistically significant effect on women's innovation. They also show that the effect operates through specific technology classes: a child whose parents patented in amplifiers was far more likely to patent in amplifiers than in antennas. The channel is gendered exposure, not generic proximity. These mechanisms imply a sectoral prediction: women's patents should concentrate in technology classes tied to industries where local female employment was high. But this prediction applies only within a specific institutional setting: the French patent system, the laws governing married women's property, and the regional structure of the French economy. These are the subjects of the next sections.

2.3 France: the setting

Scholars initially viewed French industrialization as a failure. Clapham (1921) set the terms of the debate, arguing that France never experienced an industrial revolution comparable to Britain's, instead undergoing a gradual transformation that, after a full century, remained less complete than what Germany achieved in the forty years after 1871. After the Second World War, American economic historians sharpened this pessimism. Landes (1949) and Clough (1946) argued that French businessmen were to blame: they avoided risk, restricted investment, and preferred small-scale family firms over industrial expansion, a pattern that later scholars called economic Malthusianism (Crouzet 2003). This pessimistic interpretation dominated until the 1960s, when quantitative evidence forced a reassessment.

National income estimates challenged the stagnation thesis. Roehl (1976), building on national accounts by Marczewski (1961), showed that French per capita growth was essentially indistinguishable from Britain's. Roehl argued that France may have been the first country to begin industrializing, not a laggard. Inverting Gerschenkron's argument, which holds that latecomers to industrialization rely on large-scale industry and state intervention, he proposed that small-scale, consumer-oriented production was the expected form of pioneer industrialization, not a sign of failure. If any country's experience was unusual, it was Britain's, not France's. The French domestic market was large enough to sustain industrial growth without relying on exports, unlike Britain, which depended on foreign demand to compensate for a smaller home market. High coal costs reinforced this path. French producers could not compete in energy-intensive mass production and instead specialized in skill-intensive quality goods (Lévy-Leboyer 1964; O'Brien and Keyder 1978). Walton (1992), drawing on calculations by Markovitch, shows that nearly 60 percent of French industrial production as late as 1860 was handicraft, produced in homes or small workshops where artisans worked alongside fewer than ten employees. At the Crystal Palace exhibition of 1851, French production was celebrated for its quality and artistry. The political economist Blanqui argued that small industries required less capital, employed more hands, and developed more intelligence than factory production organized around machines and extreme division of labor (Walton 1992). Specialization in quality goods reflected comparative advantage, not backwardness.

The current consensus treats France as neither a failure nor a success story but as an intermediate case (Crouzet 2003; Ridolfi and Nuvolari 2021). Ridolfi and Nuvolari (2021), constructing new GDP per capita estimates from over 26,000 wage observations and over 46,000 price quotes, find that French and English living standards were similar until the second half of the seventeenth century. Only after that point did England pull ahead consistently. France transitioned to modern economic growth in a much more gradual manner than Britain, occupying a position between the forging-ahead North Sea economies and the stagnating rest of the continent. France also underwent its demographic transition a century before any other European country (Perrin 2022b), and 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 (Lévy-Leboyer et al. 1990; Caron 1995). But per capita growth remained moderate and sustained through quality-intensive production and gradual structural change (Crouzet 1972; Asselain 1984). Women who invented did so within this economy of small workshops and skilled trades, but their capacity to act on their knowledge depended on the laws governing their property, contracts, and civil status.

The French Revolution briefly expanded women's legal standing. Gerhard (2016) documents both the expansion and its reversal. A 1792 decree introduced civil marriage and divorce by mutual consent; a decree of 4 June 1793 established equal inheritance for sons and daughters. The *Code civil* of 1804 reversed these gains. Article 213 stated that the husband owed protection to his wife and the wife obedience to her husband, a provision that remained in force until 1938. A married woman was not an independent legal person. She could possess property but could not acquire, dispose of, or benefit from the revenue of her own activity without her husband's authorization (Gerhard 2016; Lewis 1980). She needed her husband's permission to take up employment, and her earnings became by law his property (McMillan 2000). Gerhard (2016) shows that this regime was unusually harsh by European standards: the Prussian code of 1794 was more favorable to women, and the French reversal was more restrictive than in countries where women's autonomy had not yet become a contested political issue. One exception existed: women registered as public merchants, *marchandes publiques*, could enter into commercial obligations without their husband's consent (Art. 220). The Code did not fully describe women's daily lives. Perrin (2022b) argues this at the household level: French regions differed sharply in women's bargaining power within marriage, with patterns of fertility control tracking regional differences in family structure and religious practice. Law and practice were not the same.

The patent system, born from the same Revolution, took a different path. Galvez-Behar characterizes it as based on a "democratic and natural-right conception of invention," where the state's role was to register, not to judge (Galvez-Behar 2019). The 1844 reform preserved this philosophy: the law applied to whoever wished to obtain a patent, and the administration delivered patents without any governmental guarantee of their merit (Galvez-Behar 2019). The contemporary jurist Armengaud, writing in 1893, explained what this meant in practice for civil capacity: the administration was not authorized to inquire whether an applicant had the required legal standing, and a married woman, a minor, or a legally incapacitated person could file a patent application without providing any authorization document (Chanteux 2023). Marital authorization was tacit. Chanteux (2024), studying all female patentees from 1791 to 1900, finds that few applications mention a husband's authorization and that the *Code civil* was often ignored. Married women were the most active group among female patentees, filing 46 percent of all female patents, and 79 percent of them filed alone (Chanteux 2024). Beginning in the 1880s, a sequence of reforms gave women progressively greater autonomy. In 1881, women could open savings accounts without their husband's permission; in 1893, single and separated women gained full legal capacity; and in 1907, married women won the right to dispose freely of their own earnings (McMillan 2000). The legal regime created friction, not prohibition.

The implication for this thesis is specific. In an economy of small workshops and family trades, practical knowledge may have been more widely distributed than in Britain's factory system, even as the Civil Code restricted married women's legal autonomy. Formal legal constraint and practical exposure therefore coexisted. Whether that exposure could become a patent depended on the design of the patent system itself, and on how France's system compared to Britain's and America's.

2.4 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 (Galvez-Behar 2019). The 1791 legislators rejected any preliminary examination of patent applications, since they saw such oversight as censorship reminiscent of the *Ancien Régime*. These principles endured. When the Chambre des pairs debated reform half a century later, the senator Portalis declared that "the first, most sacred of all properties, is property in oneself" (*la première, la plus sacrée de toutes les propriétés, c'est la propriété de soi*) (Moniteur universel 1843a). In practice, however, an advisory body, the *Comité consultatif des Arts et des Manufactures*, informally screened applications from the early years of the system (Baudry 2019). About 20 percent of applicants withdrew after its assessment.

Between 1791 and 1844, the state granted 12,575 patents in total (Nuvolari et al. 2023). Applicants paid fees based on duration: 300 *livres tournois* (the pre-revolutionary currency) for five years, 800 for ten years, and 1,500 for fifteen years (Galvez-Behar 2019). From 1800, the state issued patents *sans garantie du gouvernement* (without governmental guarantee), refusing to certify the novelty or usefulness of any invention, and leaving courts as the only recourse for disputes over validity (Galvez-Behar 2015). Over 50 percent of patents came from applicants in the Seine department (Nuvolari et al. 2023), and the only place to consult existing patent specifications was the Paris office (Galvez-Behar 2019). The *Bulletin des Lois* published patent grants, but full technical descriptions remained available only in manuscript (Galvez-Behar 2019). Provincial inventors who wanted to check whether their idea was novel had to travel to Paris or hire agents. Patentees who failed to put their inventions into practice within two years risked annulment in court (Nuvolari et al. 2023).

Yet despite these constraints, a market for technology functioned from the start. The 1791 law defined patents as "movable property" (Art. 14), and inventors could freely assign or sell their rights without government authorization, unlike under the *Ancien Régime*, where transferring a privilege had required the Crown's consent (Galvez-Behar 2015). The *Bulletin des Lois* published patent assignments from 1824, and about 5 percent of all patents granted between 1791 and 1844 changed hands through formal assignment (Galvez-Behar 2015). Longer patents appeared far more frequently in these transactions than in overall grants: 15-year patents made up 20 percent of all grants but 39 percent of assignments, because the heavy upfront investment signaled value to buyers (Galvez-Behar 2015).

The 1844 Patent Act abolished patents for importation (patents granted for introducing foreign inventions into France) and changed the fee structure (Galvez-Behar 2019). Total fees increased for shorter durations (to 500 francs for five years and 1,000 for ten), but annual installments of 100 francs lowered the upfront barrier. Annual patent grants, about 1,000 in the early 1840s, nearly tripled by the late 1850s (Galvez-Behar 2019).

The parliamentary debates that preceded the law are revealing for what they did not discuss. Article 5 opened access to "whoever wishes to obtain a patent" (*quiconque voudra obtenir un brevet d'invention*), yet no senator questioned who "whoever" included (Moniteur universel 1843b). Civil capacity, married women, minors: none of these came up. When the vicomte Dubouchage challenged the government ("So there is an examination?"), the Commissaire du Roi Sénac reassured the chamber that the process amounted to nothing more than "a kind of registration without responsibility and without consequence," covering fifty to sixty patents per week (Moniteur universel 1843b). The minister of commerce Cunin-Gridaine opposed formal examination more bluntly: it would substitute administration for courts in judging questions of property (Moniteur universel 1843a). The 1844 reform also ended the unofficial screening by the *Comité consultatif*, and from this point the principle of non-examination applied rigorously (Galvez-Behar 2019). But lower upfront costs brought trade-offs: short-lived patents proliferated, and litigation increased as courts bore the full weight of deciding validity. Whether this system, open by law but constrained by cost and geography, was genuinely accessible remains disputed.

2.5 Democratic or oligarchic? The debate on patent systems

Khan (2005, 2020) offers the most developed comparative account of patent systems during industrialization. Khan distinguishes between "market-oriented institutions," exemplified by the United States, and "administered innovation systems," which she identifies in France and Britain. The American system kept fees deliberately low (around $30 to $35) and required that patents be granted only to the "first and true inventor," relying on market mechanisms to determine value. Khan's case against France rests on two layers of evidence. The first concerns institutions adjacent to the patent system: the Society for the Encouragement of National Industry, the Academy of Sciences, and the Councils of Commerce. Khan shows that these bodies drew their members from elite circles of aristocrats, scientists, and wealthy manufacturers, and that their prize committees favored well-connected applicants over technical merit. The second layer concerns the patent system itself. Using the 849 patents with known occupations from her sample of 1,235 for the period 1791 to 1855, Khan finds that artisans and workers accounted for 18.8 percent of patentees, while professionals and manufacturers dominated, and that over half of all patentees in her sample (53.6 percent) resided in Paris (Khan 2020). For women specifically, Khan finds that 10.6 percent of French patentees came from artisan and worker classes, compared with 26.9 percent in the United States and 8.8 percent in Britain (Khan 2017). Together, this evidence leads Khan to conclude that the declared liberal democratic principles of the French Republic differed markedly from the prevailing elitist administered innovation system. Khan does not, however, conclude that women were absent from this system. In her other work, Khan (2016) traces how manufacturing family firms gave some middle-class wives and widows a private route around the *Code civil*, limited schooling, and weak access to capital markets, compensating for what the formal institutions did not provide.

Several scholars have challenged this characterization. Nuvolari (2021) acknowledges the richness of Khan's empirical work but argues that the opposition between market-oriented and administered systems draws too sharp a line. All three countries were relatively successful industrializers, each capable of generating significant technological breakthroughs during the nineteenth century; against this background, the case for clear American superiority is not entirely convincing. Streb (2023) reaches a similar conclusion from a broader international perspective. Germany caught up significantly with Britain despite patent fees far higher than those in the United States. Switzerland, which had no patent system at all until 1888, also prospered. The British Patents Act of 1883, which took effect in 1884, increased the total number of patents but had no discernible impact on the number of high-quality patents, raising the question of whether low fees generate more valuable innovation or simply more patents.

Galvez-Behar (2019) offers the most detailed institutional counter. He argues that the state's rejection of preliminary examination in 1791 marked a genuine institutional break, not a rhetorical one. For Khan, the revolutionary legislation left the underlying structures of privilege intact; for Galvez-Behar, it created a democratic foundation that persisted through subsequent reforms. He concedes that prohibitive fees and the unofficial screening by the *Comité consultatif* restricted access in practice. But he finds that the 1844 reform produced a measurable broadening of access: in a comparison of 1,476 patentees from 1840 to 1843 with 4,875 patentees from 1845 to 1849, the share of mechanics among patentees nearly doubled, from 8.3 to 15.2 percent (Galvez-Behar 2019). His conclusion is that the argument for structural continuity with *Ancien Régime* practices does not withstand scrutiny. The system's democratic foundations were real, but the state's unwillingness to build adequate administrative capacity prevented it from fully delivering on that promise.

Nuvolari et al. (2023) provide the most systematic quantitative evidence on this question. Their dataset covers all 12,575 patents granted in France between 1791 and 1844, not a sample but the full population of patents deposited under the original laws. They compare fees across France, England, and the United States by converting costs into both U.S. dollars and working days of skilled workers (mechanics and masons). Both measures show that French fees were substantially lower than English ones: almost half in dollar terms and between 30 and 45 percent lower in working days. French fees remained considerably higher than the very low American ones, but the gap between France and England was far larger than Khan's account, which groups both countries together as administered systems, would suggest. Nuvolari et al. (2023) also apply an indicator proposed by Sokoloff and Khan (1990): the share of patentees who filed only one patent over their career. A system widely open to occasional inventors, people who patent once and never again, does not impose significant barriers to entry. By this measure, France was remarkably similar to the United States across all sub-periods between 1791 and 1842. Their occupational analysis, based on the standardized Historical International Classification of Occupations (HISCO), finds that artisans and lower-skilled or unskilled workers accounted for 34.8 percent of the 9,759 patents with recorded occupations. This is nearly double the 18.8 percent Khan estimated from her 1,235-patent sample (849 with recorded occupations) using a different set of occupational categories (Khan 2020). Part of this gap reflects how the two studies classified occupations: HISCO assigns manufacturers of specific products to production workers, whereas Khan's categories list them separately. But even accounting for classification differences, the discrepancy points to a broader social base than Khan's sample captured. Nuvolari et al. (2023) conclude that the accessibility of the French patent system was significantly wider than previously suggested.

Chanteux (2019, 2023) approaches the question from a different angle. Working from patent records and archival sources, she reconstructs the profiles of women who patented in France during the nineteenth century. Her research focuses exclusively on women and does not compare their patenting behavior with men's, but the individual cases she documents complicate the picture of an elite-only system. Among patents where women declared an occupation, she identifies 109 distinct trades, including merchants, artisans, seamstresses, midwives, and teachers alongside wealthy manufacturers and widows of industrialists (Chanteux 2023). Chanteux argues that women who succeeded as inventors needed to be autonomous, technically knowledgeable, and socially active (Chanteux 2019). Most could not rely on formal scientific training, which remained closed to women for most of the century, and about 60 percent hired professional patent agents to translate their practical knowledge into the technical descriptions required by the patent office (Chanteux 2023).

Whether the French patent system was genuinely accessible or merely open in principle remains an open question, one that depends on the period examined, the data used, and the occupational categories applied. But even in a system that imposed no formal barriers based on sex, a woman still needed time, resources, and knowledge to convert an idea into a patent application.

2.6 The life course of invention

Stanley (1990), in one of the earliest studies of when women invent, examined a few cases and reached a blunt conclusion: "for women, invention begins at 40." Her evidence came from two small samples of nineteenth-century American women: fourteen professional inventors who specialized in machines, and fifteen exhibitors with known birth dates from the Philadelphia Centennial of 1876. Among the six professionals whose birth dates were known, the average age at first patent was 39; for the fifteen exhibitors, it was 42. The samples were small, but the finding was striking: women began patenting a full decade into mid-life.

Larger studies have since confirmed the mid-life peak, though almost entirely for men. Sarada et al. (2019), linking American patent grantees to census records from 1870 to 1940, find that inventors were persistently about 41 years old on average, a figure stable over seven decades. Jung and Ejermo (2014) extend the pattern to the modern era and add a gender dimension: using population-wide data on Swedish inventors at the European Patent Office between 1985 and 2007, they report a similar average in the early forties and find that women inventors were younger than men (about 40 versus 44 in the mid-2000s). For men specifically, Akcigit et al. (2017) find that American male inventors were most productive between their mid-thirties and mid-fifties, and delayed marriage and had fewer children than the general population. The tension between family and invention was not peculiar to women. But men and women resolved it differently: men postponed family; women, as the existing evidence suggests, postponed invention.

This is a thin literature. It tells us that invention clusters in mid-life and that family formation matters, but it says almost nothing about the mechanisms. To understand why women invented late, and specifically why marriage and children shaped the timing, two broader literatures are needed: historical research on how marriage, fertility, and child-rearing structured women's working lives; and modern studies of how motherhood affects the timing of creative and inventive careers.

Marriage and children restructured women's time. Grantham (2012), working with a sample from the 1851 French census covering rural communes in northern France, finds that married women aged 20 to 40 with children under three had a labor force participation rate of 60 percent, compared with 68 percent for married women of the same age without young children. The pattern persisted: Riboud (1985), using survey data from 1977, finds that among married French women aged 40 to 44 who had participated in the labor force, three-quarters had interrupted their professional lives for more than a year. Marriage in nineteenth-century France typically occurred in the mid-twenties, and for women who had several children, childbearing continued into the late thirties (Desjardins et al. 1994; Perrin 2022b). A woman who married at 24 and bore her last child at 37 would have spent more than a decade raising children, with little continuous time for the hands-on experience that producing a patentable invention required.

What happened once children grew up is less settled. Tilly and Scott (1989), studying industrial towns in England and France, describe a substitution in which children entered the workforce and mothers withdrew to manage the household. You (2020), using the complete 1881 census of England and Wales (about 26 million records), finds the opposite: working-class mothers intensified their labor force participation as children reached working age, because families sought to use as many earners as possible. Which pattern characterized nineteenth-century French women inventors has not been established.

The cost of these interruptions depended on the structure of work. Humphries and Weisdorf (2015), constructing two long-run wage series for English women from 1260 to 1850, find that women's relative wages fell when industrial work moved from home-based flexibility to fixed schedules requiring uninterrupted hours. Women who could commit to annual service contracts, typically young and unmarried, kept pace with unskilled men; women confined to casual day-work compatible with childcare fell behind after 1750. Goldin (2006) offers a distinction that helps explain why: she distinguishes between "jobs," defined by current circumstances with no expectation of long-term employment, and "careers," defined by identity and sustained investment in training. For most of history, women held jobs, not careers, and in such a world the cost of stepping away should have come from time lost to child-rearing, not from skills lost during the absence.

The empirical record matches this expectation. Humphries and Schneider (2019), drawing on records of English spinners in putting-out networks, spinning schools, and parish accounts, find that married and widowed spinners produced at most about a quarter less than single spinners, not because spinning was easy to combine with childcare but because married women worked close to full-time. The pattern could even reverse: Burnette and Stanfors (2012), studying Swedish cigar workers in 1898, find that mothers earned six percent higher hourly wages than childless women, because skills in the industry were general and piece-rate work rewarded effort rather than tenure. The delay was real, but it did not destroy what women knew.

Modern studies of inventive careers confirm that children cost women time without permanently reducing their ability to produce original work. Kim and Moser (2025) study scientist-mothers during the American baby boom. Mothers with one or two children published 37 percent less than married women without children, reaching the lowest point seven to eight years after marriage; mothers with three or more children saw a 54 percent decline that persisted longer. But publication rates recovered in the early forties, once children reached school age. Only 27 percent of mothers achieved tenure, compared with nearly half of women without children. The earnings data show similar persistence. Kleven et al. (2019), using Danish administrative data, show that the earnings penalty from children increases by seven to ten percentage points per additional child and persists even in Denmark, with its generous parental leave and subsidized childcare. Whittington (2011), studying American doctorate-level scientists from 1990 to 2001, finds a motherhood penalty on the probability of patenting in academia but not in industry. In academia, the penalty disappeared once prior patenting experience was controlled for, suggesting that what mattered was whether a woman had entered the patenting process before, not whether motherhood had reduced her ability to do so. In each case, the penalty operated through time and access, not through lost ability.

Marriage was not purely a source of delay. It could also provide capital, commercial contacts, and access to family enterprises. Khan (2016), working with French patent and exhibition records from 1791 to 1855, shows that middle-class women were extensively engaged in entrepreneurship and innovation, and that wives and widows in manufacturing family firms were significantly more likely to invest in long-term patents. Craig (2020), drawing on trade directories from 1810 to 1880, finds women running businesses across a wide range of trades in both Lille and Paris; in 1810, 70 percent of all business categories listed in the Paris directories included at least one woman. Whether marriage on balance delayed or helped a first patent is an empirical question that the life-course evidence alone cannot resolve.

Life-course constraints explain when women could invent: after the demanding years of child-rearing, in mid-life, once time freed up. But timing alone did not produce a patent. A woman also needed access to knowledge, commercial contacts, and the practical channels through which an idea became a filed application. How women gained that access is a separate question.

2.7 Collaboration, networks, and knowledge access

This section asks how collaboration operated in an era before corporate R&D labs, when most inventors worked alone, and whether its workings differed for women and men. Modern evidence shows a steady rise in teamwork. Wuchty et al. (2007), analyzing 19.9 million research articles and 2.1 million U.S. patents, show that mean patent team size rose from 1.7 to 2.3 inventors between 1975 and 2000, and that teams came to dominate the highest-impact work in science. Jones (2009) ties this rise to a growing "burden of knowledge": as technical frontiers deepened, inventors narrowed their expertise, began innovating later, and relied more on collaborators, with patent team size growing about 17 percent per decade. Whether these patterns held in earlier technological regimes is a separate question, and one that modern team-science evidence alone cannot answer.

Collaboration in the nineteenth century took forms that were often informal and diffuse. Allen (1983) documented how firms in England's Cleveland blast-furnace district between 1850 and 1875 openly exchanged plant designs, raising furnace heights from 50 to 80 feet and blast temperatures from 600°F to 1400°F through successive incremental improvements. Nuvolari (2004) traced the same pattern in the Cornish mining district: after the monthly *Lean's Engine Reporter* began publishing engine performance data in 1811, steam-engine efficiency nearly doubled as engineers openly compared designs. Bessen and Nuvolari (2016) generalized this "collective invention" pattern across steam engines, iron and steel production, textile machinery, and American agriculture. Nineteenth-century collaboration between inventors was already widespread, and it left traces both inside and outside the patent record.

Within the patent record itself, co-authorship captures a particular kind of collaboration. Lamoreaux et al. (2013), examining U.S. patent assignments at four points between 1851 and 1911, document how financial backers typically acquired stakes through assignments, while co-inventor status tended to reflect substantive technical contribution. Co-patenting therefore captures joint technical invention at the moment of filing, not the broader financing relationships surrounding it. How this formally recorded collaboration actually operated in nineteenth-century France, and what it meant for those excluded from inventor networks, has received far less attention.

The mechanisms that network theory identifies are general: non-redundant information flows through diverse ties, and trust helps collaborators share knowledge across boundaries. Most of this work comes from corporate hierarchies and modern research networks where ties are dense and brokers span large components. Comparable nineteenth-century European evidence looks very different. Andersson et al. (2019), mapping the full co-inventor networks of Sweden and Spain between 1878 and 1914, find that about 90 percent of patents were filed by single applicants and that no giant component (a single dominant cluster) connected either country's network. That setting makes Fleming et al. (2007)'s mechanism directly relevant: a single collaborator's diverse prior experience substitutes for a broker's position, because the partner's range makes non-redundant knowledge available within a close tie. How these ties form, and for whom, is the question that follows.

Evidence from modern organizational settings, though far removed from nineteenth-century France, suggests that who benefits from collaboration depends on network position. Burt (2004), studying managers at an American electronics company, finds that people who bridge gaps between disconnected groups, gaps he calls structural holes, are more likely to have their ideas valued, because they access information that circulates in one group but not another. An earlier foundation comes from Granovetter (1973), who argued that weak ties, acquaintances rather than close contacts, perform this bridging function, because strong ties tend to connect people who already know the same things.

But this bridging advantage is not equally available. Burt (1998), studying senior managers at an American computer and electronics company, finds that outsiders, including women, who build networks spanning structural holes are promoted late; they must instead borrow the social capital of a strategic sponsor. For patenting specifically, Meng (2016), studying academic scientists at United States research universities, finds that only boundary-spanning ties with industry significantly increased the probability of patenting for women. She describes these channels as requiring "a higher level of engagement and trust." In nineteenth-century France specifically, Khan (2016) argues that family firms served as a key conduit through which women accessed innovation, compensating for the *Code civil*'s restrictions on married women, their exclusion from formal schooling, and their limited access to capital markets. The constraint also shifts with women's share of the field. Ling et al. (2025), studying co-authorship in management journals from 1970 to 2006, find that structural holes help women when they are a small minority but become a disadvantage as women's representation passes about 30 percent. The consistent finding across these settings is that the barrier for women is entry into networks, not what happens once inside them.

Section 2.6 showed that family enterprises could provide women with capital, commercial contacts, and entry into business. But did family collaboration also provide access to technical knowledge from other domains? If working with a partner from a different field redirected a woman's subsequent inventive direction, then collaboration gave inventors access to new fields of technology. Whether this happened, and whether family ties served as substitutes for the professional networks available to men, requires tracking individual inventors across time and observing changes in the direction of their work.

3 Data infrastructure and machine learning

No comprehensive database of French patents and their inventors existed when this thesis began. The three empirical papers share the first database to cover the full patent universe and link its records to individual inventors, a common data infrastructure that I built from primary sources: digitized registries, scanned government gazettes, and handwritten patent applications. Constructed at the individual level and linked across sources, this infrastructure makes visible a population of women inventors that aggregate statistics and selective samples had missed. Unless otherwise noted, descriptive totals refer to the full patent database. Some econometric analyses, however, are estimated on main patents only and therefore exclude *certificats d'addition*, which improve earlier patents rather than introduce a new main filing.

Building this database required five main stages, each involving many decisions and substeps. I begin with the sources and the rule-based identification of female inventors. I then apply machine learning to classify technologies, measure novelty and influence without citation data, and codify occupations into a standard classification. I conclude with deduplication and record linkage, which turn raw patent observations into individual inventor careers and link women to civil records.

3.1 Sources and gender identification

To study women's inventive activity, I needed to identify who invented, classify what they invented, standardize what they did for a living, track individuals across time, and measure idea quality without modern citation data.

The starting point was the digitized patent registry published by the French National Institute of Industrial Property (INPI). The registry is itself the outcome of decades of work to microfilm, conserve, and digitize what Steeve Gallizia (2026), the historical archives officer at INPI, has called "2.5 kilometers of paper" (some 4,500 boxes of original patent files), released in successive versions through INPI's online archive. Even with such care, an archive of this scale cannot yield a perfect transcription. My first task was to clean the registry of missing records, absent dates and descriptions, and discrepancies in names and spellings. I detected date errors by exploiting the sequential nature of patent identification numbers. Because numbers were assigned in order of filing, a patent whose recorded date deviated sharply from its numerical neighbors was almost certainly misdated. I manually reviewed and corrected these cases against the original records. For names and categories, I grouped similar strings by text similarity in OpenRefine, selecting the most frequent variant in each cluster, since random transcription errors are unlikely to recur identically across records. I individually verified every patent involving a woman inventor against the original patent application. After the 1870s, however, coverage in the version I worked with thinned out, leaving gaps that cleaning could not fill. To fill them, I turned to the *Bulletin des Lois*.

The *Bulletin des Lois* was the official gazette of the French Republic. Among other government decrees, it published summaries of every patent granted throughout the century. Apart from the original patent applications themselves, it was the only comprehensive record of all patents for the period. I acquired the source material by downloading over 14,500 high-resolution page images from 66 volumes digitized by the Bibliothèque nationale de France (Gallica), supplemented with additional volumes from the Bibliothèque municipale de Lyon (Numelyo). Figure 2 shows a typical page: each entry summarizes one patent grant in a few lines of text.

Turning scanned pages into structured patent data required a dedicated extraction pipeline. Each page image was processed through optical character recognition tuned for French text, which returned both the transcribed words and the geometric coordinates of every paragraph on the page. The coordinates mattered because *Bulletin des Lois* pages contain headers, footers, page numbers, and marginal annotations alongside patent summaries, and separating content from noise required knowing where each text block sat. OCR quality varied substantially across volumes (Figure 3). Most pages were transcribed with high confidence, but scan quality in some volumes was poor enough that the automated transcription was unreliable. For these pages, I used vision-based language models to produce a first reading from the original scans, then reviewed and corrected their output by hand. Pages where scan quality was too poor even for that were transcribed fully manually. In total, over 1,500 patent summaries were corrected this way.

A sequence of cleaning steps then removed headers and footers by their spatial position, corrected hyphenation artifacts, filtered out side-column noise from overscanning, and fixed spelling errors through pattern matching. I then trained extraction models on manually annotated examples to identify patent numbers, filing dates, inventor names, patent agent names, addresses, and invention descriptions from the cleaned text. At each stage, I validated the output against manual inspection of sampled pages.

A separate problem was missing first names. The digitized registries recorded surnames reliably but often omitted given names, which are essential for distinguishing inventors who share a common surname. For 65 percent of male inventor observations, the database contained no first name at all. I reduced that figure to 33 percent by transcribing first names directly from more than 150,000 handwritten patent applications held in the INPI archives. An object detection model located the section of each application's cover page where the names appeared and cropped it automatically (see Figure 4). The cropped image and the known surname were then passed to an ensemble of two vision-based language models, which read the handwritten text independently. Only when both models agreed was a transcription accepted without review; I resolved disagreements by hand. For every woman inventor whose first name was missing from the registry, I manually consulted the original handwritten patent application. Where the application provided a first name, I transcribed it by hand; where it listed only an honorific and surname, B .n° 691. — 419 —

gaud jenne, à Paris, boulevard de Strasbourg, n° 23. — Appareil serre-joints pour conrroies de transmission, etc.

140,741. Brevet de quinze ans, 22 janvier 1881; Pitoiset, représenté par Armengaud jeune, à Paris, boulevard de Strasbourg, n° 23. — Ouatage à dessins et piqûres, combiné au moyen de deux ouates.

140,742. Brevet de quinze ans, 22 janvier 1881; société dite *Farbwerke Worm Meister, Lucius et Brüning*, représentée par Armengaud jeune, à Paris, boulevard de Strasbourg, n° 23. — Procédé de fabrication du diacétate d'aldehyde benzoïque et de ses dérivés de substitution chlorés, bromés et nitrés, et procédé de transformation de ces corps en acide cinnamique ou en ses dérivés de substitution chlorés, bromés et nitrés correspondants.

140,743. Brevet de quinze ans, 18 janvier 1881; Sicard et Parodi, rue Mahan, à Alger (Algérie). — Romaine dite *romaine Sicard-Parodi.*

140,744. Brevet de quinze ans, 26 janvier 1881; Dequoy, représenté par Paul Sée, boulevard de la Liberté, n° 121, à Lille (Nord). — Mode de travail du lin, du chanvre et autres matières filamenteuses.

140,745. Brevet de quinze ans, 26 janvier 1881; Cabannes, à Lagruère (Lot-et-Garonne). — Tourniquet compteur.

140,746. Brevet de quinze ans, 26 janvier 1881; Boucheron et Mazières (société), cours Trénac, n° 2, à Agen (Lot-et-Garonne). — Pétrin mécanique à changement de vitesse des outils, dit *le boulanger mécanique.*

140,747. Brevet de quinze ans, 24 janvier 1881; Laplanche, rue Saulnier, n° 32, à Puteaux (Seine). — Application du métal émaillé à tous appareils servant à refléter la lumière quelle qu'elle soit.

140,748. Brevet de quinze ans, 24 janvier 1881; Colmant, boulevard Biron, n° 9, à Saint-Ouen (Seine). — Perfectionnements à la fabrication des liqueurs.

140,749. Brevet de quinze ans, 24 janvier 1881; de Bussy, représenté par Rombi, à Paris, rue des Ecoles, n° 33. — Nouveau système de bandage provisoire en rotins, bambous, pour le soulagement immédiat et le transport des blessés aux hôpitaux.

140,750. Brevet (brevet anglais devant expirer le 24 juillet 1894) pris, le 24 janvier 1881, par Davidson, représenté par Albert Caben, à Paris, boulevard Saint-Denis, n° 1. — Perfectionnements dans certaines infusions végétales, extraits ou essences, et dans leur préparation.

140,751. Brevet de quinze ans, 24 janvier 1881; Jucker, représenté par Tavernier, à Paris, rue de Richelieu, n° 15. — Perfectionnements apportés au tissage.

140,752. Brevet de quinze ans, 24 janvier 1881; de Sainte-Croix, à Paris, cité Martignac, n° 6. — Laminoir fendeur pour moulin à cannes à sucre.

140,753. Brevet de quinze ans, 24 janvier 1881; Gottlieb et Strakosch (société), représentée par Dumas, à Paris, boulevard Beaumarchais, n° 95. — Lanterne portative inextinguible, sans cylindre; convenant particulièrement aux chemins de fer.

140,754. Brevet de quinze ans, 8 janvier 1881; Gentil (Mme veuve), représentée par Gentil, quai l'Amiral, n° 112, au Mans (Sarthe). — Cuisine roulante, système Ch. Gentil.

140,755. Brevet de quinze ans, 14 janvier 1881; Turpaud, rue de la Corderie, n° 5, à Angoulême (Charente). — Porte ou bouche de four équilibrée, à ouverture variable à volonté.

140,756. Brevet de quinze ans, 14 janvier 1881; Lalande, rue de la Paix, n° 1, à Toulon (Var). — Machine à greffer les vignes.

140,757. Brevet de quinze ans, 22 janvier 1881; Zimmermann et société Thiele et Holzhause, représentés par Bauer et compagnie, à Paris, boulevard de Magenta, n° 30. — Machine à fabriquer de la sucrerie et des bonbons.

140,758. Brevet de quinze ans, 22 janvier 1881; Bach, représenté par Bauer et compagnie, à Paris, boulevard de Magenta, n° 30. — Perfectionnements aux aiguilles à languettes pour métiers à tisser et à tricoter.

140,759. Brevet de quinze ans, 22 janvier 1881; Greene, représenté par Armengaud jeune, à Paris, boulevard de Strasbourg, n° 23. — Perfectionnements dans la fabrication des caractères d'imprimerie et dans les appareils typographiques.

140,760. Brevet de quinze ans, 25 janvier 1881; Baudry, à Paris, rue des Vieilles-Haudriettes, n° 5. — Gravure chimique sur métaux précieux.

140,761. Brevet de quinze ans, 25 janvier 1881; Samson fils aîné, représenté par Desnos, à Paris, boulevard de Magenta, n° 11. — Procédé de décoration des porcelaines, faïences et cristaux.

Figure 2 Excerpt from the *Bulletin des Lois*, Principale series, number 691, page 419 (1882). Each entry summarizes one patent grant: number, duration, filing date, inventor name with honorific, patent agent, address, and a one-line description. Patent 140,754, filed 8 January 1881, was granted to Gentil (*Mme veuve*), listed as a widow, for a *cuisine roulante, système Gentil* (mobile field kitchen). The honorific *Mme veuve* is the type of gender marker that the rule-based detection described in this section identifies across all three source types.

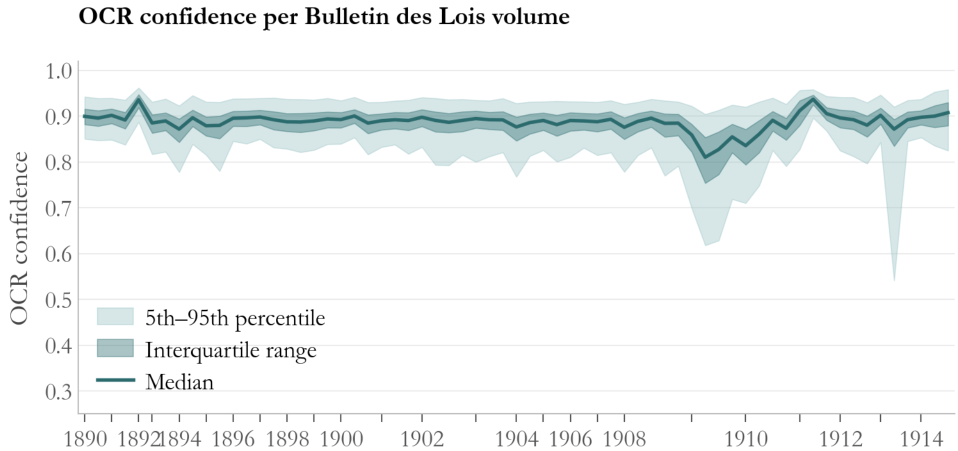

Figure 3 Distribution of OCR confidence scores per volume of the *Bulletin des Lois*, 1890 to 1914. For each volume, the shaded bands show the 5th–95th percentile and interquartile range of word-level confidence scores, with the median drawn as a line. Most pages were transcribed with high confidence, but some volumes contain pages where scan quality was poor enough to require semi-manual correction. Although the *Bulletin des Lois* extends to 1914, only data up to 1900 are used in this thesis.

no first name could be recovered. I then cleaned and standardized the extracted names using OpenRefine's clustering features, with spot-checking throughout.

French naming conventions made identifying female-linked patents straightforward once the data had been cleaned. Patent records consistently include gender-specific honorifics: *madame* (Mme) for married women, *mademoiselle* (Mlle) for unmarried women, and *veuve* (Vve) for widows. Kinship terms such as *veuve et fils* (widow and sons) or *père et filles* (father and daughters) also marked women's involvement. I applied the same rule-based detection to all three source types in the database: the INPI registry, the *Bulletin des Lois* extractions, and the original patent application scans, accounting for the full range of abbreviated forms that appeared across these different sources.

I validated the honorific method against two independent external lists: 169 female-linked patents from 1898 compiled by Chanteux (2023) from BOPI catalogues, and 55 patents from 1899 identified from the women's magazine *La Fronde*. As supplementary verification, a machine learning method that infers gender from first names found only four additional patents that the honorific approach had missed, an error rate of 0.001 percent. This systematic identification produced 6,805 female-linked patents across the full period, 1.75 percent of the nearly 390,000 patents in the database. The figure exceeds the 6,682 reported by Chanteux (2023), and the difference comes directly from the *Bulletin des Lois*: the additional patents appear in the decades where Chanteux's sources, which relied on the BOPI, were thinnest. The deduplication procedures described in Section 3.5 then grouped these patents into 4,165 distinct individual women inventors, of whom 1,076 were linked to genealogical records for demographic analysis in Paper IV.

3.2 What is a technology class?

"Hydraulic press for extracting olive oil" and "improved typographic press" share a keyword but belong in different technology classes: food processing and printing. "Apparatus for the mechanical assembly of fabrics" and "sewing machine" share no keywords but describe the same invention. A classifier that matches keywords fails both ways. To classify nearly 390,000 patents correctly, I needed a method that reads meaning from context, not from individual words. A language model provides this. Trained on millions of texts, it converts each patent title into a set of numerical coordinates, called an embedding, that locates the title in a space where position corresponds to meaning, similar to how latitude and longitude place a city on a map, but with hundreds of dimensions instead of two. Similar technologies are close together regardless of vocabulary, and unrelated ones are far apart. This representation of meaning as position is the foundation for most machine learning applications in this thesis: classifying patents by technology, measuring novelty and influence, codifying occupations into standardized categories, and identifying the same inventor across different patent records.

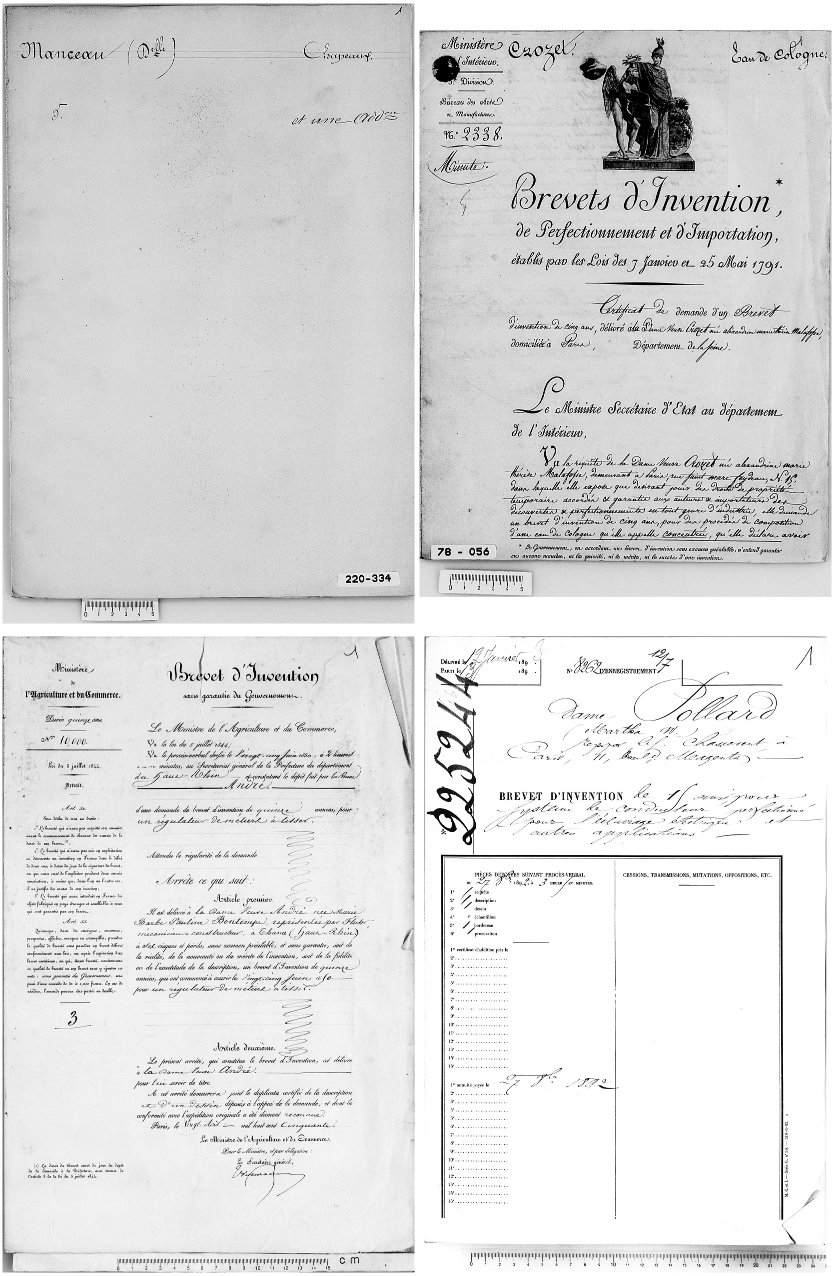

Figure 4 Four examples of patent application fronts from the INPI archives, ordered from the earliest variant (a) to the latest (d). The name-extraction pipeline first locates the inventor-name region for each variant before passing it to the vision-language ensemble.

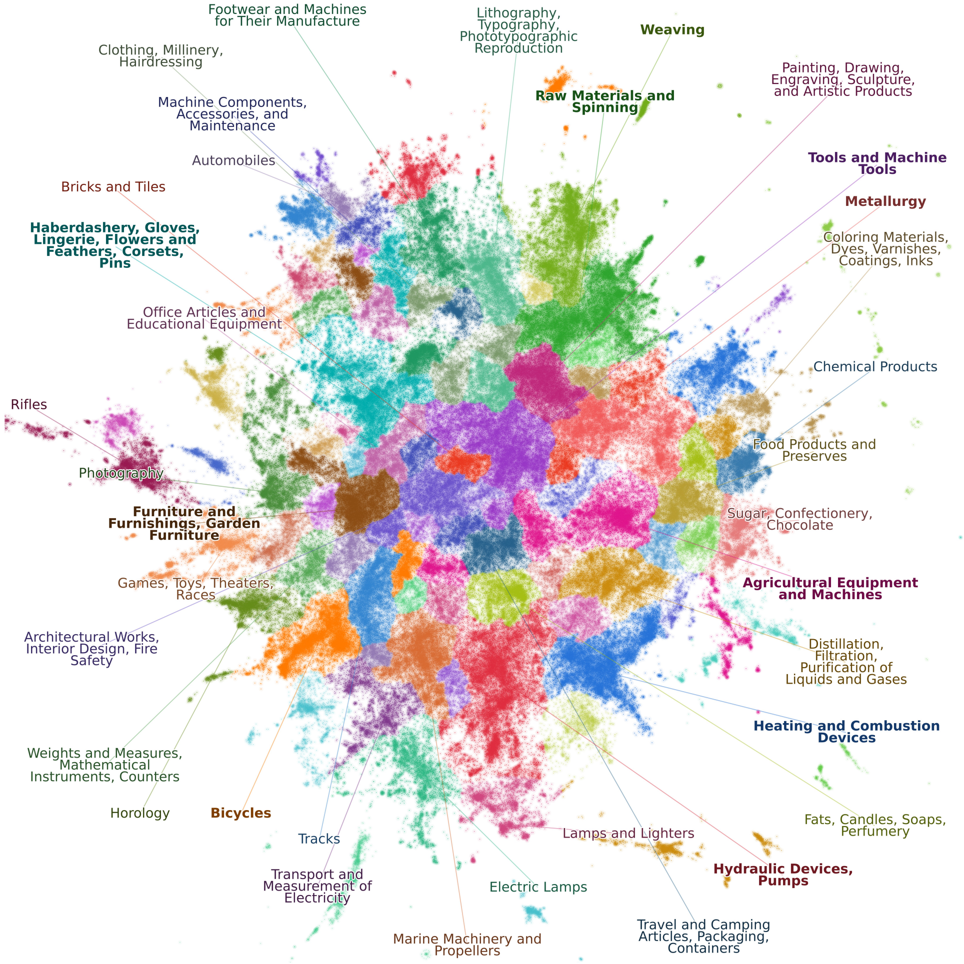

Figure 5 Semantic map of 312,588 French main patents with unique titles, 1791 to 1900. Each point represents one main patent title, positioned according to the semantic similarity of its language, with the high-dimensional embedding reduced to two dimensions for display. Patents that lie close together describe related technologies, even when they use different vocabulary. Colors mark data-driven thematic clusters, labeled by their dominant patent classification category.

Figure 5 makes this visible. Each of the 312,588 points is one main patent with a unique title.[1] The clusters are not drawn by hand. They arise from the language of the titles alone: inventions related to chemistry form one region, those related to construction another, those related to transport a third. Among the labeled clusters, one groups together haberdashery, gloves, flowers, corsets, and pins, among other items. These products share little in materials or manufacturing processes. They cluster together because their titles use related language, capturing thematic structure that a keyword-based approach would miss.

The map shows that patents cluster by technology without any classification imposed, but consistent analysis requires assigning each patent to a defined technology class. The classifications in the original patent records shifted in meaning across decades and covered only part of the corpus, making them unsuitable for comparison over the full century (Billington and Hanna 2021). I adopted the INPI 1904 technology classification, which provides precise definitions for 20 main classes and 97 subclasses, rather than the modern International Patent Classification, because the 1904 system was designed for these same patents by the office that issued them (Emptoz and Marchal 2002).[2] I trained an ensemble of two language models on nearly 40,000 expert-classified patents from the INPI database and used it to classify the rest.[3] The method correctly classifies about 9 in 10 patents at the main class level and nearly as many at the subclass level, and its classifications track meaning, not keywords: a patent about parachutes for mine safety is classified as Mining Operations while one about air parachutes is classified as Aviation.

For Papers III and IV, I improved the classifier in two ways. First, before training the classification model, I continued its general language training on all French and Italian patent titles filed up to 1930, a step called domain-adaptive pre-training. Nineteenth-century patent titles contain archaic terms, technical vocabulary, and formulaic constructions that do not appear in the modern texts the base model was originally trained on. Domain-adaptive pre-training exposed the model to this language before asking it to classify.

Second, I expanded the training data using a consensus approach. Labeling tens of thousands of additional patents by hand was not feasible; I ran two additional large

[1] The map uses a multilingual sentence transformer (BAAI/bge-m3) for embeddings, UMAP for dimensionality reduction, and HDBSCAN for cluster identification.

[2] The IPC imposes categories that reflect twentieth-century technology, and the 1904 system ensures comparability with previous studies of French patents (e.g., Nuvolari et al. 2023). See Paper II, footnote 20, for a detailed comparison.

[3] The ensemble combines CamemBERT (Martin et al. 2020), a French-language model, and BERT for Patents (Zuo et al. 2022), a model specialized for patent text. When the two disagree, the prediction with higher confidence is used. Average confidence reaches 0.97 for main classes and 0.93 for subclasses.

language models on every patent title and compared their predictions to the original classifier.[4] When all three models, each built differently and trained on different data, agreed on a patent's technology class, I treated that label as reliable and added it to the training set. The logic is the same as consulting three experts who have never spoken to each other: if all three independently reach the same conclusion, the conclusion is almost certainly correct. I also manually labeled several hundred additional patents in the technology classes where the original classifier performed worst, ensuring coverage where automated methods alone were insufficient. Together, these steps increased the training data from nearly 40,000 to over 140,000 labeled patents. On a held-out test set of 8,015 French patents, the improved classifier reaches 92 percent accuracy at the main class level and 88 percent weighted F1 at the subclass level.

3.3 Novelty and influence without citations

Modern innovation studies measure originality and impact by counting citations. Nineteenth-century French patents have none. The system granted patents without examination, and inventors did not cite predecessors. But the embedding space from the previous section offers an alternative. Consider a patent's position on the map. If no patent filed in the previous twenty years is close to it, this patent describes something genuinely new. If many patents filed in the following twenty years cluster near it, later inventors were describing similar ideas, and the patent was influential.

Kelly et al. (2021) first showed that word overlap between patent texts can proxy for these concepts, but counting shared words fails when the same invention appears under different vocabulary: "vulcanizing rubber" and "hardening caoutchouc" describe the same process but share no words. I developed measures that compare meaning rather than vocabulary, using the domain-adapted embeddings from the previous section, and adapted the approach for historical conditions in four further ways: penalizing generic phrases like "improved method for manufacturing," counting only statistically close neighbors rather than summing all similarity, adjusting for the volume of available prior art, and allowing patents to belong to multiple technology classes.[5]

This approach addresses a broader limitation of the patent record. Griliches (1990, p. 1661), in his survey of patent statistics as economic indicators, described them as a "mirage of wonderful plentitude and objectivity" amid otherwise scarce empirical evidence, and concluded that, despite the difficulties, patent statistics remain a unique resource for the analysis of technical change. Recent work has quantified the gap between patent records and the underlying innovation record more precisely. Using Swedish data, Taalbi (2025) estimates that international patent data capture about 15 percent of the information content of the innovation record. Even so, patent data remain unparalleled

[4] The two models are GPT-OSS-120B and Qwen3-30B-A3B.

[5] See Paper III, Section 3.2, for the full specification and comparison with Kelly et al. (2021).

for studying inventor activity, firm collaborations, and invention processes. Most of the signal that patents do contain has been extracted through citation-based quality measures, but patent citations were recorded only from the mid-twentieth century onward (Kelly et al. 2021). The text-based measures developed here extend that signal into an era without citations at all.

I validated these measures against 41 historically notable French patents, including Pasteur's preservation method and the Lumière cinématographe.[6] The influence measure correctly ranks a famous patent above an ordinary patent 67 percent of the time for the period 1850 to 1899, rising to 87 percent in the 1880s. The approach generalizes: La Mela et al. (2024) validate it for Swedish patents from 1890 to 1929, where text-based importance correlates strongly with patent renewal data. Yang (2025), working with over six million modern U.S. patents, finds that text-based measures rank breakthroughs at the 92.8th percentile on average, outperforming citation-based indices, because text captures knowledge content that citations often fail to acknowledge. Novelty and influence capture different dimensions: among the 41 landmarks, pioneering patents that opened new fields scored higher on novelty, but both pioneering and improving patents scored equally high on influence because both were widely adopted. The measures rely only on patent titles, which are short, and the signal is moderate. But they provide a consistent way to compare idea quality across the full century.

3.4 Codifying occupations into HISCO

Patent records list each inventor's occupation as free text, but nineteenth-century French titles are inconsistent and often ambiguous: *fabricant de papier* (paper manufacturer) describes a specific trade, while *fabricant* alone could mean a factory owner or a production worker. To standardize about 176,000 occupation strings, I built an ensemble of three machine learning models that independently classify each title into the Historical International Standard Classification of Occupations (Van Leeuwen et al. 2002). One model, a sentence transformer fine-tuned on French occupational data, reads semantic meaning. A second, OccCANINE, uses character-level information to handle spelling variations and historical orthography (Dahl et al. 2024). A third, a large language model, classifies using official HISCO definitions. When all three agree, the code is accepted. When they disagree, a structured decision process with manual review resolves the ambiguity. The HISCO codes are then collapsed into five HISCLASS social classes (Leeuwen and Maas 2011), from higher managers and professionals to unskilled workers, which Papers II and IV use to test whether an inventor's socioeconomic background predicted who patented and what they patented in.

[6] The 41 benchmarks were drawn from standard histories and encyclopedias of nineteenth-century invention. Paper III, Appendix C, lists all 41 with their short titles, technology classes, and application codes.

3.5 Deduplication and record linkage

The patent database records observations, not people. The same inventor may appear on dozens of patents filed over decades, but nothing in the records says which observations belong to the same person. Before any analysis of careers, collaboration, or life histories, I needed to solve two distinct problems. The first was deduplication: grouping the roughly 448,000 inventor-observations in the database into distinct identities. The second was record linkage: connecting those identities to external demographic records to find out who these people actually were. Deduplication turns anonymous patent filings into individual careers that can be followed across time. Record linkage asks what those inventors' lives looked like.

3.5.1 Inventor deduplication

Firms were the simplest case. A firm's name tends to stay stable over time, and the samples are small: about 8,200 family-firm observations and 26,200 non-family firm observations. I matched firm observations using rules based on name, occupation, technology class, and the keywords extracted from patent titles. I assumed a firm would not survive more than fifty years without filing a new patent. In practice, almost no observations reached that threshold. Of the resulting firm identities, 130 are female-linked, meaning at least one woman is named on their patents.

Women inventors posed a harder problem. The 6,805 female-linked patents produced 6,916 female inventor-observations because some patents named more than one woman. The sample was small enough to examine closely, but French naming conventions made the problem harder than rules alone could handle. A seamstress named Flore-Félicité Prophète was listed as "Mademoiselle Prophète" on her early patents, "Madame Bresson" after marriage, and "Veuve Bresson" after her husband's death: three different names across a career spanning more than twenty patents. Maiden names, when recorded, connected records across these name changes, but they were not always present. I developed 51 matching rules that codify the manual linking process I carried out for every inventor in the sample, each rule tailored to a specific combination of name fields, marital status, and biographical details. The rules make the decisions transparent and replicable, but I still examined every cluster of observations against the original patent applications by hand. This produced 4,165 distinct individual women inventors. Together with the 130 female-linked firms identified above, they make up the 4,295 distinct female-linked entities used in Paper III. Paper IV starts from the 4,165 individuals, since civil records can only be matched to people; I reconstruct life courses for 1,076 of them.

Male inventors were the hardest problem by far. The comparison table for men with the surname Martin alone held over 56,000 rows. A single missing first name, or a slight variation like "Jean" versus "Jean-Baptiste," could make one inventor look like several or several inventors look like one. Even after reducing missing first names from 65 to 33 percent, the scale of the problem required more than rules.

Comparing every pair of male inventor-observations sharing a surname would mean millions of comparisons for common names alone. To narrow the search, I required that any two observations also share at least one other detail: an overlapping occupation, location, or technical keyword. This produced more than 1.5 million plausible pairs. Simple rules resolved the obvious cases: inventors listed on every application within the same patent family (a main patent and its additions) were clearly the same person, and inventors whose first names or kinship terms conflicted were clearly different. These clear-cut cases accounted for about 60 percent of all pairs. The remaining 40 percent were ambiguous.

For ambiguous pairs, I added three layers of increasing sophistication. A probabilistic model assigned each pair a match probability based on how their names, occupations, and locations agreed or disagreed, adjusting for the fact that sharing a rare surname like "Siemens" is far more informative than sharing a common one like "Martin." Next, language models compared the full text of each record and scored how closely they matched in meaning. This step captures connections that comparing individual fields cannot: "forge master" and "iron works" look nothing alike as strings, but they describe the same world. Finally, a machine learning classifier trained on 25,000 labeled pairs, deliberately degraded to mirror the gaps in the real data, produced sharper predictions than any single method alone.

The final step grouped these predictions into inventor identities. The grouping respected hard constraints: pairs that rules had marked as definite matches or definite non-matches, and a maximum career span to prevent implausible merges. Where a group spanned too wide a range, I removed the weakest connections. The design is deliberately conservative: when in doubt, the algorithm splits rather than merges. A false merge mixes unrelated careers. A false split leaves one real career divided across two identities. The first error is worse. The algorithm therefore errs toward splitting.

The process yielded about 233,000 distinct male inventors from the 407,000 male inventor-observations, a ratio of 1.7 observations per inventor. The women's ratio, based on identities I linked by hand, was 1.65. That an automated pipeline and a fully manual one converge on nearly the same ratio is not proof that either is correct, but it is reassuring that neither systematically overcounts nor undercounts.

3.5.2 Genealogical record linkage

Deduplication identified the individual inventors. But patent records contain almost nothing about who they were: a name, an address, and sometimes a marital status. Paper IV asks how life circumstances shaped women's patenting. Answering that question required birth years, marriage timing, geographic origins, and death years. France lacks digitized civil registries at the national scale for this period; I turned to collaborative genealogical databases compiled by archivists and private individuals, which aggregate millions of birth, marriage, and death records from departmental archives alongside user-submitted family trees (Charpentier and Gallic 2020). Civil vital records carry the greatest weight in the linkage procedure, while notarial, census, and user-submitted genealogical material are used as lower-reliability supporting evidence.

The feasibility of linking depended on how much the patent record revealed about each woman. Married women with a recorded maiden name were the easiest to trace because the combination of birth surname, given name, and spouse surname narrows the search sharply. Single women appeared with only a birth surname and given name, offering fewer points of identification. Married women without a recorded maiden name were the hardest: the marital surname alone is circular, since every search result will share it by definition. I built three separate algorithms, each tailored to the identifying information available, and tightened acceptance thresholds as the information weakened. The less I knew from the patent record, the more I demanded from the genealogical evidence.

I built all three algorithms around a shared four-stage architecture. Each began by filtering out implausible records: names too different, ages at patenting outside the range of 14 to 85, deaths before the patent was filed. Surviving records received a quality score combining five dimensions: name match, spouse match, geographic consistency, source reliability, and timing plausibility. The scoring was multiplicative, meaning a record had to score well on every dimension to receive meaningful weight; a perfect name match from an unreliable source counted for little. Compatible records were then grouped into clusters, each representing a different possible identity for the inventor, and I assembled a best-fit biography by giving priority to the most reliable sources.

The hardest cases required specific solutions. For single women, who have no spouse information to work with, I used parent names instead as the primary way to confirm identity: a record naming the same father and mother as other records in a cluster is unlikely to describe a different person. For married women without a maiden name, the insight was that the spouse's first name is informative even when the surname is not. If a search for women married to someone named "Dupont" returns thirty records and twenty-one name the husband "Jean," that consistency is strong evidence they describe the same woman. I required 70 percent agreement on the spouse's given name and applied the strictest acceptance thresholds of the three algorithms.

The three algorithms together produced 1,076 linked demographic profiles, of which 86 percent were classified as high quality. I assessed accuracy by hand-checking 60 inventors, deliberately oversampling difficult cases and correcting for that oversampling statistically. For each sampled inventor, I independently verified dates against original handwritten civil records in departmental archives rather than relying on transcribed metadata. The algorithm correctly identified 96 percent of birth years, 96 percent of marriage years, and 90 percent of death years.

The linked sample is not fully representative. Women with common surnames or from departments with sparser genealogical coverage are underrepresented, because name ambiguity and record scarcity make linking harder for precisely those groups. I test whether linking skewed the sample toward certain industries by comparing the sectoral distribution of linked and unlinked inventors: the distributions are statistically indistinguishable for both married and single women. But the balance test does not cover geography or birth cohort, and the selection it cannot measure may still matter.

4 Methods

With the database built, each of the three empirical papers asks a different question and uses a different econometric strategy. Paper II asks what predicted whether a patent involved a woman, exploiting variation across the full patent population without a within-unit design. Paper III asks what changed within an inventor's career after first collaborating, comparing each inventor over time. Paper IV asks what predicted which technology class a woman patented in, comparing sectors within the same department.

The three approaches differ in identification strength but share a common logic. Papers III and IV go further than Paper II by holding constant more of the unobserved differences between inventors: Paper III absorbs time-invariant inventor characteristics through inventor fixed effects; Paper IV's conditional logit absorbs inventor characteristics that do not vary across her sector alternatives. The results throughout are strong associations identified under stated assumptions, not estimates from a clean natural experiment. Each is paired with robustness checks that test sensitivity to alternative specifications, estimation procedures, and sample definitions. Their value is that the same pattern appears in the patent universe, in inventor careers, and in linked life histories. Each method was chosen to address a specific identification problem, and each has limitations that the papers discuss in detail.

4.1 Binary outcomes and rare events (Paper II)

Paper II examines a binary outcome: does a given patent involve a woman inventor, or not? For a binary outcome, the simplest approach is the linear probability model, which estimates the probability directly using ordinary least squares. But when the outcome is this rare, the linear probability model becomes less attractive because it imposes constant marginal effects despite a strongly nonlinear relationship: a variable that matters when the baseline probability is 50 percent may have a very different effect when it is 2 percent, and the linear model cannot capture this curvature. It can also predict probabilities below zero. A probit model addresses both problems by mapping predictors through a cumulative normal distribution, which constrains predicted probabilities between zero and one and allows the effect of each predictor to vary across the distribution.

The model introduces explanatory variables sequentially to test specific hypotheses: the 1844 patent reform and patent duration (financial constraints), team size (collaboration), technology sector (sectoral concentration), and the lead inventor's skill level (occupational background). The twenty technology sectors are entered using effects coding rather than standard dummy variables. With standard dummy coding, each coefficient measures the difference from one arbitrarily chosen reference sector, and the results look different depending on which sector is omitted. Effects coding instead measures each sector's deviation from the grand mean across all twenty sectors; a positive coefficient means a patent in that sector is more likely to be female-linked than a patent in the average sector. This is the appropriate comparison when the question is which sectors women are overrepresented in, not how each sector compares to one arbitrary baseline.

Because probit coefficients cannot be read directly as changes in probability, we compute average marginal effects: for each observation, we calculate how much the predicted probability changes for a one-unit change in the explanatory variable, then average across all observations. The resulting estimates can be read as percentage-point changes. Given how rare female-linked patents are in the estimation sample, even small absolute effects in percentage points represent large relative changes. With a rare outcome and many categorical predictors, some cross-tabulations contain very few female-linked patents, and the maximum likelihood estimator can become unstable in these sparse cells. As a robustness check, we re-estimate the model using Firth's penalized logit, which corrects for this instability. The results are similar. The final model adds the lead inventor's skill level, but occupation data are available for only half the sample, and the missingness is not random. Propensity score matching, which creates comparable groups of female and male patents based on application year, patent type, team size, cost, and technology sector, confirms that the skill-level findings are not driven by this selection. The reform dummy captures a time break, not an isolated policy experiment: other changes around 1844 could contribute to the association.

The second model in Paper II examines which factors predicted a woman inventor's marital status: married, single, or widowed. These three categories have no natural ordering:

widowhood is not "more" than marriage in the way that a higher income exceeds a lower one; an ordered logit would impose a false structure. A multinomial logit treats each category as a distinct unordered outcome, estimating the probability of each without assuming any ranking among them. The sample is restricted to 4,811 female-linked patents where the lead inventor is a woman, and the model tests whether financial constraints, team composition, and technology sector predict marital status differently across the three groups.

4.2 Collaboration, networks, and within-inventor change (Paper III)

Paper III asks what happened to an inventor's output, novelty, influence, and technology-class choices after first collaborating. The goal is to trace how these outcomes change around the year an inventor first works with another inventor, compared to inventors who have not yet done so. The challenge is that different inventors first collaborate in different years, and a naive comparison can be distorted if the comparison group includes inventors who have already collaborated and are therefore themselves affected.

The design compares each inventor before and after this transition, using inventor fixed effects to control for all time-invariant differences. Because the comparison is always within the same inventor over time, permanent characteristics like social background or innate ability cannot drive the result. Home-class-by-year fixed effects, where "home class" is the technology class in which an inventor filed the most main patents before first collaborating, control for technology-specific trends: if a particular technology experienced a boom in a given year, that boom affects treated and control inventors equally and does not bias the estimate. The sample is restricted to inventors with at least two patents, the minimum needed to define a career span and estimate within-inventor changes.

The standard approach for this type of analysis is a two-way fixed effects event study, but this estimator is biased when treatment timing is staggered (Goodman-Bacon 2021). Because different inventors first collaborate in different years, the estimator implicitly uses already-treated inventors as controls for newly-treated ones, and if the effect of collaboration changes over time, these comparisons produce biased estimates. I use the Sun-Abraham stacked specification to avoid this (Sun and Abraham 2021). The approach groups inventors into cohorts by the year of first collaboration and compares treated inventors only to clean controls: inventors who have not yet collaborated or who never collaborate. For the diversification outcome, where the outcome is a technology-class choice, I restrict controls to not-yet-treated inventors only, because never-collaborators who never switch technology classes may follow a different counterfactual path of diversification absent collaboration, and including them would conflate these differential trends with the effect of collaboration. These cohort-specific comparisons are stacked and estimated jointly, with stack fixed effects controlling for level differences across cohorts. The result is an event-study path showing how each outcome evolves around first collaboration, with the year immediately before as the reference point. I group event times three years and beyond into a single coefficient to preserve statistical precision. Standard errors account for repeated observations from the same inventor.

Even where pre-trends pass, as they do for the diversification outcome, the timing of first collaboration is not random, because inventors choose when to collaborate. The results are therefore associations, not causal effects. For productivity, the pre-trend test fails, and the paper reports those results with further caution. Three additional tests address the possibility that the diversification result is an artifact. Excluding each inventor's first collaborative patent from the outcome tests whether the shift is mechanical: if the collaborative patent itself accounts for the entire increase, the coefficient would fall to zero, but it does not. Restricting the outcome to solo patents only tests whether collaboration changes the inventor's independent work or only team output. And interacting the event-time coefficients with the 1844 patent reform tests whether diversification was driven by cost-sharing rather than knowledge exchange, because the reform replaced upfront fees with cheap annual installments and reduced the financial motive for co-patenting. The diversification result is robust to all three tests.

Paper III also reconstructs the full inventor collaboration network, where two inventors are linked if they appear together as applicants on the same patent. Co-patenting is a conservative definition of collaboration: most knowledge sharing in the nineteenth century was informal and left no patent trail; the network captures only the partnerships formal enough to appear on a legal document. I characterize the network's structure using standard measures from social network analysis: the distribution of component sizes (separate clusters of connected inventors), the clustering coefficient (how often an inventor's collaborators also collaborated with each other), and degree assortativity (whether well-connected inventors tended to work with other well-connected inventors or with newcomers). Together, these measures describe the macro shape of the network: whether it was organized around a few dominant hubs that channeled most collaborations, or fragmented into many small disconnected groups. That shape matters for interpretation: in a dense network with central brokers, access to cross-class knowledge hinges on occupying a brokerage position; in a sparse network of many small components, it hinges on the specific partners an inventor happens to find. I then examine how the composition of collaborative ties, particularly the share involving family members and the share crossing technology-class boundaries, differed between men and women.

The event study establishes that collaboration coincides with a shift in technological scope, but it cannot identify which features of the collaborative relationship drive that shift. A separate set of inventor-year panel regressions decomposes the association between network structure and subsequent solo diversification. The outcome is the share of solo patents filed outside the inventor's entry class (the technology class of her first patent) in the five years that follow, measured after the network variables to avoid simultaneity between tie formation and diversification in the same year. The main regressors capture three channels: the range of an inventor's ties across technology classes, whether repeated collaborations span class boundaries, and the extent to which collaborators themselves work outside the inventor's home class. Gender interactions on all mechanism variables test whether women receive different diversification returns from the same network features. The specification includes entry-class and year fixed effects but not inventor fixed effects, because the event study already shows that diversification shifts once at first collaboration and persists, leaving little within-inventor time variation for fixed effects to exploit. The regression complements the event study by asking a different question: not whether collaboration changes diversification, but which features of the cumulative network predict it.

4.3 Discrete sector choice within departments (Paper IV)

Paper IV asks whether the gendered composition of local industry predicted what women invented. The empirical challenge is separating two channels: pure agglomeration, where larger industries produce more patents regardless of who works there, and gendered knowledge, where women patent in sectors where women specifically are concentrated because practical knowledge comes from engagement with production. A standard regression comparing inventors across departments cannot separate these two because female and male employment are 97 percent correlated at the department level: a department with many women in textiles almost always has many men in textiles too. A regression with department fixed effects could control for overall department differences, but the question is not how many patents appear in each sector within a department. The question is which sector a specific inventor chooses to patent in. The conditional logit fits this individual-level choice problem by treating each inventor's patent technology class as a discrete choice among the industries available in her birth department.

The conditional logit avoids the cross-department collinearity by comparing sectors within the same department. Instead of asking whether textile departments produce more textile inventors, it asks: within a given department, does a woman patent in the sector where women are concentrated rather than in the sectors where they are not? This within-department comparison controls for all department-level differences, including wealth, culture, infrastructure, and overall industrialization, because these are identical for every sector choice facing the same inventor. The identifying variation is across sectors within each department, where raw female and male employment still co-vary. The within-department comparison alone does not separate agglomeration from gendered knowledge. The preferred specification handles this by decomposing local employment into a level and a ratio: total industry size in the sector, and the female employment share within it. These two move much more independently than raw female and male counts, which lets the regression separate their effects. The coefficient on total industry size is consistent with agglomeration; the coefficient on the female employment share is consistent with the gendered-knowledge channel. To compare magnitudes, I standardize both coefficients to ensure that a one-standard-deviation increase in each variable is comparable. Standard errors are computed using a department-level cluster bootstrap, because all inventors born in the same department face the same employment figures and are not truly independent observations.

Marie Josephe Thevenet was born in Isère, where three industries employed women: clothing at 88 percent female, chemicals at 35 percent, and food processing at 10 percent. She patented an automatic mounting system for umbrellas, parasols, and sunshades, an invention in the clothing technology class where women in her department were most concentrated. Whether Thevenet herself drew on local knowledge from Isère's clothing sector cannot be established from the patent record; the conditional logit tests whether this pattern holds systematically. It does.

A permutation test establishes that the observed match between inventors and local industry is non-random: randomly reassigning each inventor's patent technology class while holding her birth department fixed, and repeating this 10,000 times, confirms that inventors systematically patent in sectors concentrated in their department. The same test using male employment shares also rejects the null, which is expected because female and male employment are highly correlated across departments. The conditional logit's within-department decomposition is needed precisely because both predict the match; the question is which dominates when industry size is held constant.

Because the industrial survey likely undercounts women's work, the measured female employment share is biased downward, which pushes the coefficient toward zero. Any positive result is therefore a lower bound. The 1860 industrial survey measures local industry at a single point, but inventors were born between 1764 and 1881. I test this by splitting the sample by distance from 1860: inventors born within twenty years of the census and those born further away both produce significant coefficients, though the effect is smaller for more distant cohorts. This pattern is consistent with persistent local specialization rather than a snapshot of one year's labor market. The model assumes that adding or removing a sector from the choice set does not change the relative odds of choosing among the remaining sectors, an assumption called the independence of irrelevant alternatives. Formal tests reject this for some sector pairs, particularly textiles and clothing, which are closely related. A mixed logit, which allows different inventors to respond differently to female employment and does not require this assumption, produces a larger coefficient, indicating that the baseline estimate is conservative.

5 Summaries of papers

This section turns from the thesis framework to the four papers. The summaries follow the same movement as the argument: Paper I identifies the historiographical and methodological problem, Paper II establishes the full-population facts of women's and men's patenting, Paper III examines collaboration and technological scope, and Paper IV links women inventors to life-course evidence. I focus on each paper's research question, findings, and contribution to what shaped women's inventive activity during French industrialization.

5.1 I: Gender and the long-run development process

This paper is co-authored with Faustine Perrin. The scope and structure of the review were developed jointly. The sections were divided by topic. Both authors contributed throughout and the conclusions were written together.

Women are central to three forces that drive long-run economic growth: human capital formation, fertility decisions, and labor supply. Yet until recently, the theoretical models that describe the transition from stagnation to sustained growth said little about gender, and the historical data that could test those models systematically undercounted women's contributions. Perrin and I survey this literature. We ask two questions: why do countries differ in gender equality, and to what extent does gender equality foster economic development? We review theoretical models, empirical evidence on the relationship between education and fertility, the contested U-shaped pattern of women's labor force participation, and research on family systems and culture, covering mostly Western Europe from pre-industrial times to the present.

The survey traces how growth theory evolved to account for gender. Unified growth theory models the transition from stagnation to growth through a tradeoff between the number of children and the human capital invested in each child (Galor 2011), but the original models were gender-blind. Diebolt and Perrin (2013, 2019) extended the model by showing that women's empowerment drives the demographic transition and, through it, sustained growth. A puzzle motivates this theoretical work: while England industrialized before its fertility transition, France experienced its demographic revolution at the end of the eighteenth century and industrialized only in the second half of the nineteenth. This French-English paradox challenges the standard predictions and makes France a particularly important case for studying gender and development.

Across the empirical literature, three patterns stand out. First, women always worked, but official records increasingly missed their work as production moved from home to factory. Chiswick and Robinson (2021) show that 57 percent of free adult American women participated in the labor force in 1860, while the census recorded only 16 percent. Second, the male breadwinner model fits the empirical record of pre-industrial households poorly when used as a baseline for measuring living standards. Gary and

Olsson (2020) show that in southern Sweden, unskilled men's wages alone were insufficient to sustain a family at a respectable consumption level; survival required women's and children's earnings. Whether the model holds better as a description of ideology or household structure in other settings remains contested, with the strongest case for it tied to specific industrializing paths such as Britain's. Third, deep cultural and institutional forces, from agricultural practices to marriage patterns to family structures, shaped gender roles persistently across centuries, though these roles evolved alongside formal institutions. The evidence that gender equality fostered economic growth is stronger and more consistent than the evidence for the reverse.

The survey's most distinctive contribution is its closing argument: the field is constrained by its data. Historical sources undercount women's labor, earnings, and human capital. They rarely capture unpaid work, and the definition of work itself shifts across time and place. Perrin and I argue that new technologies can change this. Optical character recognition and machine learning now make it possible to digitize handwritten documents at scale. Full-count censuses and record linkage allow researchers to track individuals across their lifetimes and across generations. Linking women poses a specific challenge because women typically changed their names at marriage, but machine learning is improving the accuracy of this process. The goal is to move the field from documenting correlations to identifying the causal relationships that theoretical models predict.

Paper I provides the conceptual foundation for the rest of the thesis. It identifies the problem: women were central to long-run development, but the historical record made them hard to see. It also identifies the solution: linked micro-level data built from digitization, machine learning, and record linkage. Papers II, III, and IV execute that agenda in the case of women inventors in France. They do not test unified growth models directly. They work at a level of individual detail beyond what those models address, asking instead where women acquired inventive knowledge, how collaboration widened their scope, and when in their lives they could patent.

5.2 II: Women inventors and the origins of the gender patenting gap

This paper is co-authored with Faustine Perrin. The conceptualization and research design were developed jointly. I was responsible for the data collection and the machine learning classifications. Perrin contributed most of the theoretical framing. The analysis and the remainder of the paper were written jointly.

Across the full period 1791–1900, patents involving at least one woman accounted for 1.75 percent of French patents, a higher share than in Britain or the United States. After 1844, the share averaged 1.79 percent and stayed low through 1900, even as education expanded and women entered new occupations. Yet women patented across all twenty technology sectors, from clothing and textiles to machinery and precision instruments. Perrin and I ask how extensively women participated in the patent system, how their activity compared to men's, and what shaped this persistent gender patenting gap.

To answer these questions, we build an original database of all French patents granted between 1791 and 1900, drawing on the registries of the French National Institute of Industrial Property and the *Bulletin des Lois*. The database contains nearly 390,000 patents, including 6,805 linked to at least one woman, identified through gender-specific honorifics (*madame*, *mademoiselle*, *veuve*).

What factors shaped the probability that a patent involved a woman? We estimate the probit analysis on 308,374 main patents, excluding *certificats d'addition*, which improve an earlier patent rather than mark a distinct patent filing of the same analytical status. Using this sample, we test whether financial constraints, collaboration, technology sector, and inventor occupation predict the likelihood that a patent was female-linked. Financial constraints shaped women's patenting. The 1844 patent reform, which introduced installment payments and lowered the effective cost of entry, is associated with a 0.7 percentage point increase in the probability of a patent being female-linked, a 40 percent increase relative to the base rate. Cheaper five-year patents show an even stronger association: 0.8 percentage points, or a 45.7 percent relative increase. Collaboration also raised the probability of female involvement: each additional inventor is associated with a 0.6 percentage point increase. But 81 percent of women patented alone, and women were underrepresented in teams overall. The strongest sectoral effect is in Clothing, where the probability of female linkage is 2.5 percentage points above the cross-sector average, a 142 percent relative increase. Women were most active where female employment was highest: in 1860, they made up more than half of workers in Clothing and Textiles, the two largest sectors of French industry.

But women were not a monolithic group. Did marital status shape what they invented and how they collaborated? Using a multinomial logistic regression on 4,811 female-linked patents where a woman is the lead inventor, we test whether financial constraints, team size, and technology sector predict the lead inventor's marital status. In Paper II, these marital-status and occupational patterns are observed at the patent level rather than after deduplication to unique inventors. Widows are especially visible: they account for 27.4 percent of these patents. Although that figure is not directly comparable to person-level population rates, it is consistent with the prominent role of widows who inherited or continued to run family enterprises after their husbands' deaths. In the general female population, widows typically accounted for 10 to 20 percent. Financial constraints do not differ across marital statuses, but collaboration does: each additional inventor decreases the probability of a married lead by 11.8 percentage points while increasing it for widows by 7 percentage points, consistent with widows using collaborative teams to sustain inherited family businesses. Sectoral concentration also varied: single women patented disproportionately in Clothing, widows in Textiles and Machinery, and married women in Construction and Road Transport.

Socioeconomic background shows a similar breadth. In the patent-level Paper II sample, 44 percent of female-lead patents with known lead-inventor occupations were filed by women from higher social classes, 31 percent by women in medium-skilled trades concentrated in garment work, and 25 percent by women from low-skilled and unskilled backgrounds. French patenting was not the preserve of a narrow elite.[7]

Paper II provides the empirical starting point for the thesis's argument. It establishes that women were present across the patent system, across sectors, and across social classes. It also provides the first part of the substantive answer: women's patenting was concentrated in the sectors where women worked, showing that invention was embedded in women's economic lives rather than separate from them. Papers III and IV then explain how some inventors moved beyond those initial domains, and when in their lives they were able to do so.

5.3 III: What happens when inventors collaborate?

Collaboration drives modern innovation. Teams dominate the upper tail of scientific impact, mix diverse knowledge, and generate the recombinations that produce breakthroughs. As knowledge accumulates and individual scope narrows, collaboration increases to fill missing expertise. But we know far less about how collaboration operated in earlier technological regimes, where much expertise remained tacit, institutional barriers shaped who could work with whom, and most inventors worked alone. In nineteenth-century France, collaboration was rare: 69 percent of inventors never co-patented, and the co-inventor network split into over 200,000 disconnected components, mostly isolates and small pairs. When collaboration did occur in this sparse setting, what did it change?

I address this question using the full universe of French patents from 1791 to 1900. Because historical patents lack citation data, I develop text-based measures of novelty and influence from patent titles, validated against 41 historically notable inventions. I reconstruct inventor careers from the deduplicated patent database (see Section 3.5.1), build the complete co-inventor network, and track four outcomes around each inventor's first collaboration using within-inventor event studies: annual patent output, novelty, influence, and the share of patents filed outside the inventor's home technology class.

What changed when an inventor first collaborated? Not productivity in any simple sense: the only output spike was mechanical, reflecting the joint patent itself, and it disappeared once that patent was excluded. Because output was already rising before first collaboration, this result is descriptive rather than causal. Not novelty, which showed no response at any horizon. Influence rose modestly but faded within two years. The durable effect was a large, persistent shift in technological scope: at first collaboration, inventors redirected about 35 percentage points of their output outside their home technology class,

[7] Within Khan's (2020) 1791–1855 sample window, 58 percent of female-lead patents come from medium-skilled and lower-skilled backgrounds, indistinguishable from the 56 percent for the full century. The breadth is not a post-1844 artifact.

and the reallocation remained stable for years. The shift was largest when the first collaboration spanned a technology boundary, but even collaborations that stayed within the home class led to gradually increasing diversification over time. The diversification was not mechanical (it survived when the first collaborative patent was excluded), not compositional (it appeared in solo patents alone), and not driven by cost-sharing (it was indistinguishable before and after the 1844 patent reform that substantially decreased upfront patenting costs).

Knowledge passed directionally along collaborative ties rather than through random exploration. Post-collaboration solo patents appeared in a collaborator's specific technology class at 4.2 times the random rate, with a median gap of one year between first collaboration and first entry into that class, compared to nine years for unrelated classes. Inventors showed no semantic drift toward their future partner's technology class before collaborating; the redirection began at the moment of first collaboration. Women faced a sharp access barrier: 76.5 percent were network isolates, compared to 68.8 percent of men, and 35.8 percent of women's collaborative ties were family links versus 8.8 percent for men. Family ties helped many women enter the network, but their cross-class advantage came mainly through non-family ties, which crossed class boundaries more often than their family collaborations did. Women who entered collaboration therefore built ego networks that were significantly more cross-class than men's within the same technology class, exceeding men's cross-class share by 5.6 percentage points. I cannot detect a gender difference in the overall diversification outcome. The path differed. For men, the range of cross-class partners predicted diversification; for women, the repeated, trusted relationship with a partner who had already crossed a boundary mattered more.

Paper III shows that collaboration changed the scope of invention rather than its volume or originality. The dispersed network structure, with many small disconnected components and no dominant hubs, is more consistent with an open patent system than with elite control (see Section 2.5). Substantively, the paper identifies the second mechanism of the thesis: women were not mainly limited by lower returns to collaboration once inside the network, but by the difficulty of entering the ties through which new technological domains became accessible.

5.4 IV: What shaped women's invention during industrialization?

Between 1791 and 1900, French women patented across technology sectors from clothing to chemistry. The patent record documents what they invented, but not why: what determined the sector a woman chose, and what determined when in her life she first filed? Patent records contain the invention but not the inventor's age, family, or geographic origins. I link patent records to genealogical sources, producing 1,076 demographic profiles that include birth years, marriage timing, children, and death years (see Section 3.5.2 for the linking methodology). The linkage exposes a measurement problem: 80 percent of patent addresses are in Paris, but civil records show that only 47 percent of married women married there. Women who married outside Paris but listed Paris patent addresses lived, on average, over 200 kilometers from where they filed, because the centralized filing system routed applications through Paris-based agents whose addresses replaced inventors' own. I use birth departments rather than patent addresses to identify where inventors came from.

Did it matter which industries employed women locally, or only how large those industries were? A conditional logit compares industries within each inventor's birth department, asking whether a woman patented in the sector where women were concentrated rather than in sectors where they were not. Because the comparison is within departments, differences in wealth, culture, infrastructure, and overall industrialization cannot drive the result. Among 453 inventors in the eight directly mapped technology classes, the female share of local employment predicts where women patented about twice as strongly as total industry size. Industry size also matters, but the share of women in the workforce matters more. Individual occupations confirm this for clothing, where the sample is largest: 37 of 70 inventors with a recorded occupation (53 percent) worked in a clothing trade themselves.[8] Marie Massart, born in Haut-Rhin where textiles dominated women's employment, patented a textile innovation. Marie Louise Trouilhas, born in Bouches-du-Rhône where the soap industry put women in contact with industrial chemistry, patented a chemical process. The result holds across seven alternative samples, including one that excludes Paris-born inventors.

The same local economy showed no detectable relationship with when women patented. Married women first patented at a median age of 41.5, compared with 30 for women who were unmarried at the time of first patent. Most of these "unmarried" inventors were not lifelong never-married women: among the 101 whose later marriage year is observed, 91 percent married after their first patent. The gap therefore reflects both the delaying effect of family formation and selection into later marriage among women who patented early. I test whether local conditions narrowed this gap. Regressions that account for birth decade show that female industrial employment, literacy, urbanization, population density, wage gaps, girls' school enrollment, and five other department-level variables are all unrelated to the age at first patent. The marriage gap was the same everywhere.

Among the 477 mothers with recorded children, 83.2 percent patented only after their last recorded child was born, with a median gap of 11 years between the last recorded birth and the first patent. Recorded family size showed only a weak relationship with patenting age, though genealogical records can miss births, especially when children died young, and I observe only women who eventually patented. The recorded null is

8 The figure rises to 93 percent among the 40 whose occupation named a specific trade rather than a managerial role; the remainder hold roles such as "working proprietor" that name an economic position rather than a product.

therefore consistent with no relationship between completed family size and patenting age, but cannot rule out that the pattern would change if women whom additional children kept out of patenting entirely could be observed. Raising children consumed time, but the knowledge women had acquired through work survived.

But while the marriage gap held across departments, the age at first patent fell across cohorts. Among mothers observable across ages 20 to 50, those who came of age around the 1844 patent reform patented about four years sooner than earlier cohorts. The shift coincides with falling age at first marriage (Perrin 2022b) and falling age at last birth across cohorts (Desjardins et al. 1994), and with a sequence of institutional changes that followed the 1844 reform (Galvez-Behar 2019): expanding girls' education (Perrin 2022a) and reforms from the 1880s onwards that gave married women greater financial autonomy (McMillan 2000; Lewis 1980).

Paper IV provides the clearest statement of the thesis's final two claims about direction and timing. Women patented in the sectors where women in their local economies worked, but the timing of first patenting was shaped instead by the life course: marriage and childbearing delayed entry into invention, while cohort change coincided with falling age at first marriage and with institutional changes following the 1844 reform. The genealogical linkage shows what individual-level data can tell about women's inventive lives that patent records alone cannot. The geographic finding, that patent addresses in centralized filing systems do not reliably indicate where inventors lived, matters for any study that maps innovation from administrative records.

6 Concluding discussion

The gender patenting gap in nineteenth-century France was produced less by exclusion at the patent office than by the unequal distribution of practical knowledge, collaborative networks, and time across the life course. Women patented where they worked. They moved beyond those fields when collaboration gave them access to new technological domains. They often patented only when marriage and childbearing had freed time to act on knowledge they had acquired much earlier. The patent office mattered, but the conditions that made invention possible were set elsewhere.

The first mechanism was direction. Comparing sectors within each inventor's birth department, I find that the female share of local employment predicted a woman's patent sector more strongly than industry size alone. Women did not patent randomly across the technological field. They patented in sectors where women around them handled materials, solved recurring production problems, and accumulated competence through work, household production, or family enterprise. Invention was not detached from women's economic lives. It arose within them. The gender patenting gap therefore began before any application was filed, in the earlier distribution of occupations, skills, and practical knowledge.

The second mechanism was scope. Collaboration did not mainly show up as higher post-collaboration productivity or novelty. Its durable effect was to widen technological range. Once inventors first collaborated, the share of their output outside their home technology class rose by about 35 percentage points and remained higher for years. Knowledge moved along specific collaborative ties, not through random exploration: post-collaboration solo patents appeared in a collaborator's technology class at far above the random rate. For women, the key problem was access. Women were more likely than men to remain outside the collaboration network, and when they did collaborate, family ties mattered disproportionately as an entry point. Men diversified mainly through a wider range of cross-class partners. Women diversified mainly through repeated, trusted ties to collaborators who had already crossed class boundaries. What differed was not how much inventors diversified once inside the network, but how they got in.

The third mechanism was timing. Married women filed their first patent at a median age of 41.5, compared with 30 for women who were unmarried at the time of first patent. Among mothers, 83.2 percent patented only after their last child was born, with a median lag of eleven years between the last birth and the first patent. Family formation delayed invention, but part of the married-unmarried gap also reflects life-course selection, since many women who patented while unmarried later married. What family formation delayed, it did not erase: the practical knowledge women had accumulated through work remained available once time constraints eased. The same point appears across cohorts. Among mothers observable across ages 20 to 50, the generation that came of age around the 1844 patent reform patented about four years sooner than earlier cohorts, a shift that coincided with falling age at first marriage across the nineteenth century (Perrin 2022b) and with institutional changes that widened women's room for economic action (Galvez-Behar 2019; McMillan 2000; Lewis 1980). Entry became easier. The underlying life-course constraint did not disappear.

One of the clearest results of the thesis is that direction and timing responded to different forces. The same local economy that predicted what women patented had no detectable relationship with when they patented. The local structure of women's work shaped the sectoral direction of invention. The life course shaped when invention could begin. Institutional reform shifted the cohort baseline without closing the individual gap. That separation is one of the clearest gains from linking patent records to demographic histories.

The thesis contributes to a long-running debate on how the French patent system should be understood. Khan argues that French institutions filtered access toward an elite of professionals and manufacturers, with artisans and workers accounting for 18.8 percent of patentees in her 1791–1855 sample (Khan 2020), and identifies manufacturing family firms as one route through which some wives and widows reached the patent office (Khan 2016). My evidence qualifies that reading. In the patent-level Paper II sample, 25 percent of female-lead patents with known lead-inventor occupations were filed by women from lower-skilled backgrounds and 31 percent by women in medium-skilled trades, a broader social base than an elite-only reading allows. The collaboration network was dispersed rather than organized around a few dominant brokers, and the apparent concentration of inventors in Paris turns out to reflect centralized filing through patent agents more than the true geography of invention. Family ties did matter, making up 35.8 percent of women's collaborative links compared to 8.8 percent for men, but they formed only part of a wider network through which women reached across technology classes. The French system was open by law and broader in social composition than earlier studies suggested. But openness at the patent office did not produce equality in the conditions that made patenting possible. Formal access and practical access were not the same thing.

This helps explain the stable aggregate gap. Across the full period 1791–1900, patents involving at least one woman accounted for 1.75 percent of all French patents. Read in isolation, that low aggregate share suggests little changed. A shift-share decomposition across the twenty technology classes between 1791–1844 and 1845–1900 shows a more complex pattern. Within classes, women's share rose by 0.324 percentage points after 1844. But patent growth shifted toward classes where women's presence was lower, above all Machinery and Precision Instruments, while several female-intensive classes declined in relative weight; this between-class reallocation subtracted 0.125 points. A small positive interaction term added 0.034 points. Taken together, these components yield a net increase of 0.232 percentage points, from 1.56 to 1.79 percent. The aggregate gap therefore appears stable only because gains within classes were partly offset by structural change across classes. Figure A.1 in the appendix shows the pattern by class.

One alternative reading would place more weight on differences in the value of patenting across sectors. If secrecy, brand, or first-mover advantage protected inventions more effectively in clothing, food, and domestic goods than formal monopoly rights ever could (Moser 2005, 2016), then part of the observed gap would reflect which inventions were worth patenting, not only who could invent. That possibility cannot be dismissed. But it does not fit the whole pattern. Women's share of patents was 1.75 percent in France, 1 percent in Britain, and under 0.5 percent in the United States: differences in patent systems, legal rights, and access conditions are more consistent with the cross-country spread than sector-level appropriation alone. Women's patenting also responded sharply when access became cheaper and legally easier. The 1844 French reform raised the probability of a patent being female-linked by 0.7 percentage points, a 40 percent rise over the base rate. In Britain, the 1883 Patents Act, together with the Married Women's Property Acts of 1870 and 1882, coincided with about a 750 percent rise in grants to women and more than doubled the female share of patents (Khan 2024). These reforms changed the cost and legal conditions of access, not the appropriation value of a clothing or textile patent.

Nor were these simply symbolic patents. Marie-Madeleine-Adélaïde Breton née Fournier, a Parisian midwife, patented in 1824 the feeding bottle redrawn on the cover of this thesis (INPI 1BA1048); she sold it from her shop, shipped it by mail with endorsements from members of the Académie royale de médecine, and defended her monopoly in court (Breton and Ratier 1826). Fifty-three years later, Madeleine Brès née Gebelin, daughter of a wheelwright from Bouillargues in the Gard, patented her own *biberon régulateur* (self-regulating feeding bottle) in three age-calibrated sizes and published its ninety-four-page memoir after becoming the first woman to defend a medical thesis for a French degree (Brès 1875, 1877). Marie Virginie Decroisette, a village *lingère* (linen seamstress) from the Somme, patented a vegetable-down wadding in 1844 and was selling it in Paris under her own name within months (Le Commerce 1844). Patents are an incomplete record of invention, but in this setting they are also a record of market-oriented inventive activity. The main constraint on women's patenting lay earlier: in the knowledge they could acquire, the ties they could enter, and the time they could find to use what they knew.

The mechanisms identified here also speak beyond nineteenth-century France. They are recognizable in the modern record. The motherhood penalty appears in mid-twentieth-century American science, where mothers' publication output declined during the years of early childcare and did not recover until children reached school age (Kim and Moser 2025); in Danish earnings under one of the world's most expansive parental-leave regimes, where the arrival of children opened a long-run gender earnings gap of around twenty percent (Kleven et al. 2019); and in Finnish patent records, where mothers' annual patenting rates fall by 65 percent after a first child (Pudas 2025), female inventors postpone childbearing in the years preceding their first filing, and the gender pay gap among inventors emerges years before patent filings (Pudas 2026). The direction mechanism is equally durable. In linked data on 70,000 American and Canadian scientists, Lubczyk and Moser (2025) show that the persistent innovation gender gap visible for scientists born from the 1920s onward is driven principally by women's sorting into research fields where patenting is rare, and estimate that gender parity in innovation would be reached in 38 rather than 118 years if women entered STEM at the same rate as men. That the same sorting and timing patterns appear in an economy without welfare states, parental leave, anti-discrimination law, or formal access to engineering means the modern findings cannot be fully accounted for by the institutions in which they have been observed. Institutional change still moves the gap, in 1844 France as in modern Finland. It does not close it. What recurs across these settings is older and more general than the institutions in which each generation has measured it.

The thesis also contributes methodologically. Research on gender and long-run development is constrained by sources that undercount women's work and make individual women difficult to trace across time. Here, the data work turns the full universe of nearly 390,000 French patents into a linked inventor-level resource: about 448,000 raw inventor-observations classified by entity type and deduplicated, yielding roughly 233,000 distinct male inventors and 4,165 distinct individual women, with 1,076 of the women further linked to demographic life histories drawn primarily from civil vital records. The gender comparisons in Papers II and III rest on the full population; the life-course analysis in Paper IV rests on the linked sub-sample. None of this removes the limits of patents as a source, nor the selectivity of genealogical linkage. But it makes it possible to study women inventors as a population and as people rather than as isolated names in an administrative record, and to compare them with men on a footing that the historical literature has not previously had.

Three next steps follow directly. One is to extend demographic linkage to men, to determine whether the life-course patterns identified here reflect parenthood more generally or a more distinctly gendered constraint. Another is to compare France with Britain and the United States, to test whether the mechanisms identified here depended on France's particular mix of artisanal production, centralized filing, and legal structure, or whether they were more general features of how women entered invention during industrialization. A third would refine the link between work and invention below the departmental level, matching inventors to the specific workshops, trades, and household enterprises in which their practical knowledge was formed. A natural complement to all three would be to link patents to trade directories and newspaper advertisements, to ask how often women carried their inventions from patent records into markets.

The patent office recorded the gender gap. It was not where the gap was produced. The gap was produced in the organization of work, the structure of collaboration, and the timing constraints of family life. It was produced before the patent application was ever written.

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Appendix

A Technology-class composition and the stable gender patenting gap

A shift-share decomposition of the aggregate female share of patents between 1791–1844 and 1845–1900 separates the change into within-class, between-class, and interaction components; magnitudes and interpretation are in Section 6.

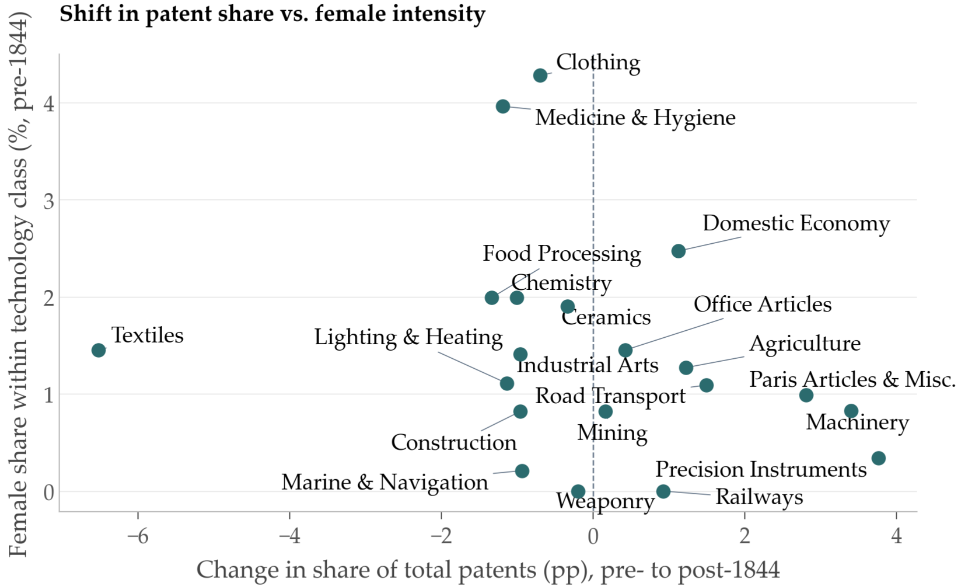

Figure A.1 Change in each sector's share of total patents (horizontal axis) plotted against the sector's pre-1844 female patent share (vertical axis). Sectors that grew fastest after 1844 had the lowest female patent shares. Sectors that shrank included several of the most female-intensive technology classes.

Papers

Author contributions

Paper I: Gender and the Long-Run Development Process. A Survey of the Literature

Co-authored with Faustine Perrin. The scope and structure of the review were developed jointly. The sections were divided by topic. Both authors contributed throughout and the conclusions were written together.

Paper II: Women Inventors: On the Origins of the Gender Patenting Gap

Co-authored with Faustine Perrin. The conceptualization and research design were developed jointly. I was responsible for the data collection and the machine learning classifications. Perrin contributed most of the theoretical framing. The analysis and the remainder of the paper were written jointly.

Paper III: What Happens When Inventors Collaborate? Evidence from 19th-Century French Patents

Single-authored.

Paper IV: What Shaped Women's Invention during Industrialization?

Single-authored.

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