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Abstract

Both theoretical and empirical economic studies have tended to underestimate incremental changes in consumer goods and design innovations that enhance allocative efficiency and structural dynamics. This paper empirically examines panel data comprising over 12,000 innovations by female patentees and participants in industrial fairs and prize-granting institutions in Britain, France and the United States during the nineteenth century. The sample uniquely allows for the systematic assessment of women's creativity within the nonmarket household sector. These records are compared with parallel samples of male inventors of some 60,000 patented and unpatented innovations. The analysis distinguishes between improvements in consumer final goods, changes in designs, and other forms of technological creativity. The results indicate that women were far more likely than men to be associated with innovations in consumer final goods and design-oriented products, and this was especially true of nonpatentees. Significantly, even those who did not work outside the home or sell their products in the market were engaged in devising such creative improvements to benefit their families. The results suggest that, rather than postulating a "gender gap," it might be more productive to assess women's economic activity on its own terms. A general implication of these findings is that, by inaccurately gauging the extent of consumer innovations within the household and in the market, economic research likely underestimates the extent of technological progress and advances in welfare.

Keywords: women inventors; incentives; institutions; technological innovation; technology policy; European industrialization
JEL Codes: B54, D12, L26, N40, O31, O33

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INTRODUCTION

"Women have been scientists and warriors, but there have never been any female inventors." --Voltaire[1]

The gender gap in technological achievements has never been as stark as the Voltaire epigraph might indicate, even in early France, but it remains persistent and pervasive in the twenty-first century. Many scholars have already produced significant research that illuminates women's contributions to technological improvements and their commercialization in different times and places. However, systematic examination of broad patterns and general tendencies has been quite limited, and more cross-national comparative analysis is needed to better understand female participation in the market for technology. My project therefore examines the sources and nature of technological discoveries by women in the three leading industrial nations of Britain, France and the United States, over the course of the nineteenth century.

Prior empirical research on women's inventive activity has primarily drawn on patent records. Patent fees and rules likely deterred many women inventors from participating in the patent system, especially in Europe where the cost of patent applications and grants was many times greater than annual per capita income. Accordingly, a different perspective on women and technology can be gained from combining patent records with less-restrictive industrial exhibitions that included unpatented inventions and innovations. This paper employs an extensive dataset comprising over 12,200 observations drawn from a dozen annual exhibitions throughout the United States and Europe, and includes information on women who were associated with patented discoveries, as well as innovations that would not have qualified for patent protection. These observations were matched with information from a number of other sources, including lawsuits, information about commercialization, city directories and manuscript population censuses.

[1] "On a vu des femmes très savantes comme il en fut de guerrières; mais il n'y en a jamais eu d'inventrices." Voltaire, Dictionnaire philosophique, Voltaire, éd. Lequien, 1829, tome 4, article « Femme », p. 354.

These extensive international data on female patentees and participants in industrial exhibitions offer unique insights on women's contributions to technological invention and innovation during the early industrial period. Systematic examination of the patterns for both patents and prizes at exhibitions illustrate ways in which women in all jurisdictions overcame institutional and cultural constraints and employed entrepreneurial abilities that ensured their inventions were valued in the marketplace. The results indicate that women's creativity in these jurisdictions were characterized by more similarities than differences. At the same time, inventive activity by American women inventors primarily reflected their comparative advantage in household and domestic innovations, whereas many Europeans exploited links with family firms to engage in extensive commercialization.

The results raise fundamental questions about conventional perspectives regarding the scope and nature of technological innovation. The economic analysis of technological advances typically fails to capture improvements in consumer final goods and designs. Moreover, a general lacuna exists in empirical scholarship regarding creativity that lies at the border aesthetics and utility, of art and technology narrowly defined. In particular, the "machine-centric" orientation of patent rules and records frequently misses subtle changes in consumer final goods, especially in the case of product designs that extend beyond alterations in the visual appearance of the item. As this study shows, women tend to make disproportionately greater contributions in just such areas, and part of the gender gap owes to the analytical gap in current approaches to technological innovation.

THE SCOPE AND NATURE OF TECHNOLOGICAL CREATIVITY

"A newe way by her invented"
--Amy Everard (1637)

The conventional approach to the economics of technology centers on advances in producer goods and inputs that cause outward shifts in the production possibility frontier of a society. This form of productive efficiency increases social welfare by leading to higher output for given amounts of inputs. A number of theorists (Romer 1990, Grossman and Helpman 1991, Gualerzi 2012) have incorporated consumer goods in their models of economic growth. Luigi Pasinetti (1981), in particular, highlights the

central and mutually reinforcing roles of demand, consumption, and human learning in attaining dynamic growth outcomes. Allocative efficiency, on the other hand, comprises movements along the production possibility frontier, that improve consumer welfare without increasing productive possibilities, holding other things constant. Although it is acknowledged that improvements in the nature and quality of consumer products and design innovations might have a direct impact on household utility, such innovations are difficult to measure and quantify. Both theoretical and empirical economic studies have tended to underestimate incremental changes in consumer goods and design innovations that enhance allocative efficiency and structural dynamics.

During the past decade, significant advances have been made in the economic analysis of new goods (Bresnahan and Gordon 2008). Tratjenberg (1989) usefully assesses the uniqueness and degree of substitutability of one product relative to others in the same class. At the same time, many of these studies evince a bias towards the "great invention" model of technological change, which characterizes inventions in terms of discontinuities, and ignores or dismisses the incremental nature of all inventive activity.[2] Bresnahan and Gordon (2008, p. 12), for instance, contend that fundamental differences exist between "new goods which open up whole new product categories and other new goods which increase quality or variety within product categories …new goods that establish entire new categories (like the automobile) will be economically more important than improvements that occur within categories." This tendency to organize technological innovation in terms of broad categories or macroinventions -- "the" jet plane, telephone, radio, automobile, or computer -- has negative implications for the economic analysis and valuation of women's technological contributions, which tend to lie within and at the boundaries of such categories.[3]

A similar orientation was evident among nineteenth-century feminists. This group had the political objective of promoting equality by highlighting heroines of invention. They seized on examples

[2] Khan and Sokoloff provide an empirical analysis of supposed "great inventors" and demonstrate the incremental nature of conventional great inventions, and the similarity of "great inventors" to their "ordinary" counterparts.
[3] For a discussion of "macroinventions" and "microinventions" see Joel Mokyr, Lever of Riches: Technological Creativity and Economic Progress, New York: Oxford University Press, 1992.

of women, however atypical, who fulfilled their conceptual requirements, rather basing their strategies on the reality of representative patterns.[4] Accordingly, they idealized women who patented "great inventions," or technically demanding machines that were regarded as comparable with the most valuable men's discoveries; and determined "to make no note of the inventions of women unless it is something quite distinguished and brilliant. We must not call attention to anything that would cause us to lose ground."[5] The women's movement increasingly denigrated traditionally female activities such as housework, and attempted to downplay the importance of incremental "feminine technologies."[6] The organizers of the Women's Pavilion at the World's Columbian Exposition in 1893 were concerned to find that their submissions largely comprised ordinary household products such as kitchen tools and apparel. As an official *Women's Bureau Bulletin* declared: "If the steady increase in the numbers of patents granted women is accounted for merely by the increase in the number of patented hairpins, hair curlers, and such trifles in feminine equipment, it is without large significance either to civilization or as an indication of women's inventive abilities."[7]

Traditional economic theory has additional shortcomings when applied to a historical context. For instance, the analytical bias towards free trade based on comparative advantage implies that mercantilism and nationalism are regarded as inefficient. The United States was the first country to offer patent protection that was contingent on a global definition of novelty; that is, the invention had to be new to the world. However, mercantilism was a central approach of European societies in the nineteenth century, that was also evident in their technology policies. As such, novelty in technological innovation was limited within national boundaries, and their objective was often to re-create, or offer patents of

[4] Judith McGaw, "Inventors and other Great Women," p. 219: "Similarly, emphasizing woman's capacity to invent outside the domestic sphere, an approach characteristic of earlier feminist efforts and one that shapes Macdonald's and also Stanley's work, evidently left popular conceptions of inventors and invention virtually unaltered."
[5] Cited in Jeanne Weiman, The Fair Women. Chicago: Academy, 1981, p. 429.
[6] Reva Siegel, "Home as Work: The First Woman's Rights Claims Concerning Wives Household Labor, 1850–1880," vol. 103 Yale Law Journal (1994): 1073–1217.
[7] U.S. Department of Labor. Women's Contributions in the Field of Invention. Women's Bureau Bulletin, No. 28. Washington, D.C.: GPO, 1923, p. 13.

importation for, foreign technologies that could have been obtained through free trade.[8] Within the context of a closed economy, the re-creation of goods increased domestic consumption possibilities; whereas, from a global perspective, such imitation did not add to net social welfare. This form of import substitution was especially directed toward designs, dyes, colours, the decorative arts, and luxury goods where women's innovations were disproportionately represented.

Scholars in the history of technology and gender studies have directed a great deal of attention to the question of how to adequately capture the contributions of women (Bray 2013). Judith McGaw (1996), for example, calls for an extension of the scope of technology beyond hardware, to incorporate the skills and knowledge that belong to women. However, her discussion of "feminine technologies" seems equally narrowly focused, highlighting innovations related to women's biological and social differences.[9] Gearhart-Sema (2016) argues that women "should not have to inhabit the largely Western- and male-dominated paradigm of the scientific inventor," and that policy and efforts to understand female creativity should encompass traditional knowledge. The feminist perspective has only recently broadened their conception of what constitutes technology to also incorporate design studies (Wajcman 2000, Shepard 2012).[10] As such, both from an economic and social perspective, it is useful to highlight the technological activities of women in Britain and Europe in terms of their contributions to consumer and design-related innovations.

[8] At the Royal Society of Arts, early awards were offered for the domestic production of verdigris, Turkey red dyes, madder, and marbled paper that was of similar quality to the items imported from Europe (Khan 2016). In France, Mlle Manceau received awards from the Industrial Expositions and the Conservatory for Arts and Trades because her firm re-created a type of bonnet that was original to Italy. She was able to export the bonnets to other cities in Europe, the United States, and "remarkably" to Naples and Florence as well, possibly because of the lower price of her products.

[9] McGaw, Judith A., "Reconceiving technology: why feminine technologies matter," Gender and archaeology (1996): 52-75. Gearhart-Sema, Terra L. "Women's Work, Women's Knowing: Intellectual Property and the Recognition of Women's Traditional Knowledge," Yale Journal of Law & Feminism 21.2 (2016): 374-403.

[10] The Maryland Institute noted that "there is in woman's mind and hand full capacity for excellence in the art of Design, and that the practice of them is congenial to her sphere" (Annual Report of the Board of Managers, Maryland Institute for the Promotion of the Mechanic Arts, 1850, p. 110).

PATENT SYSTEMS AND EXHIBITIONS

"Go invent something, for it pays much better"
--New York World (1889)[11]

Institutions, or the rules and standards that frame human interaction, create opportunities and boundaries for women that have varied by place and time. In order to better understand the fundamental aspects of women's experience regarding technological innovations, it is therefore necessary to adopt a comparative perspective. The data sets for this study (see Appendix for specific details) comprise the most extensive sample of women inventors and innovators to date, comprising over 12,200 observations across three countries during the entire period of the first and second industrial revolutions. The measures of women's contributions were drawn from patent records and from numerous exhibits at industrial expositions, and include the type of invention, commercialization, co-inventors, prizes that were awarded, litigation, and inventive careers.[12]

Patents have been widely used by economists as a systematic measure of some types of inventive activity, and their sales or licensing allow us insights into the market for technology. These data are especially valuable because they enable women, who are typically invisible to history owing to a lack of documentation, to become visible once again (Khan 2016a). At the same time, patent protection is limited to inventions that fall within the set of items that satisfy the rules for patentability, which implies that certain types of creativity are not represented. It is difficult to find analogous information about technological discovery and commercialization outside the patent system, but many historians and economists have used exhibits and prizes from industrial exhibitions as a means of gauging various sorts of creativity (Warner 1979, Darney 1982, Cordato 1989, Moser and Nicholas 2013). Patent systems differ across countries, and the laws and their enforcement have also changed over time, whereas

[11] The epigraph is from an article about a woman patentee who manufactured little bags to hold powder puffs that "filled a long felt want," and "now advises women who toil at fancy work for the shops for a pittance to 'go invent something, for it pays much better'." The story was reprinted in the Daily Tribune of Bismarck, North Dakota (Thursday, October 31, 1889). The first woman from this state to obtain a patent was Ella G. de Laney, of Conway, who invented an improvement in kettle-cleaners (Patent No. 560,060, dated May 12, 1896).

[12] These data were supplemented by additional information that were obtained from biographies, city directories and from manuscript population censuses, which offered details about occupations, age, marital status, households, wealth, and location, among others.

industrial exhibitions were even more variable in terms of their coverage and operation, so it is important to first discuss the nature of these institutions (Khan 2013).

Today it is difficult to retrieve further information about female pioneers who devised new inventions and innovations. Patent records offer an admittedly narrow window on inventive activity by women, but even this limited glimpse often reveals significant systematic details that cannot be replicated elsewhere (Khan 2016b). English patentees Sara Jerom and William Webb filed in 1635 for legal protection for a machine to slice wood into thin pieces to make items such as bandboxes. Two years later, the patent specification (description) of Amy Everard, a widow, declared her intention "to use and exercise within England and Wales the mistery, skill, and invention of making, ordering, or contriving of saffron into a manner or forme which shall dissolve into tincture and of divers other vegetables (as of roses, gilliflowers, and the like), into an essence, after a newe way by her invented." The British patent records also indicate that the 1715 and 1716 patents to Thomas Masters of Philadelphia, for a means of curing Indian corn and for making straw bonnets, were obtained on behalf of his wife Sybilla, who was thus the first patentee in the American colonies.

The British patent system has been in continuous operation since 1624, when the Statute of Monopolies offered patent grants for fourteen years (Khan 2005). The registration system did not require examination about whether the applicant was the true inventor, and patents were often bestowed on individuals who simply acquired an invention, such as importers of foreign discoveries.[13] Early on, before the system was reformed in 1852, procedures for obtaining a patent were extremely costly in terms of time and money, requiring the payment of fees varying from £100 (four times per capita income at mid-century) to £300. Patent agents and lawyers could help to negotiate the bureaucracy and legal pitfalls, but at an additional cost. The system also inhibited the diffusion of information, and made it difficult for inventors outside of London to conduct patent searches, increasing the likelihood that their property rights would later be subject to adverse judicial rulings. Reforms in the system occurred in 1852

[13] For both buyers and sellers of patent rights, the legal and economic risks associated with a registration system likely reduced the net expected value of trade in the market for inventions (Khan 2005, 2013).

and in 1884. The patent application process was rationalized in one Patent Office, and patent term varied according to willingness to pay for extensions.[14] The time series (Figure 1a) shows that these changes had a significant impact on all inventors, including women patentees. The patterns suggest that the cheaper patents after 1884 disproportionately benefited women, who typically would have had lower financial resources and access to capital markets.

The French patent system was similar to the British, but French women were relatively more successful at negotiating the process of obtaining patent rights and appropriating returns from their efforts, in part because of association with family firms (Khan 2016a).[15] The proportion of patents that was issued to women increased substantially after the 1844 legal reforms, rising from 1.6 percent to 3.0 percent of total grants in France. Despite the significantly higher fees for long-term protection, French women were more likely than men to file for these higher-valued patents. Working requirements meant that, at least according to the law, the invention had to be put into practice within two years from the initial grant; however, enforcement was likely lax, since the patentee could point to unforeseen events which had prevented complying with the provisions of the law. French rules about access likewise made it difficult to obtain information about patented inventions, because viewers had to state their motives; foreigners had to be assisted by French attorneys; and no extract from the manuscript could be copied until the patent had expired. Patent assignment documents were filed in the office of the Prefect for the district, but since there was no central source of information it was difficult to trace the records for specific inventions. If the patent was assigned the annual fees for the entire term of the patent had to be paid in advance. In short, in both Britain and France, wealthy inventors clearly had a greater ability to file for patent protection, to commercialize their inventions, and to enforce their rights at law.

[14] The initial grant was contingent on a payment of £25, an extra £50 was due after three years, and after seven years patentees were required to pay £100 to maintain the patent to full term. The costs fell further after 1883, when only £4 was charged for the initial term of four years, and the remaining £150 could be paid in annual increments.

[15] Access to property rights in invention was also hampered by fees that were several multiples of average income, and the registration system left the sorting of claims about priority, novelty, and general validity to the costly arena of the courts. The 1791 statute stipulated patent fees from 300 livres through 1500 livres, based on the declared term of the patent. After the reforms of 1844, fees fell but were still out of reach of the working class, ranging from 500 francs ($100) for a five-year patent, 1,000 francs for a ten-year patent and 1,500 for a patent of fifteen years, payable in annual installments.

The United States patent policy made a deliberate departure from such European precedents (Khan 2005). The American patent system stood out as offering strong incentives for inventive activity, regardless of the identity of the inventor.[16] As a result, in the federal patent system, creative women had the same standing as their male counterparts. The examination system that was set in place in 1836 enabled early reviews of the basic validity of the patent grant, and the judicial system strongly enforced patents that had survived this technical filter. In a significant departure from Britain and France, only the true inventor was permitted to apply for patent protection, so U.S. patent records offer more accurate indexes of inventive activity by women.[17] U.S. patent fees were not intended to provide revenues for the state, and were deliberately kept low so that the filter was technical creativity, not financial standing. Patentees in the nineteenth century paid a fee of $30 to $35 to the Patent Office (average per capita income nationally was approximately $128 at this time, and $180 in the inventive Northeast region.) Another important feature of the U.S. system was that it was extremely favorable to trade in patent rights, and markets for inventions were the most developed in the world (Khan 2013a, Lamoreaux and Sokoloff 1996). Strong enforcement of these property rights, and efficient capital markets, meant that impecunious creators of useful inventions were readily able to find outside capital to fund their patent applications and ventures. American institutions also encouraged cumulative invention and trade in technology by requiring immediate public disclosure of the specifications of patents, and by helping to widely disseminate this information.

Patent records offer invaluable insights, but also have well-known problems as measures of inventive activity. Most significantly, some inventions are not patentable, not all inventors apply for patents and the propensity to patent differs across countries, industries and individuals, and patented

[16] The text of the first U.S. Patent Act of 1790 specified "That upon the petition of any person or persons that **he, she, or they**, hath invented of discovered any useful art, . . . it shall be lawful . . . to cause letters patent to be made out in the name of the United States" (my emphasis).

[17] For instance, Ella E. Boland's British patent for a curtain pole bracket included Joseph Boland, her husband, as a co-inventor whereas, in order to avoid invalidity, her U.S. patent was in her name alone. U.S. Letters Patent No. 593,920, dated November 16, 1897; and GB189726731 (A) 1898-02-12, the specification of which notes that the invention was intended "to avoid the necessity of climbing upon chairs, tables, and step ladders which are dangerous and inconvenient for any one and especially for ladies." She sold half of the patent rights to her U.S. patent to a merchant tailor in Pittsburgh. Ella Boland also bought the rights to another curtain pole patent belonging to Otto E. Wagener, suggesting efforts at commercialization of the invented item.

inventions vary greatly in terms of value. One way to supplement patent information is to consider prize-granting institutions, although these are associated with their own drawbacks (Khan 2013, 2015, 2016). Exhibitions, for instance, did not require potential exhibitors to pay entry fees, and thus provide information on a larger and more diverse population of innovations. Panels of judges in decentralized committees granted prizes, based on a wide array of criteria that ranged from novelty to the characteristics of the entrants.[18] There were minimal rules about the identities of the exhibitors, and no examination process for eligibility of exhibits, so these fairs were functionally equivalent to low-cost registration systems.

As the Appendix shows, the nonpatent sources used in this study cover both international and national sources, including the Royal Society of Arts in England, the Exhibitions of National Industry in France, the Paris Universal Exhibition of 1855, 1876 Centennial Exhibition and the 1893 World's Columbian Exposition. Mechanics' institutes in the United States sponsored industrial fairs in most large American cities, on a roughly annual or biennial basis, and these were sampled to construct a panel data set of technological innovations from major cities—including Boston, New York, Philadelphia, San Francisco, Cincinnati, and St. Louis—over the course of the nineteenth century. The organizers of many industrial exhibitions encouraged women to submit entries, expecting that their "taste and delicacy" would lead to visually appealing displays that would attract more visitors to the events. Special gallery spaces were often set aside for a "Woman's Department," with the intention of encouraging female participation.[19] These unpatented innovations illustrate that considerable and diverse creativity was indeed occurring outside the formal patent system, and the records of exhibits are especially useful for identifying innovations with subject matter that was not eligible for a patent.

[18] The Centennial rules, for example, provided that "awards should be based upon inherent and comparative merit; the elements of merit being held to include considerations relating to originality, invention, discovery, utility, quality, skill, workmanship, fitness for the purposes intended, adaptation to public wants, economy and cost." (Report of the United States Centennial Commission, J.B. Lippincott, 1877, p. 15.)

[19] See the Report of the Exhibition, 1887, p. 16. "Another notable feature of the Exposition were the inventions of women. It has been so often reiterated that women are not inventors, that many have fallen into the trap of believing the statement. To all such, the eye evidence which they received at the Fair, that the inventive genius of women is rapidly developing, will be a beneficial correction of their misapprehension" (*The Repository*, vol 51, 1874, p. 396).

In all three countries, a significant gender gap is evident in women's patenting relative to patents filed by men, over the entire period (Figure 1). However, the variation in women's patenting is similar to the general population of inventors, suggesting that women responded to many of the same factors.[20] This is not to say that the experience of male and female inventors was identical. One notable exception relates to legal rules, which comprise a significant institution that can constrain or enable inventive activity and innovation. During much of the nineteenth-century, while single women had the same legal rights as men, married women in all three countries were subject to the rules of coverture, which vested legal rights in their husband (Khan 1996, 2016a).[21] Coverture affected women's economic activities negatively: legal reforms that removed such laws altered the economic costs and benefits associated with women's involvement in commercial activity, and significantly increased inventive activity by female patentees (Khan 1996). Similarly, women's entrepreneurship was likely constrained by their legal disability under the law. Investors and creditors would be less inclined to offer funding if they were uncertain about their ability to enforce their rights, leading to far greater capital imperfections for women relative to men.[22]

GENERAL PATTERNS OF INNOVATION

"The world is in perpetual motion, and we must invent the things of tomorrow… Act with audacity."
-- Barbe-Nicole Clicquot Ponsardin (1777-1866)[23]

[20] For instance, patenting for both men and women was responsive to major economic cycles (Sokoloff 1988, Khan 2005). Like other patentees, women inventors appear to have varied their efforts to accommodate changes in market demand and expected profitability (Khan 2000).

[21] By law, a woman's husband controlled any property she owned or acquired, as well as her earnings and wealth. Married women were prohibited from entering into contracts, could not be sued, and could trade on their own account only if authorized by their husband.

[22] Commercial exploitation of patented innovations depended on the right to contract, to produce the invented article, to assign or purchase patent rights, and to prosecute infringers. The implications for women in business were sufficiently important that entire legal treatises were directed to the analysis of the law towards the wives of businessmen, including those who were active partners in the family firm. See, for instance Bressolles, Paul, De la femme du commerçant : examen critique de la jurisprudence, Paris: Rousseau, 1888.

[23] Cited in Tilar J. Mazzeo, The Widow Clicquot: The Story of a Champagne Empire and the Woman Who Ruled It, New York: Harper Collins, 2008, p. 181.

As economic actors, nineteenth-century women have a visible presence largely as unskilled workers in factories, as sole proprietors, petty producers and, to a lesser extent, as passive investors in securities markets. Middle-class women, in particular, have often been characterized as members of a "separate sphere" who had retreated from activity in the market economy in accordance with social norms. The patent and exhibition records reveal a much more complex reality, in which women of all backgrounds and marital status were engaged in creative endeavours that encompassed the entire range of technological discovery, from conception through commercialization. As contemporary feminists highlighted, a number of women's inventions were technically-sophisticated and made lasting contributions to industrial machines and production innovations. However, this emphasis on male-equivalence overlooked or actively disregarded the fact that the majority of women's inventions exploited their comparative advantage in household activities and consumer-oriented technologies.

Table 1 provides summary statistics on patenting by women in the three countries, which reveals a striking similarity among the central tendencies (and the exhibitions data also mirror the general patterns for these variables). The majority of these female inventors were or had been married, although the percentage of single women inventors is marginally higher than in the age-specific general population.[24] Significantly, even those who did not work outside the home were engaged in devising creative improvements. As such, rather than retreating to a "separate sphere," these women worked in a context that productively combined household and nonhousehold activities. Families often provided resources and a social context that had the potential to increase women's inventive activities.[25] French women inventors demonstrated greater productivity at both invention and commercialization, in part

[24] Marriage for women was more common in the United States, where both the age at first marriage and the proportion of never-married "spinsters" were lower than in Europe (Hussey and Ponsonby, 2016). Clark (2016) employs a sample of English women authors, 44 percent of whom were single, although the sample size is very small (144 born from 1800-1880).

[25] Women patentees could and did benefit from family resources, regardless of their marital status, especially in the case of wealthy households. For instance, the Honourable Maude Agnes Lawrence, of Belgravia, in 1911 was living at home with her elderly mother and 14 servants, including a butler. Lawrence was appointed Director of Women Establishments, H.M. Treasury, and made a DBE in 1926. Her estate was valued at £172, 382 at her death in 1933.

because they were able to exploit family connections, as well as the tangible and intangible assets of relatives and of family businesses (Khan 2016). For instance, the 1881 UK census shows that the 30-year old housewife Caroline Newman Bintcliffe was married to a builder, and living in the same London household as her brother-in-law Harry Parkins, a manufacturer of stationery. In 1897, she obtained a patent for envelopes, which records her occupation as a stationer. By the census of 1911, a family business had developed, where Caroline was now a "manufacturing stationer," assisted by her adult son.

The data on co-inventors in the Table reflects some of the mechanisms that promoted inventive activity by women. The majority of U.S. women patentees (92.4 percent) had no co-inventors, indicating the independent nature of female inventive activity, and this was also true to a lesser extent for the French and British inventors (74.5 and 81.7 percent, respectively). The Prest siblings -- Thomas, James and Mary – of Blackburn, Lancaster, were all joint applicants for an 1898 patent to protect their improvements in cycle tyres. Less common was the example of the sisters Eva and Cecilia MacKenzie of Inverness, who together obtained six patents between 1895 and 1913, including two improvements in hairpins that included their mother Mrs. Georgina MacKenzie.[26] A significant fraction of multiple-inventor patents included unrelated males, typically from the same geographical location. Many of the co-inventor listings in the United States testified to women's collaborations with machinists, engineers, pattern makers, toolmakers, manufacturers, and artisans, who, according to patent law, were required to have made a substantive contribution to the invention in order to be granted co-inventor status.

Women inventors who intended to financially benefit from their efforts also benefited from markets in patents. The ability to assign part of their property rights provided a means of compensating intermediaries who helped with funding, advice on commercialization, and litigation about property rights and related issues. Intermediaries helped inventors to mobilize venture capital and to exploit their

[26] By 1911, when they applied for another patent for improvements in ladies' and children's apparel, the sisters listed their occupation as "manufacturers." In France, Madame Houel and her daughter provide insights into the relationship between entrepreneurial mothers and their children. Mme Houel received a favourable citation from the jury at the 1823 exposition in Paris. She had created a form of paint that dried quickly without a strong smell, which could be used on wood and metal. In 1839, her daughter exhibited her own improvements on this paint, for which the jury granted her a bronze medal.

inventions in other ways, and some also took positions in inventions as partners or outright owners. For instance, Maria Beasley transferred part of the rights in an uncompleted invention to James Henry of Philadelphia, in exchange for advance financing to complete her machine. Patentees in need of the services of lawyers who might help with such transactions as foreign patent filing were able to pay upfront, by assigning part of their patent rights. Alberta Mary Caspar of London, England obtained an 1884 patent (GB13442) for improvements in imitation stained glass; when she proceeded to file for an American patent a few months later, she assigned half of her patent right to Eugene Pearl, a patent lawyer in New York.[27] The tendency to file for patent rights in foreign countries may be regarded as an index of higher-valued inventions, so it is worth noting that 22.2 percent of the U.K. women's patents came from overseas, primarily from the United States. Foreign women who entered the competitive American market were likely associated with inventions that were in the higher tails of the distribution for expected returns.

The number of patents per person indicates greater investments in inventive capital and professionalism in patenting activity. The patterns for multiple inventions (as gauged by both patents and exhibits) are significantly different in France, relative to the other two countries. In Britain and the United States, two-thirds of women's patents were issued to inventors who never filed a second patent, whereas almost three-quarters of French patents (including improvements) were for multiple patents. For instance, Sophie-Geneviève Mercier obtained 15 patents between 1842 and 1855, the majority for various inventions to treat laundry, and two for cleaning cutlery, which all required some familiarity with chemical processing. In France, professional patenting was associated with greater ownership of manufacturing companies and other related businesses (Khan 2016a). In short, women were active on both sides of the market for inventive rights, as buyers and sellers, and as recipients of titles on behalf of their firms.

[27] US340485A, which was granted in 1886. This patent received two citations in patent documents belonging to inventors from the late twentieth century, indicating that it was a somewhat influential technology.

Table 2 suggests that participation in business and in the labour market provided obvious advantages for women that furthered their ability to appropriate returns from their creativity. Still, in an era when labour force participation rates were low for married women, it is illuminating to find evidence in these records for significant entrepreneurial and commercial activities among the participants in patenting and exhibiting of inventions. Entrepreneurship requires flexibility to meet new opportunities, and this characteristic can be observed in many of the women in this sample -- indeed, one might argue that all individuals who participated in patenting or exhibitions had to some extent demonstrated entrepreneurial abilities. This is especially evident in the French context, where manufacturers accounted for a disproportionate number of occupations (47.4 percent of patentees and 62.6 percent of exhibitors). For instance, the Joly sisters obtained a full-term patent on corsets, and listed themselves as corset-makers in 1848; however, by 1853 the sisters were manufacturing envelopes that were secure enough to use for confidential business transactions, for which they had obtained another patent. The exhibitions data are also valuable for revealing women's activities in commercialization and innovation. Mme Désirée Debuchy inherited a large-scale and prosperous textile-making enterprise in Tourcoing (Nord), which under the ownership of her husband, had won medals each year from 1827 up to the time of his death. Under her management, the juries at the 1849 and 1855 exhibitions rewarded the products for their good taste, low prices, success in the marketplace, and their competitiveness with English goods.

The much higher fees for patents likely explains the frequency of the professional and teaching classes among the European women patentees, relative to the United States. The democratic nature of the American patent system is evident in the higher percentage of patentees from the artisan and worker classes (26.9), as compared to Britain (8.8) and France (10.6). These patterns are reinforced by the difference in the occupations of women who obtained patents, and those who participated in exhibitions, which were much less costly and therefore associated with lower financial barriers. The proportion of professional women/teachers is roughly the same for patents and exhibitions in the United States; but varies markedly in France, where this category accounts for 23.2 percent of known occupations for patentees, and just 6.3 percent for exhibitors. Of course, not all innovative women had formal

occupations. In the United States, 33.7 percent of female patentees who could be traced were listed as keeping house or without occupations, relative to 45.7 percent in the U.K., and 38.0 percent in France. As might be expected, this figure is higher for participants in exhibitions.

Prior research into the occupations and patenting of ordinary and "great inventors" indicates that the majority tended to produce job-related inventions (Khan and Sokoloff 1993, Khan 2005), suggesting a correlation between occupation and industry. The industrial distribution of patents filed by working women yields evidence that female inventive activity was related to experience they had obtained in the course of their jobs, but their inventions also responded to perceived market demand. Elizabeth Barnston Parnell of Sydney, Australia, a professional metallurgist, obtained several British patents for her improved methods of processing ores and furnaces, which met a need in the production of complex minerals with sulphides of copper, lead, zinc, silver and antimony. The E.B. Parnell Sulphur process, and an improved furnace, were successful in trial experiments, and created a great deal of interest among investors. Lizzie H. Goggs, an art dealer in Liverpool, obtained a patent for making metallic paints, along with T. T. Irvine, her partner in The Fine Art Company. A more esoteric example is offered by Elizabeth French, a medium and practitioner of "galvanic medicine," who obtained an 1875 U.S. patent for an electro-therapeutic device, that received some nine long-term patent citations.

Manufacturers were also likely to be responsible for inventions that were related to their enterprises. For instance, Martha Kerr, a manufacturer of washing machines in Liverpool, filed a patent claim for a spring lever washing machine. French widows who inherited businesses that had been founded or managed by their husbands, in particular, were the least likely to offer exhibits in traditionally female industries such as apparel and household items; instead, 18.1 percent of their awards were in technical fields, and one-third were in the textile industry (Khan 2016a). Similarly, Eliza Rippingille became the head of a flourishing lamp and stove manufacturing company when her husband and father-in-law both died on the same day, and she obtained a patent along with the foreman of the Aston Brook Lamp Works,

the Birmingham branch.[28] However, the causality was sometimes reversed, when inventors established manufacturing enterprises to appropriate returns from their inventive activity, either on their own accord, or along with partners and investors who provided financial or physical capital to float the business.

Nevertheless, since all women participated in household activity, it is not surprising that, regardless of their formal occupations, a significant fraction of their contributions were related to personal experience and to their role in the home and the family. Victoria Isabella Heliodora Bundsen, an internationally famous opera singer and prima donna alto, obtained a British patent in 1898, for a folding umbrella. Lydia Huntley Sigourney, a notable American "poetess" from Hartford, Connecticut, exhibited an improved silk stocking, at the Massachusetts Mechanics Institute in 1853. Sophronia Dodge, a resident of the state of Iowa which suffers from cold winters, patented an appliance in 1872 for raising dough that "does the work thoroughly and perfectly in the coldest weather." Eliza Scofield Wood, an American farmer's wife, invented a wring mop bucket, for which she submitted two patents, in 1889 and 1891. This household-orientation was especially evident in the case of exhibitions, where women of all backgrounds tended to display unique works of arts and craft, clothing, household and domestic enterprise. When Margaret P. Colvin of Battle Creek, Michigan, exhibited the Triumph rotary washing machine at the Philadelphia Centennial Exhibition, she noted that her invention was "the successful result of years of experiment by a practical woman, to accomplish the perfect cleansing of all fabrics, from carpets to laces, without rubbing. With this machine, a child of twelve years can do more work, and do it better, than two women by ordinary methods."

CONSUMER TECHNOLOGIES AND DESIGN INNOVATIONS

[28] The Rippingilles were noted for their manufacturing of such appliances (advertised as "world renowned patent oil cooking & warming stokes, lamps, &c.")

> "It is need in the market that causes industrial progress. When a need manifests itself, everyone starts working to develop a solution." –Universal Exposition, 1855[29]

According to some scholars, in the nineteenth century a specialization by gender was evident, whereby men were associated with "production, competition, and material gain," whereas women belonged to a sphere that encompassed "ideal virtues, beauty, and consumption" (Owen 2001, p. 16). At the same time, such dichotomies fail to capture the interactions between production and consumption, and the similarities between material incentives and the desire (at times competitive) to improve household welfare through innovations. An alternative approach might suggest that it is both need in the market and need in the household that causes social progress. Khan (2000), for instance, shows how women on the American frontier disproportionately devised improvements to remedy their lack of access to household help. The data on the industrial distribution of inventions and innovations, as well as the information on women's occupations, allow us to explore such issues and the distinctive nature of female creativity in this era.

The information in the prior section already showed that feminine technologies were likely to vary significantly from those of male inventors, especially in the context of unpatented innovations. The category of arts and education in Table 3 comprises a stark distinction between the industrial allocation of women's inventions at exhibitions and patents, most evident in the 86.7 percent of the entries attributed to women who applied for awards at the Royal Society of Arts in London. Among the inventors who worked outside the home, a third of the women exhibitors in the United States were identified in official records as professional artists and designers. Many of these artists, who were responsible for the patenting of such items as corsets, tapestries, and apparel inventions, were devising improvements at the boundary of design, art and technology. These descriptive statistics suggest that an understanding of "feminine ingenuity" requires a broader perspective than the conventional focus on production technologies, machinery and industrial inventions, that dominate the patent records and empirical research in the history of technology.

[29] Rapport sur l'exposition universelle de 1855 présenté à l'Empereur, Paris: 1856, p.148.

This section therefore considers the patterns of women's inventive activity and innovation in terms of their contributions to consumer final goods and improvements in designs.[30] Table 4 categorizes the observations from both the patent records and from the exhibitions to show the proportion of entries that could be regarded as consumer-oriented; as well as design inventions that had been granted utility patents, which could constitute either consumer or producer innovations. About 46.1 percent of the patented inventions in France were consumer final goods, a figure that did not diverge greatly from the 43.4 percent for the United Kingdom. American patents by women were significantly less likely to be consumer-oriented, but still comprised almost one third of all inventions. As might be expected, the proportion of utility patents that were related to changes in designs was lower than was the case for consumer final goods, and these patterns were more similar across countries.

Patents for corsets, bonnets, skirts, shoes, and other forms of apparel accounted for a fifth of the patents filed in all three countries (Table 3).[31] Some of these grants were for machinery and producer

[30] The current study is based solely on utility patents (granted for new and useful functional improvements); and does not include design patents, copyrights or trademarks. However, it is interesting to note that, in the United States, patterns for design patents are similar to utility patents, since women accounted for just 3.2 percent of designs granted in 1900, and 13.1 percent in 1995 (Howard and Eric Setliff 2000, p. 269). The law of product designs and commercial art requires a precarious balance on the borders of patent, copyright, and trademark laws. French protection of the work of silkworker guilds in 1711 evolved into the pioneering design law of 1806, but some items could still be copyrighted. In England, designs were first covered by the copyright protection laws of 1787. The 1862 case in the Circuit Court of New York, Jonas Drury And Lavinia Drury, His Wife, V. John Ewing And Sarah 0. Ewing, His Wife, Et Al. illustrates that some design innovations were also covered by copyright (Lavinia Drury had copyrighted a "system of taking measures for, and cutting ladies' dresses, with instructions for its practical use," which the defendants had infringed, and was issued an injunction.) In the 1880 census, Lavinia Drury's occupation is listed as an "inventor of scale for cutting garments," and she exhibited both inventions at exhibitions and county fairs in Ohio.

The U.S. statute of 1842 allowed for the protection of industrial designs, but early patent examiners found it difficult to distinguish between utility and aesthetics. Several hundred design patents actually covered trademarks, and there was also overlap with utility patents: "The Patent Office, until of late, held that new shapes, patterns, etc., whose object and purpose is utility, were patentable as designs; but it now, and correctly, holds that only those things,— mentioned in section 71 of the Act of July 8, 1870, as patentable subjects,—whose object and purpose is aesthetic or ornamental, are properly patentable as designs." (Simonds 1874, p. 166). Possibly the most iconic design patent in the world is US Patent D11,023, granted in 1879 to the French sculptor Auguste Bartholdi to protect his creation of the Statue of Liberty.

[31] Swanson (2011, p. 2) notes that "As American women donned their corsets, they had a daily intimate relationship with a heavily patent-protected technology." Male observers in all three countries made disparaging remarks about this (factually true) tendency of women to contrive improvements in clothing. "There is no need to make mention here of patents for mechanical inventions, taken on behalf of the woman when she runs a trading house or factory or workshop. It is easy to see, in this case, the idea is due to a manager, a worker; ...Now, where we find the hand and mind of the woman herself is in the patented manufacturing of new corsets." de Neuville, A. "Le genie de l'invention chez les femmes." La Revue mondiale: ancienne Revue des revues 32, no. 1 (1900): 184–91.

inventions, but the majority of the improvements in clothing (broadly defined) typify the sort of consumer final goods that were difficult to distinguish from designs. When Beatrice McMaster of Surrey, England, obtained Patent No. 15, 739 (1916) for a glove for waiters, she motivated her invention by noting that "cloths or serviettes rapidly become dirty and are unsightly in appearance," and employed the word "elegant" four times to describe her invention, adding that she preferred to add an edging of lace when the item was used by a woman. Other women's patents similarly frequently appeared to conflate the item's attractiveness in appearance with its functional utility.[32] Such inventors were arguably responding to the nature of demand in the market for these items, since appealing appearance comprised a valuable form of product differentiation for women's clothing. Moreover, because the potential market was large, such "feminine technologies" as corset innovations could prove to be extremely profitable, encouraging several professional women inventors to specialize in such creations (Khan 2005).[33] In France, Mlle Caroline-Françoise Lukkow assigned the rights to her orthopedic corset invention even before the patent was granted, to Auguste Daubian, a medical doctor, indicating a strong belief in the commercial value of the improvement.

A significant number of the inventors who obtained patents for consumer final goods and design-related innovations were associated with the American Arts and Crafts movement. As Zipf (2007) noted, invention and technological innovation were central to the Arts and Crafts ideal.[34] Mary Louise

[32] Searches in early patent specifications for high-frequency adjectives regarding aspects of beauty or appearance results disproportionately in those by female inventors. See for instance, the specification for US 1234735 (1917) filed by Mrs. Margaret Davidson of Philadelphia for an invention "to provide an attractive and useful head covering chiefly designed for feminine wear," which included nine phrases relating to un/attractiveness. She also noted that "Of course, the quality and beauty of the cap will be entirely governed in direct ratio to its economic cost, for instance, when the cap is employed for morning wear it will be relatively plain, but when a cap of the above character is utilized as a dress garment it may be more or less elaborate in its aspect." Ethel Eva Levien's 1900 application was quickly processed within a month, and she was granted GB6929 for "improved women's cycling knickers," that were "more graceful in appearance and more convenient in every way from a hygienic point."

[33] Corset-related inventions comprised 5.4 percent of female patenting in France, and 5.8 percent in the United States. However, although women filed corset improvements disproportionately, it should be noted that men obtained approximately 90 percent of the total patents for corsets that were issued during the nineteenth century.

[34] Zipf (2007, p. 60) points out that "By participating in the Arts and Crafts movement, women inventors improved their mechanical knowledge, found jobs to support the development of their ideas, and learned how innovation could enhance artistic production. They also experienced less social pressure by capitalizing on their traditional social roles. Because of these advantages, women inventors involved in the Arts and Crafts production were better equipped to develop their ideas into useful and marketable products."

McLaughlin of Cincinnati, Ohio, an American ceramic painter and potter, influenced numerous artists and potters throughout the country.[35] Diffusion at exhibitions were more likely in the case of changes of appearance that were evident on their face, such as innovations in decorated ceramics. French potters had created an underglaze technique which was on display at the 1876 exhibition in Philadelphia and, after viewing the pieces, Mary Louise McLaughlin determined to replicate it. This re-invention was not patented, probably because the method was not sufficiently different from the French precedents, but it quickly diffused among artisans and the products were known throughout the United States as "Cincinnati faience." In 1894, she obtained a patent for a new ceramics process involving "the application of decorations of clay or of clay mixed with mineral colors to the inner surface of the mold, in order to produce, after casting, an inlay of clay in the body of the ware." McLaughlin was a competitor of Maria Longworth Nichols, who established the influential Rookwood Pottery in Cincinnati in 1880. Longworth herself obtained patent US361231A in 1887 for "the chromatic ornamentation of pottery… By these means I obtain greater depth and richness of color and more delicate blending of color with color, and transition from shade to shade, than by any admixture of colors before application."

The Rookwood establishment was careful to get patent protection for its innovations, and also acquired related patent assignments from outside inventors. At its peak, the pottery employed several hundred men and women, who were trained in the firm's methods, and also proceeded to make their own innovations. Some of these artisans moved to other companies, and even opened their own establishments, and this labour mobility created the possibility for conflict over the ownership and use of intellectual property rights. Laura Anne Fry, a Rookwood employee, designed a method of creating subtle gradations of colour using an atomizer, which she patented in 1889.[36] Fry had used the resources

[35] McLaughlin is regarded as "a leading exponent of the art pottery movement in the United States. Her contributions, both technical and aesthetic, were critical to Cincinnati's rise as a center of pottery production in the United States" https://www.brooklynmuseum.org/eascfa/dinner_party/heritage_floor/mary_louise_mclaughlin. She was one of the women who published manuals that played an important role in the diffusion of technical information. (See, for instance, M. Louise McLaughlin, China Painting: A Practical Manual for the Use of Amateurs in the Decoration of Hard Porcelain, Cincinnati: Robert Clarke, 1877; Susan Stuart Frackelton, Tried by Fire: A Work on China Painting, New York: Appleton, 1886.)

[36] US399029A (1889) sprayed wet clay to the ceramic item: "As the coloring-matter is blown from the tube of the atomizer and carried therefrom in a cloud of line, almost imperceptible, particles, it may be readily directed upon the

of the pottery over the course of several years to experiment and perfect her method. After Fry moved from the Rookwood Pottery to work for a competing firm, she filed a lawsuit against her former employers for their infringement of her method. The court was instructed to consider "whether the step she took in the art required the exercise of the inventive faculty", and the case was dismissed on the grounds of want of invention, despite the widespread use of the Fry method.[37] Judge William H. Taft's decision noted that, even if Fry's patent were upheld, her dealings with the Rookwood Pottery implied a license for them to freely use her invention.[38]

Many of these inventions were related to pursuits that were dominated by women, and some (predominantly male) patent examiners may have found it difficult to distinguish the degree of novelty in such applications.[39] For instance, Mary Tillinghast applied in 1881 for a patent to protect an invention for "a new article of manufacture of artistic character, which may be termed Needle-Woven Tapestry, … for purposes of decoration or for any artistic use it presents an extremely rich appearance and is of great value." Tillinghast, a notable artist in her own right, had been a former associate and employee of Candace Wheeler, who is regarded as a pioneer in the field of interior and textile designs. Wheeler also applied for a patent for an invention regarding the "art of embroidering tapestries" in July 1881. This led the patent office to declare an interference, which occurs when it seems that two individuals have made the same invention. However, ultimately each woman was granted her own patent in 1882, implying that further investigation had revealed the differences in their technologies.

The ceramics industry and the Arts and Crafts movement highlight the close relationship between many female-intensive creative pursuits and improvements in designs and consumer final goods. Thousands of women join formal and informal clubs, and increasingly attended schools of art and design,

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article in such manner as may be found best adapted to produce the desired effect, the application being freely made where the color is to be intense, and more delicately made in proportion as the color effect is to be delicate, or otherwise varied as the taste, skill, or ingenuity of the operator may dictate."

[37] The Daily Evening Bulletin of San Francisco, California (Saturday, March 07, 1891; Issue 128), among other newspapers, publicized her discoveries, reporting that "Miss Laura A. Fry of Chicago is a bright young artist who has discovered a secret which has puzzled many a learned chemist. She has taken out a patent for applying color to pottery and china… her invention is remarkable for its extreme simplicity and ease of application."

[38] Fry v. Rookwood Pottery Co. (Circuit Court, S. D. Ohio, W. D. No. 4,531, December 1898) was initiated in 1892.

[39] Sarah J. Noyes, the first woman to be employed as a patent examiner in the United States, was hired in 1873. Noyes, a specialist in chronological devices, was appointed First Assistant Examiner of the Electrical Division.

gaining technical knowledge and learning by doing that contributed to their inventive capital (Zipf 2007). A specialization by gender was evident in the pottery and glass industry, where women worked as painters or decorators, whereas men dominated the more technical aspect of firing the items in professional kilns. Women's participation in the entire process from shaping to firing the end product received a substantive boost when inventors such as Susan S. Frackelton and Ellen M. Ford obtained patents for small portable kilns that could be used at home to finish decorated items. As Ford's patent description noted: "it is no small advantage to an artist anywhere to have the means of acquiring practice in firing, thus being able to accomplish the entire work of decorating from beginning to end, and increasing his own abilities and talents by the additional knowledge which such experience affords" (Patent 262391, 1882).

Although these examples indicate the degree to which women were participating in patents for consumer good inventions, it might be expected that their creativity extended well beyond the boundaries circumscribed by formal intellectual property. The information from exhibitions and prize-granting institutions testifies to inventive activity and innovation of items that were largely unpatentable (Khan 2013). Sponsors of exhibitions like the Massachusetts Mechanics Institute provided benefits to many women in terms of training, invention and commercialization. Their efforts included allocating space for women at the annual exhibitions, education in design and vocational training, and the provision of facilities so women could practice their craft. In the case of the Maryland Institute, the influence of women helped to ultimately change its orientation from an interest in mechanics, to a school of art and design (Glickman 1993). However, the majority of participants in annual exhibitions comprised middle-class women, many of whom had no intention of engaging in the marketplace and had no further interest in appropriating financial returns from their creativity. Their recorded activities offer valuable evidence regarding the nature of female innovativeness within the household.

As Table 4 indicates, the difference between the inventive activity of men and women is especially striking in terms of items displayed at exhibitions. At the Royal Society of Arts in England, approximately a half of the innovations for which men received awards were in the consumer good and

design-related categories, whereas almost all of the items females submitted were consumer final products that included some aspect of improvements in design. The Society of Arts adopted progressive policies towards women, and was the first such institution in Britain to include women among its members.[40] The "ingenious of both sexes" were invited to apply, and over ten percent of the premiums were given for contributions by women.[41] A number of women received notice because of excellence in such consumer goods as hats and improvements in starch. In 1824, awards were given to women from various parts of the United Kingdom who had made bonnets using local materials, including Mary Marshall of Ireland, and the Dyer sisters of Hampshire. However, the majority of these female recipients obtained awards in "the Polite Arts," among which a typical example is Hannah Chambers' design for a candelabra. Mary Pingo, who won four design-related prizes between 1758 and 1762, was a member of the noted Pingo family of engravers and medallists. Similarly, in France Madame Amélie de Dietrich was credited with being the first to introduce decorative designs into industrial products made from cast iron, in her innovative business enterprise.

The contrast between men and women's activity at exhibitions is even more evident among the participants in the major American cities, as the lower quadrant of Table 4 shows. Only 19.1 percent of men's exhibits consisted of consumer final products, and even fewer of them were changes in the design of products. By way of contrast, three quarters of the women's exhibits were consumer goods, and designs constituted an even larger proportion. The variance in the technical inputs of items that women offered was extremely high, ranging from embroidered rugs, pleating, and varieties of lace, featherwork, and artificial flowers (made from wax, paper, silk, feathers, and other materials), to commercially

[40]The original 1753 prospectus for the Society noted that "Ladies as well as Gentlemen are invited into this Subscription, as there is no Reason to imagine they will be behind Hand in a generous and sincere Regard for the Good of their Country." Patrons of the Society included the "bluestocking" Elizabeth Montagu who joined in 1758, the Countess of Denbigh, and the Duchess of Northumberland (Wood 1913). Ann Birch Cockings (c. 1766-1844) was employed as a Housekeeper/Registrar of the Society from 1802 to 1844, and wielded a great deal of influence that went well beyond her presumptive job description.

[41] "The ingenious, of both sexes, are invited to submit their works and their inventions to the inspection of the Society, …and thereby secure to themselves not only honour and profit, in the present instance, but have also the pleasing consciousness that their names will stand recorded to posterity, among those who have contributed to the increase of the Arts, the Manufactures, and the Commerce of their Country" (Transactions of the Society of Arts, Volume 16, 1798, p. xvii).

successful dishwashers and sewing machine components.[42] Many of these changes in materials or designs or new colours would not have met the rules for patentability. Nevertheless, the reports of the juries testify to the degree of creativity evinced by the women who received awards for improvements that would not have qualified for patent protection.

Economic historians have shown that inventive activity and innovation responds to incentives and to changes in the factors that influence the returns to the creators of new technologies (Sokoloff 1988, Khan 1996). Like their male counterparts, women were able to appropriate returns from their investments in creativity through a diverse array of channels. Most notably, professional patentees like Helen Augusta Blanchard earned large fortunes from royalties and assignments in several countries, and from the establishment of their own manufacturing enterprises.[43] To some extent, all women who chose to follow the official procedures to obtain patents can be regarded as committed to inventive activity, and this is especially true in Britain and France where patents were contingent on the payment of high fees. The exhibitions data are more representative of the general population of creative women, whose efforts varied in terms of market and technical value to a greater extent than for patentees. The fraction of women exhibitors that earned medals was closer to the patenting rates: only 25 (0.5 percent) obtained a gold medal, 157 (3.1 percent) silver medals, and 86 (1.7 percent) received bronze medals (Khan 2013). Relative to male exhibitors and to female patentees, women at exhibitions were significantly less likely to receive the top financial awards and gold medals, in part due to the type and quality of their inventions.[44] Still, for professional women who participated in exhibitions, such recognition provided valuable

[42] This commercial diversity is sometimes evident in the backgrounds of individuals, as evidenced by exhibitor Mme Minnetta Mourgeanna, who was listed in city directories as an artist, photographer, hair dresser, and maker of hair restorers and toiletries. Similarly, Mrs. A. O. Cook of San Francisco participated in numerous fairs, winning cash prizes and medals for her innovations in preserved flowers, wax shells, statuary, hair jewelry and other decorative devices.

[43] Helen Blanchard was associated with the Blanchard Overseaming Company of Philadelphia, and the Blanchard Hosiery Machine Company. She obtained 21 U.S. sewing machine patents through 1895, and her patenting career (which included patents in Britain) continued until the year before her death in 1916.

[44] The 1850 exhibition of the Maryland Institute for the Promotion of Mechanic Arts rewarded creativity by gender: they presented men with gold and silver medals, whereas women received butter knives, ladles, teaspoons, pencils and thimbles.

advertisement and publicity that could enhance their reputations, and lead to more profits for traders.[45] For women who "kept house" the returns were likely more variable, ranging from enhanced personal and household utility, to greater influence among their peers.

At a national level, some of these inventions were responsible for increases in market demand and supply, export industries, and employment for children, men and women. An example is the industry for hats and bonnets in the United States, which in 1830 amounted to $10 million with exports of half that value (Case 1872). Scientific American (vol. 1, 1859, p. 206) published the first-hand account of twelve-year-old Betsy Metcalf, who independently devised a method to make hats from braided straw that she and her aunt had bleached with the smoke from "brimstone." She earned as much as $1.50 per day for several years, and instructed residents in nearby towns, leading to a flourishing women's bonnet industry in the region. Sophia Woodhouse of Connecticut similarly obtained a large silver medal and twenty guineas from the Royal Society of Arts, for information about another type of bleached straw material that could be used to make bonnets, and also obtained an American patent for the process. Numerous other women obtained premiums and cash awards for unpatentable changes in materials associated with new or improved products that were valued in the household and in the marketplace.

CONCLUSION

> "The economy of the household is generally as much the source of family wealth as the labor and enterprise of man"
> (Women's Rights Convention, New York, 1852)

Technology (broadly defined) has been pervasive in the everyday life of even the most primitive societies, and inventive activity comprises a major factor in economic growth and transformation, so it is not

[45] For instance, Dr Carrie Wolfsbruck, a young and attractive dentist, gained an international reputation (probably the first celebrity dentist!) after she exhibited her work on artificial teeth, fillings, and dentures. Wolfsbruck, the first woman to graduate from NY State Dental School, earned her degree in 1889. (She was likely born in 1863, as shown in the 1900 census, although she was cavalier in the declaration of her date of birth on her several passport applications.) The British Journal of Dental Science, vol. XL (Jan-Dec. 1897) featured her in an article on "Women who Pull Teeth," noting that "This lady has received a medal for artificial work." Newspaper articles across the country mentioned her, and amusingly reported her winnings in Monte Carlo. Wolfsbruck progressed from having a practice in an unfashionable part of New York city to an office on Madison Avenue.

surprising that scholars in every field have devoted a great deal of time and paper to the analysis of the technological change. Gender has become a central aspect of feminist research in the history of technology. According to Bray (2007, p. 38), "in the Western nations which pioneered industrialization and have thus been able for so long to dominate worldwide production of material and intellectual goods, services, and desires, technology is firmly coded male." Historians of technology have called for more studies that expand the scope of technology research beyond hardware, to incorporate the skills and knowledge that belong to women.[46] They reject implicit or explicit assumptions that men are producers of machines, whereas women feature exclusively as consumers of technology. Many of these concerns are reflected in the dissatisfaction of economists with the current state of theoretical and empirical approaches to technology, especially in the effort to measure and account for innovations in the characteristics of existing products and new goods.

This paper contributes to the existing literature by offering the first large-scale empirical study of women inventors in Britain, France and the United States, during the period of the first and second industrial revolutions. The panel data of over 12,200 observations includes biographical information from city directories and population censuses, and data from patent records; as well as prizes and exhibits at industrial fairs and related institutions. Although it is inherently impossible to determine the representativeness of such a sample relative to the entire population of innovators, we would expect that these combined data would offer broader insights than could be obtained from smaller numbers of individuals and inventions. Together, the combined samples reflect the different facets of inventive activity, capturing more machine-oriented discoveries that were likely to be protected by patents, as well as the inventions and innovations that women were making outside the patent system. Moreover, the analysis is unique in allowing for the systematic assessment of women's creativity within the nonmarket household sector.

[46] Wajcman (2010) notes that in conventional approaches "technology tends to be thought of in terms of industrial machinery and military weapons, the tools of work and war, overlooking other technologies that affect most aspects of everyday life. The very definition of technology, in other words, is cast in terms of male activities."

Economists have investigated the gender gap in many contexts, including that of patenting (Ding et. al 2006). Whittington and Smith-Doerr (2008) find that differences in the organization of work settings affect the likelihood of women's involvement in scientific patenting. Similarly, this study shows that patent systems were associated with differences in the inventive activity of women, relative to institutions with less exclusive rules. Patent systems in Britain and France, which required exorbitant fees and costs as a precondition for the grant of property rights in invention, served as a filter which excluded or deterred women without financial backing or connections, and in part resulted in lower proportions of patents for household inventions in these countries. Exhibitions, on the other hand, were administered by committees and judges, who imposed their own arbitrary standards on the items that could be displayed or receive awards, perhaps in part accounting for the lower propensity of women to gain the highest rewards. Nevertheless, participation in these events could also lead to nonmonetary returns or gains in reputation that benefited manufacturers, professionals, and homemakers alike.

The results in Britain, France and the United States together challenge the standard conclusions about the nature of women's economic and social involvement in the nineteenth century, and their role in industrialization. Middle class women did not choose to retreat away from the marketplace and from participation outside the domestic sphere. The experience of women in France, in particular, highlights the hidden nature of their extensive participation in business, entrepreneurship, and management oversight of sole proprietorships, as well as large scale corporations. It is worth noting that their inventive and commercial endeavours were not limited to a specific period, but ranged over the entire life cycle, and were typically not interrupted by marriage. Indeed, many of their discoveries were motivated by the challenges they encountered in the course of their duties as mothers, wives and managers of households.

One of the major challenges in accounting for the role of women in technological progress arises because their contributions defy unique categorizations and lie at the intersection of well-defined conventional boundaries. The distinction between consumption and production becomes blurred when the process of consuming creates insights that allow users to transform the set of available goods. In

particular, the experience of women inventors who did not work outside the home illustrates the skills and creativity that can be derived from learning by using. Perhaps the most valuable result of the empirical analysis of women's patenting and creativity is that it highlights the prevalence of innovations in consumer goods and designs. These extensive quantitative records, that allow us to trace so many thousands of examples of female ingenuity within the home and market, support the conclusion that women in general tended to specialize in technological change that is embedded in new varieties of standard goods, and subtle changes in function and perceived value that accompany design improvements. A pessimistic perspective is therefore that it is unlikely that empirical analysis will ever be able to fully measure the relative contributions of such designing women. A more optimistic conclusion is that these findings suggest that economic research underestimates the extent of technological progress and advances in consumer welfare attained within households and the market economy.

Figure 1 a) Britain: Women and Total Patenting, 1800-1900

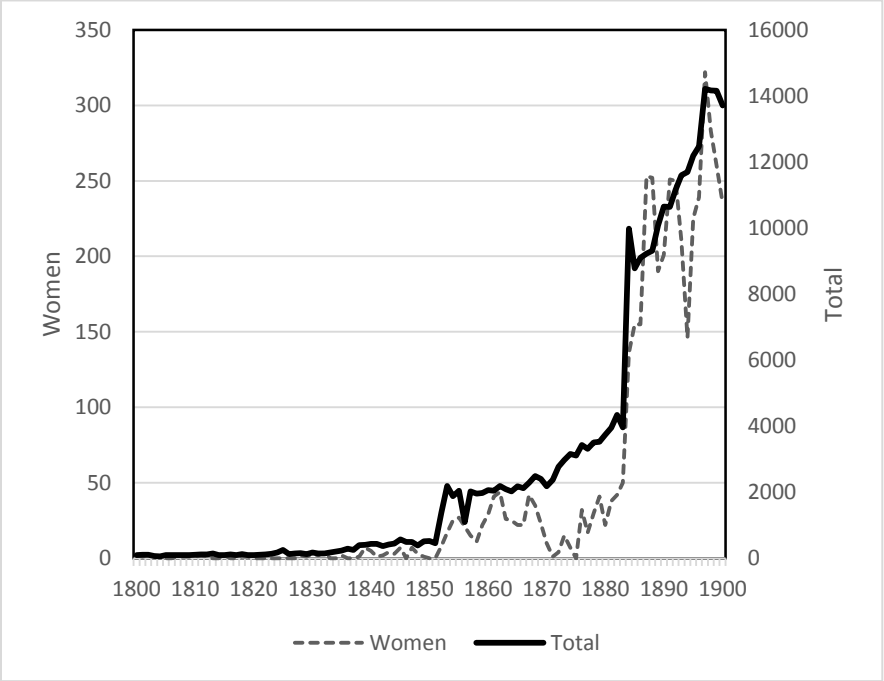


Figure 1 b) France: Women and Total Patenting, 1791-1855

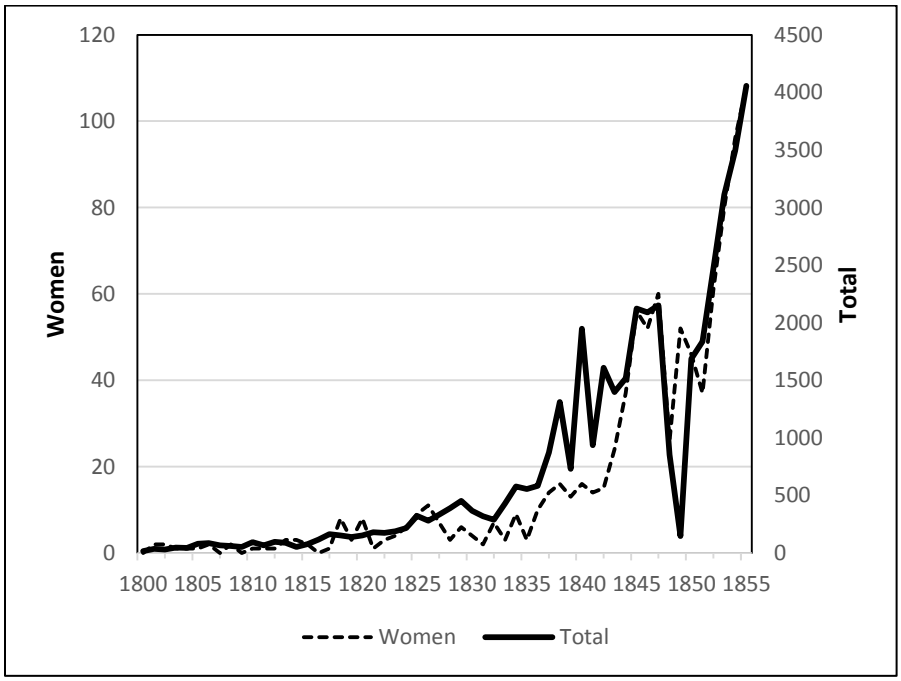


Figure 1 c) United States: Women and Total Patenting, 1850-1895

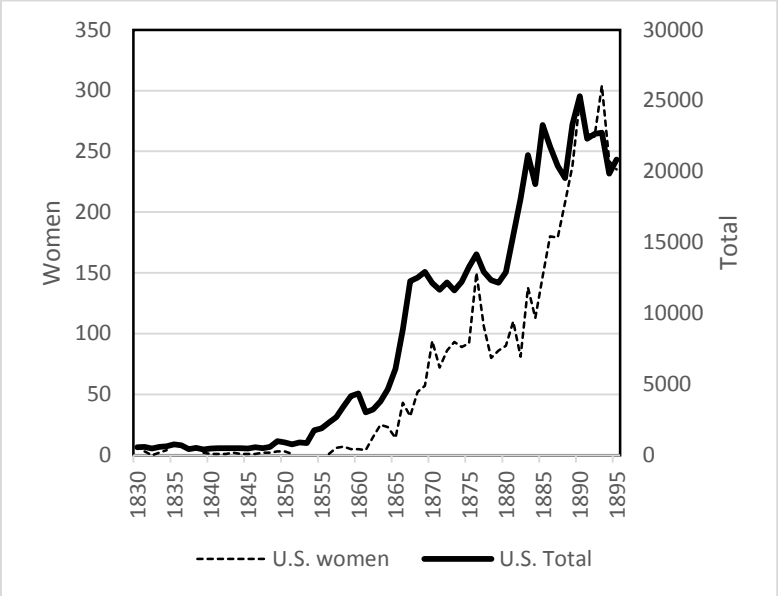
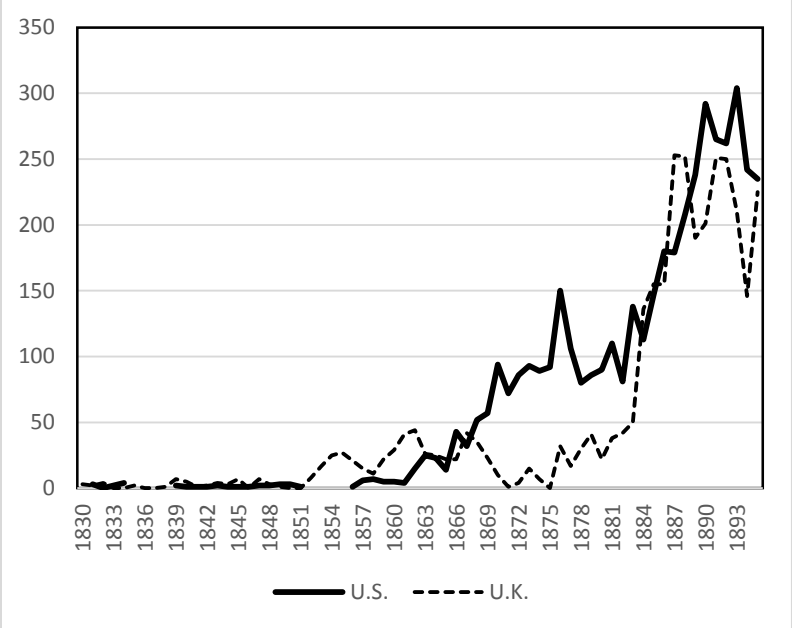


Fig 1 d) Patenting by Women in Britain and the United States, 1830-1895



Notes and Sources: See Appendix. The data for women patentees from France and the United States consist of all patents granted. The information for women patentees in the United Kingdom consists of a random sample.

TABLE 1: SUMMARY STATISTICS
PATENTING BY WOMEN INVENTORS IN BRITAIN, FRANCE AND AMERICA

	US		UK		FRANCE	
Multiple Patenting						
	Patents	Percent	Patents	Percent	Patents	Percent
One patent filed	2683	66.6	2133	69	368	36.8
Two or Three	874	21.7	659	21.3	346	34.6
Four to Nine	324	8	285	9.2	227	22.7
Ten or More	149	3.7	14	0.5	60	5.6
Coinventors						
	Patents	Percent	Patents	Percent	Patents	Percent
Female, Related	19	6	45	5.8	20	7.8
Male, Related	115	36.3	214	27.6	99	38.8
Female, Unrelated	35	11	84	10.8	36	14.1
Male, Unrelated	148	46.7	432	55.7	100	39.2
No coinventors	3857	92.4	2526	81.7	746	74.5
Marital Status						
	Patents	Percent	Patents	Percent	Patents	Percent
Single	127	21.2	--	--	296	29.6
Married	240	40	--	--	414	41.4
Widowed	233	38.8	--	--	290	29
Foreign Patents	Patents	Percent	Patents	Percent	Patents	Percent
Women	167	4	565	18.3	45	4.5
Total	34668	6.3	3483	22.1	80	7.5

Notes and Sources: Coinventors' relationships were determined by whether the individuals had the same surname, which will tend to be an underestimate. See Appendix for sources.

TABLE 2

DISTRIBUTION OF OCCUPATIONS AMONG WOMEN PATENTEES AND EXHIBITORS, IN BRITAIN, FRANCE AND THE UNITED STATES
(percentages)

	U.S.		U.K.	FRANCE	
OCCUPATIONS	Patents	Exhibits	Patents	Patents	Exhibits
Artisan/worker	26.9	11.7	8.8	10.6	8.8
Artist/designer	6.4	32.9	7	0	5.7
Businesswoman	18.4	2.5	5.3	9	7.6
Corsetmaker	9.7	3.2	7	9.8	5
Manufacturer	19.3	28.6	24.6	47.4	62.6
Mechanical	3.5	3.9	5.3	0	4.1
Professional/elite	11.1	7.8	35.1	17.9	6
Teacher	4.7	9.5	7	5.3	0.3
Percentage who did not work outside the home	33.7	41.1	45.7	38.0	50.5

Notes and Sources: The percentages for jobs outside the home are based on all women with listed occupations, exclusive of those who did not work outside the home (keeping house, at home, none). Occupations in the United States were obtained from city directories, and from the population census. British occupations were included in patent documents and in the population census. French occupations were drawn from the patent documents and from the reports of the exhibitions. See appendix for sources.

TABLE 3

INDUSTRIAL DISTRIBUTION OF PATENTS AND EXHIBITS BY WOMEN
(percentages)

	U.S.		U.K.		FRANCE	
INDUSTRY	Patents	Exhibits	Patents	Exhibits	Patents	Exhibits
Agriculture	2.1	1.8	1.8	1.1	1.7	0.3
Apparel	17.3	20.3	20.7	6.5	19	25
Chemicals/Medical	8.3	3.6	7.8	0.0	12	5.0
Machines, Engines and Transport	21.3	1.2	17.2	1.5	7.6	1.7
Food	0.7	2.7	4.7	0.0	10.3	3.1
Household/Building	32.1	31.7	23.0	0.0	17.8	9
Industrial	4.2	2.4	13.6	1.5	8.6	11.9
Arts and Education	5.4	32.7	5.4	86.7	5.0	14.6
Textiles	5.8	1.1	3.6	2.7	15.3	28.9
Miscellaneous	2.8	2.6	2.3	0.0	2.7	0.5

Notes and sources: Entries were allocated to industry of final use. See Appendix for sources.

TABLE 4

PATENTS AND EXHIBITS: CONSUMER FINAL GOODS AND DESIGN INNOVATIONS

	U.S.		**U.K**		**FRANCE**	
PATENTS	Number	Percent	Number	Percent	Number	Percent
<u>Women</u>						
Consumer final products	704	30.7	1340	43.4	461	46.1
Design innovations	458	19.9	480	15.5	222	22.2
EXHIBITS	Number	Percent	Number	Percent	Number	Percent
<u>Women</u>						
Consumer final products	2250	74.4	243	92.4	394	61.1
Design innovations	2468	81.6	246	93.5	195	30.2
<u>Men</u>						
Consumer final products	593	19.1	1210	54.9	-----	----
Design innovations	380	12.2	1190	54.3	-----	----

Notes and Sources:

Consumer final goods exclude furniture and appliances. Design innovations relate to all entries, including capital goods. Percent refers to the percentage of total observations for patents and exhibits by gender (women's patents; women's exhibits; men's patents; men's exhibits.) See Appendix for sources.

APPENDIX

SOURCES OF DATA FOR PROJECT

DATA	**Location**	**Period**	**Total Sample**	**Women**	
			Number	**Number**	**Percent**
UNITED STATES					
PATENTS	National	1790-1895	22,000 (of 561805)	4200*	0.8
PRIZES					
American Institute	New York	1847-1870	5656	38	0.7
Centennial Exhibition	Pennsylvania	1876		641	
Exhibition of Industry	New York	1853		104	
Franklin Institute	Pennsylvania	1840-1897	5068	106	2.1
Mechanics Institute	Massachusetts	1837-1874	4617	596	12.9
Mechanics Institute	Ohio	1850-1881	3772	356	9.4
Mechanics Institute	California	1858-1897	4855	787	16.2
Mechanics Institute	Missouri	1858-1870	2272	296	13.0
World's Fair	Illinois	1893		102	
Total U.S. Prizes			**26,240**	**3026**	
FRANCE					
PATENTS	National	1791-1855	5000 (of 41808)	1001*	2.4

PRIZES					
Exhibitions of National Industry	National	1798-1850	(21833)	382	1.7
Paris Exposition	International	1855	(10731)	263	2.5
Total Prizes				645	
BRITAIN					
PATENTS	National	1750-1900	15,700 (of 288046)	3091	1.1
PRIZES					
Royal Society of Arts	National	1750-1850	2466	263	10.7
BRITAIN, FRANCE, U.S.					
TOTAL PATENTS			**42,700**	**8289**	
TOTAL PRIZES			**28,706**	**3934**	
TOTAL			**71,406**	**12223**	

Notes and Sources:

The data in parentheses include total populations of patents or prizes which are not included in the dataset. *Patents for women in the United States and France comprise the total numbers filed in each country. The data from the exhibitions and other prize-granting institutions, U.S. general patent grants, and British patents were obtained from random samples.

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