'A new way by her invented': Women inventors and technological innovation in Britain, 1800–1930

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Abstract

What accounts for the common perception that women have contributed little to advances in entrepreneurship and innovation in Britain during the early industrial era? This paper empirically examines the role of gender diversity in inventive activity during the first and second industrial revolutions. The analysis of systematic data on patents and unpatentable innovations uniquely enables an evaluation of women's creativity within both the market and nonmarket sectors. British women inventors were significantly more likely than men to focus on unpatentable innovations in consumer final goods and design-oriented products that spanned art and technology, and on uncommercialized improvements within the household. Conventional approaches that fail to account for nonmarket activity and for such incremental changes in consumer goods and design innovations therefore significantly underestimate women's contributions to household welfare and overall economic progress.

KEYWORDS

British Industrial Revolution, consumer goods, gender, patents, technological innovation, women inventors

JEL CLASSIFICATION B54, D12, L26, N40, O31, O33

Technological innovation was central to economic growth and social advances attained during the era of the British Industrial Revolution. Economists and historians have exhaustively studied such related issues as overall inventive activity and innovation, links to theoretical and applied

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science, human capital, general purpose technologies, and heroes of invention.¹ However, the marked absence of systematic studies of women's contributions to inventive activity in Britain might seem to support long-standing gender biases regarding female creativity.² Scholars have certainly produced valuable case studies and descriptive accounts of inventions by nineteenth-century British women, but empirical examinations of broad patterns and general tendencies have not yet been attempted.³ Even popular articles about women inventors in contemporary newspapers in England generally turn out to be accounts about American patentees.⁴ As a result, in the realm of inventive activity, 'one is left with a strong sense that the industrial revolution is primarily a men's story'.⁵

This study of British women inventors has two major objectives. The first is to provide an overall analysis of the rate and direction of technological invention and innovation by women in Britain during the early industrial era. The second is to empirically test existing hypotheses regarding why inventive activity is typically regarded as 'almost exclusively male'. A number of scholars contend that the creative contributions of women are undervalued because of gender biases in the scope of technology studies.⁶ Machines and hardware discoveries tend to be male dominated, and women disproportionately direct their attention beyond such inventions. Similarly, others argue that the conception of technology needs to be broadened to incorporate design studies, and improvements to the 'look and feel' of consumer goods. These claims are based on the previously untested assumption that women disproportionately direct their attention. In general, these perspectives are connected to the premise that social progress is caused by both need in the market and need in the household, and further highlight the similarities between material incentives and the desire (at times competitive) to improve household welfare through innovations.⁷

A fuller appreciation of women's social and economic contributions across time and place has suffered from a lack of systematic data. A notable exception arises with regard to empirical research on women's inventive activity in the United States during industrialization, which

¹ For example, see Allen, *Revolution*; Crafts, 'Steam'; MacLeod, *Heroes*; Ó Gráda, 'Science'; Khan, 'Human capital'.

² This conclusion is accepted as obvious by most popular and academic assessments. For instance, Edgerton, *Science*, in his otherwise comprehensive survey of science and technology in Britain, states that 'The characters in this book are almost exclusively male, reflecting the historical fact that women were a tiny minority in industrial science and technology, as well as the bias of the historiography'. The *Dictionary of National Biography* similarly reinforces the impression that women did not contribute to inventive activity and innovation during the early industrial era, Macleod and Nuvolari, 'Pitfalls'.

³ Jungnickel, *Victorian*; Summers, *Corset*. Even extensive and informative accounts of women's work and enterprise such as Pennington and Westover, *Homeworkers*, and Kay, *Female entrepreneurship*, fail to examine inventive activity.

⁴ For instance, 'Woman as Inventor', *The Review of Reviews*, London (April 1900), p. 351, addressed US and French women. The British Library similarly posted an account of 'Seven female patent pioneers you should know', none of whom was from Britain. https://blogs.bl.uk/business/2021/03/female-patent-pioneers.html#:~:text=Therefore%20just%2062% 20out%20of,between%202%25%20and%203%25

⁵ Dublin, Transforming, p. 2. See also Jordan, 'Exclusion'; Martineau, 'Science and technology'; Oldenziel, Modern machines.

⁶ McGaw, 'Feminine technologies' and 'Great women'; Wajcman, 'Feminist theories'.

⁷ Khan, 'Women inventors', for instance, shows how women on the American frontier disproportionately devised improvements to remedy their lack of access to household help, and, as prominent suffragists maintained, 'the economy of the household is generally as much the source of family wealth as the labor and enterprise of man'. See *The proceedings of the Woman's Rights Convention, held at Worcester, October 15th and 16th* (New York, 1852, p. 18). For an early opinion piece, see Romney, 'Household'; and Styles, 'Product innovation'.

has primarily drawn on reliable patent data.⁸ In Europe, substantial application fees and high transactions costs likely deterred many women inventors from participating in the patent system, especially in Britain, where the expense of patent applications and grants was many times greater than annual per capita income.⁹ Accordingly, a broader perspective on women and technology can be gained from combining patents with records from other institutions, including award-winning innovations that would not have qualified for patent protection because of inadmissible subject matter or lack of substantive novelty. The present study further matches inventors and inventions with a number of related sources, including lawsuits, information about commercialization and business ownership, city directories, archival documents, probates, and population censuses. The emergent patterns from this plethora of data help to identify ways in which women employed entrepreneurial abilities to minimize risk and gain returns in the marketplace both within and beyond the formal intellectual property system, and also shed light on previously unmeasurable nonmarket activity and advances in household welfare.

The resulting insights into women's patenting, inventive activity, and commercialization 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 and commercially valuable changes in consumer final goods and designs. Moreover, a general lacuna exists in empirical scholarship regarding creativity that lies at the borders of aesthetics and utility, and of art and technology narrowly defined. In particular, standard studies that focus on a 'machine-centric' orientation and the highlighting of large-scale 'general purpose technologies' have undervalued subtle changes in design products and consumer final goods, especially within the household. As this study shows, women tended to make disproportionately greater contributions in just such areas, and part of the 'gender gap' arguably owes to the analytical gap in orthodox approaches to technological innovation.

I | FEMALE PATENTING AND INVENTIVE ACTIVITY

Patent documents provide a valuable index that enables the systematic analysis of inventive activity in the past and present, but patent systems are not identical and it is important to understand variation in their specific rules and standards.¹⁰ The British patent system has been in continuous operation since 1624, when the Statute of Monopolies offered inventors exclusive

¹⁰ Patents 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, *Democratization*, and eadem, 'Invisible'. At the same time, patent protection is limited to inventions that satisfy the rules for patentability, which implies that certain types of creativity are not represented. It is difficult, if not impossible, to find analogous information about female technological discovery outside the patent system. However, many historians have effectively used women's entries in prize-granting institutions

⁸ Patents have long been used by economists as a systematic measure of inventive activity and associated productivity growth. For an assessment of their costs and benefits, see Griliches, 'Patent statistics' and Khan, *Democratization*.

⁹ Prospective women inventors might have feared that male patent officials would misunderstand or undervalue their applications: 'Take, as an example, the last-named class – wearing apparel – and imagine a dozen, or more male examiners seated round a table, gravely discussing the advantages or disadvantages of an improved corset or a dress-fastener. What, for instance, does "mere man" know of the working, the uses, of one half of the inventions intended for women's sphere? What might appear absolute nonsense in babies' soothers, or feeding bottles, or night-lights, may in reality, be most practical and valuable, and in such a light would appeal to a woman examiner', *The Englishwoman's review of social and industrial questions*, 1901, p. 214. It was not until 1929 that the British Patent Office appointed the first woman among its cadre of more than 300 patent examiners.

grants for 14 years.¹¹ The institutional characteristics of patent laws and administration were likely to be especially disadvantageous for women inventors who wished to protect and commercialize their discoveries. The registration system that prevailed until the twentieth century did not examine whether the applicant was the true inventor, nor the novelty of the idea, and patents were often bestowed on individuals who had simply acquired an invention, such as importers of foreign discoveries, and who paid the fees.¹² Prior to 1852, procedures for obtaining a patent were extremely costly in terms of time and money.¹³ 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 discoveries might later be replicated by other inventors, or subject to adverse judicial rulings.

Significant changes in the British patent system occurred with the legal reforms of 1852 and 1884.¹⁴ The patent application process was rationalized into one Patent Office, and a renewal system was introduced whereby the patent term varied according to willingness to pay for extensions to the life of the property right.¹⁵ The policy after 1852 required an initial payment of £25, another £50 after 3 years, and after 7 years patentees were required to pay £100 to maintain the patent to full term. Limits were placed on the number of investors in a patent, which restricted the market for inventions. The filing costs fell further after 1883, when only £4 was charged for the initial term of 4 years, and the remaining £150 could be paid in annual increments. The laws changed in 1902 and 1907 towards more of a nominal examination system, and foreign patent owners were required to 'work the patent', or put patented ideas into actual practice. Overall, the system disadvantaged the creators of incremental inventions in terms of their ability to file for patent protection, to commercialize their inventions, and to enforce their rights at law.

One of the first women to obtain an English patent was Amy Everard, a widow, who had come up with the patented idea 'by her own invention and industry, and by infallible experience'.¹⁶ The 1637 patent granted her the sole right to practice for 14 years 'the misterie, skill, science, and invention' of concocting long-lasting tinctures from saffron and other flowers. The Crown allowed

14 Khan, Democratization.

as case studies that capture their broader nonpatentable creativity and efforts at commercialization (Cordato, Woman's sphere; Darney, 'Expositions'; Warner, 'Centennial').

¹¹ Boehm and Silberston, Patent system; MacLeod, Inventing; Khan, Democratization; Bottomley, British.

¹² 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 technological innovations. Indeed, the British market for assignments (sales of the patent right) and licenses (permissions to use) seems to have been quite limited; for instance, in 1853 only 273 assignments were recorded (Khan, *Democratization*, and eadem, 'Selling ideas').

¹³ Patent fees for England alone amounted to \pm 100–120, while a patent that also covered Scotland and Ireland could cost as much as \pm 350. Additional expenses were incurred to search patent records, which were lodged in several different locations, and a co-inventor was likely to increase the costs by another \pm 24. Patent terms could be extended only by a private Act of Parliament, which required political influence, and such extensions could cost as much as \pm 700. In addition to the monetary costs, inventors confronted complicated administrative procedures and high transactions costs.

¹⁵ Holding other things constant, a patent that was renewed signalled a higher value than one that was allowed to lapse (Sullivan, 'Estimates'). Between 1852 and 1883, about 30% of all patent grants were renewed after the third year, and only 10% survived for the full term of 14 years. The reforms of 1883 did not have a marked effect on renewal rates, and in 1895, 30% of patents were renewed for the first time, while 6% survived the full term of 14 years.

¹⁶ Patent no. 104, *English Patents of Inventions, Specifications* (London, 1857), p. 3. The caption from this paper's title, 'a newe way by her invented', was included in her specification. An earlier 'inventresse of yellow starch', Anne Turner (1576–1615), used a mixture of saffron to dye and stiffen the fashionable ruffs of the day.

the petition (according to the text of the patent grant) to enable the inventor and her assignees to appropriate returns, and to further benefit society. The inventor's agents had permission to enter and inspect the premises of suspected infringers, and any wrongdoers would meet with criminal penalties for violating the royal decree, including confiscation of the infringing goods. In return, Everard had to pay an annual sum of five pounds during the term of the patent, with a penalty for nonpayment. She was also required to sell the produced tincture 'at moderate rates and prices'. The patent could be revoked at any time if it were deemed 'mischievous or inconvenient to the state'.

Women were notably affected by the holding that English patents were not necessarily granted to 'the first and true inventor'.¹⁷ The earliest examples of women's patenting activities included Sarah Jerome who, together with William Webb, obtained patent no. 87 in 1635 for a machine to slice wood into thin flexible strips to make items such as bandboxes. Jerome had not invented this device herself, but had acquired the machine as repayment of debts that were due to her.¹⁸ The widowed Mary Marshall petitioned in 1684 for protection for an improvement in tapestry making that her late husband had created, and some proprietors of firms filed patent claims for their employees' inventive ideas. Patent agents or other representatives and administrators could obtain intellectual property rights in their own name on behalf of inventors.

Moreover, the scope of protected novelty was limited to the domestic market, so many patents covered discoveries that replicated foreign innovations. For example, making lace in the intricate style of the elegant and enormously expensive Venetian and French points was a primary objective of weavers throughout the major capitals of Europe. The first English patent for producing points in the manner of Venice and Spain was filed in 1675 by Rebecca Croxton, William Fanshawe, and Gabriel Cox. It is unknown what role her co-patentees played, but the evidence suggests Mrs. Croxton had significantly contributed to the inventive process. She promptly advertised that she had acquired a patent from his Majesty for 'my invention', and had set up an establishment as a lace-tatting instructor of Point de Venise and Point d'Espagne in a fashionable part of London.¹⁹ The patent helped to reinforce her credentials and expertise in lace making, and she also subsequently came up with a novel method of washing the delicate fabrics.²⁰ Similarly, in 1709, patent no. 386 went to Jane Tasker, a widow, who 'with great industry and expences' had perfected making cases covering glass flasks with rushes and straw, in emulation of the products of artisans from Florence.

The British patent registers also included applications from, or on behalf of, foreign inventors for valuable discoveries.²¹ Thomas Masters of Philadelphia, an American planter and merchant, successfully obtained two British patents in 1715 and 1716, a first for these colonies. However, as the patent document notably stated, it was his wife, Sybilla, who had developed new ways to cure Indian corn and to make straw bonnets.²² Patent no. 403 (1716) noted that Sybilla Masters

²² Patent no. 401 (1715) to Thomas Masters was for 'a new invention found out by Sybilla his wife, for cleaning and curing the Indian corn grown in the several colonies in America'. Sybilla Masters (1675–1720) and her husband were prominent

¹⁷ American patent records are especially useful in the case of women's inventions, since the law required that patent rights had to be claimed by the inventor and no one else. Thus, if a British woman obtained a US patent, or a US patentee filed for a British patent, it provided an official validation of her status as an actual inventor.

¹⁸ The patent was reissued as no. 120 in 1638, in Jerome's name alone.

¹⁹ See Palliser, History of Lace, p. 51.

²⁰ Three years later, in 1678, 'well liking' Amy Potter's invention, King Charles granted her patent no. 204 for a means of making Flanders woollen lace.

²¹ In 1802, Elizabeth Duke and James Jacks, a merchant, received patent no. 2603 for waterproofing textiles and other goods, an invention that had been 'communicated to them by a person residing in America'.

had 'with great charge, pains, and expence, invented and brought to perfection a new way of working and staining of straw...and covering and adorning hat and bonnet, in such a manner as was never before done or practiced in England or any of our plantations'. The patent's protection covered England, Wales, the town of Berwick-upon-Tweed, the American colonies, and other British 'plantations', so the rights were later protected from infringers in Pennsylvania. Masters and her husband were both born in Bermuda, which was the source of palmetto leaves that could be plaited into straw hats, and in 1716 they further secured a valuable 14-year monopoly over the importation of palmetto from the West Indies, using the persuasive argument that the trade would increase employment for unskilled English workers. To aid in commercialization, Sybilla set up a store front, West India Hat & Bonnet, on the Strand in London, before returning to Pennsylvania.

Women filed lower numbers of patents than men in all industries and over the entire period. However, the variation in women's overall patenting was similar to the general population of inventors, suggesting that women responded to many of the same economic impulses.²³ This is not to say that the experience of male and female inventors was identical – the Masters case illustrates a notable difference related to legal rules governing women's market activities, such as married women's property rights. During much of the nineteenth century, while single women and widows had many of the same legal rights as men, married women were subject to the rules of coverture, which vested legal rights in their husband. Coverture negatively affected women's economic behaviour: legal reforms that removed such laws altered the costs and benefits of women's commercial involvement, and significantly increased inventive activity by female patentees.²⁴ Similarly, women's entrepreneurship was likely constrained by their legal disability under the law. Since investors and creditors would be less inclined to offer funding if they were uncertain about their ability to enforce their rights, the laws engendered greater capital market imperfections for women relative to men.

The time series of patent grants in Britain (figure 1) demonstrates that changes in the cost of patenting had a significant impact on all inventors. The temporal changes in patterns of patenting indicate that female inventors had been disproportionately deterred by the prohibitively high cost of patent fees that prevailed through to 1852. Women accounted for just 81 patents prior to the reforms, or less than 1 per cent of the total filed by the middle of the nineteenth century. After the fall in fees in 1852, overall patenting in the following decade increased by 355 per cent over the prior decade, whereas women's patenting grew by almost 800 per cent. The additional cuts in the cost of patents in 1884 similarly resulted in a 290 per cent growth in total patenting, relative to 750 per cent for grants to women inventors. Declines in filing fees increased inventive activity primarily through the effect on prospective patentees who were credit constrained.²⁵ These results support the finding that the policy of cheaper patents benefitted women to a greater extent relative to

and wealthy Pennsylvania Quakers, and she contacted influential English aristocrats to request their assistance with the patent application (UK National Archives, SP 34/21/43, Folio 89.)

²³ For instance, patenting for both men and women was responsive to major economic cycles (Sokoloff, 'Inventive'; Sokoloff and Khan, 'Evidence'). Like other patentees, women inventors varied their efforts to take advantage of changes in market demand and expected profitability (Khan, 'Women inventors').

²⁴ Khan, 'Married women'. 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. Reforms that allowed English women separate property rights were first implemented in 1870 (Combs, 'Bargaining power').

²⁵ Kuegler, 'Responsiveness'.

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FIGURE 1 British patents granted by gender, 1800–1900. Notes and sources: see Appendix.

male inventors, as women typically would have had lower financial resources and more restricted access to credit and capital markets than their male counterparts.

By the early twentieth century, more British women were applying for patents per capita than ever before in the history of the patent system. Their annual applications averaged 500–600, which amounted to between 2 per cent and 3 per cent of all patents filed each year (figure 2). However, shifts towards higher technical standards for patent grants and more stringent rules were associated with a marked fall in applications and patents granted to women after 1910. These changes were compounded during the First World War, when the fraction of female patent applications fell to around 1.4 per cent of total filings. Even as late as the 1960s, the gender gap for inventors had not narrowed significantly, as women's patenting in the UK remained below 3 per cent of total patents granted.²⁶

Several of these women inventors succeeded in contriving discoveries that addressed emerging perceived demands in the marketplace. This was especially evident during the First World War, when Elizabeth Pratt patented 'foodstuffs for military use', and Laura Shaw's improvement on artificial limbs was among the rising number of prosthetic inventions.²⁷ Alice Hoare-Ward, a volunteer for the British Red Cross, devised an adjustable head and arm rest for invalids and Clara Elizabeth Craddock, a nurse, patented medical bandages. The Countess Helen Moerner applied for a patent in 1914 for 'bullet proof garments', made of interwoven flexible metal strips and covered in khaki, although there is no evidence it was ever adopted. Hertha Ayrton, who has sometimes

²⁶ The UK Intellectual Property Office, *Gender profiles*, estimated that the rate remained below 3% through 1965, and had increased to just above 8% in 2015.

²⁷ Elizabeth Craddock GB191419410A (1915); Laura Shaw, GB166306A (1921); Elizabeth Pratt (1913); Alice Hoare-Ward GB191513235A (1916).



FIGURE 2 British patent applications by gender, 1895–1935. Notes and sources: see Appendix.

been described as Britain's foremost women inventor, was credited with saving soldiers' lives during the First World War when she distributed a simple hand-held patented fan to dispel poison gas in the trenches, which she later adapted for dispelling noxious gases in mines and industrial settings.²⁸

II | PATENTED INVENTIONS AND INNOVATIONS

Patent records offer unique and invaluable insights, but also have well-known problems as measures of inventive activity, especially since all inventions are not patentable, and some inventors might not have been able to afford the patent fees. One way to supplement patent information is to consider entries at prize-granting institutions, although these are associated with their own drawbacks.²⁹ The organizers of industrial fairs encouraged women to submit exhibits, expecting that their 'taste and delicacy' would lead to visually appealing displays that would attract more

²⁸ Ayrton came from a working-class background but was fortunate in attracting the financial support of suffragist backers. Her most significant technological contributions owed to her electricity research, including anti-aircraft searchlights and arc lamp technology. Patents for these discoveries were filed internationally. Her nomination for membership at the Royal Society was rejected because married women were deemed ineligible. See also Bruton, 'Ayrton'.

²⁹ Appendix and Khan, 'Inventing prizes'. Empirical studies of prizes and exhibits reveal that they are typically associated with unpatentable innovations, rather than novel or patentable inventions. Industrial fairs stipulated few rules about the identities of the exhibitors, who were often sales agents rather than inventors themselves. Panels of judges in decentralized committees granted prizes on the basis of a wide array of criteria that ranged from novelty to aesthetics and idiosyncratic

	Britain		United States		France	
Multiple patenting						
	Patents	Percentage	Patents	Percentage	Patents	Percentage
One patent filed	2133	69.0	2683	66.6	368	36.8
Two or three	659	21.3	874	21.7	346	34.6
Four to nine	285	9.2	324	8.0	227	22.7
Ten or more	14	0.5	149	3.7	60	6.0
Co-inventors						
	Patents	Percentage	Patents	Percentage	Patents	Percentage
Female, related	45	1.4	19	0.5	20	2.0
Male, related	214	6.5	115	2.8	99	9.9
Female, unrelated	84	2.5	35	0.8	36	3.6
Male, unrelated	432	13.1	148	3.6	100	10.1
No co-inventors	2526	76.5	3857	92.4	746	74.5
Foreign patents						
	Patents	Percentage	Patents	Percentage	Patents	Percentage
Women	565	18.3	167	4.0	45	4.5

TABLE 1 Patenting by women inventors in Britain, France and the United States.

Note: These data were obtained from patent records over the following periods: UK (1800–1920), US (1800–1920), France (1800–1900). Co-inventors' relationships were determined by isonomy (whether the individuals had the same surname), which will tend to underestimate familial ties.

Source: See Appendix.

visitors to the events. Special gallery spaces were often set aside for 'Woman's Departments', with the intention of encouraging female participation, and in 1900 there was even a 'Woman's Exhibition' in London.³⁰ Such exhibited displays illustrated diverse forms of creativity that generally were not eligible for patent protection, and most often reflected innovation (commercialization) rather than novel inventions. However, they do shed light on a broader scope of endeavours than patented inventions alone, and offer valuable comparative insights into women's nonpatentable innovative efforts in particular.

Table 1 presents characteristics of patentees in Britain, with information on women inventors in the United States and France to offer a comparative perspective. Multiple patenting provides an indicator of professional inventive activity and greater investments in inventive capital. Inventions associated with multiple patentees had a greater propensity to be sold in the marketplace, and these inventors were more likely to be engaged in entrepreneurial activities to commercialize their discoveries.³¹ A few early inventors, such as Sarah Guppy, the wife of a wealthy Bristol merchant, who filed four patents, were sufficiently financially secure and confident in the prospects of their invention that they followed up their first patent with additional applications.³² However, as might

³¹ In Britain and the United States, the majority of 'great inventors' obtained dozens and even hundreds of patents. More than 15% of American women inventors were multiple patentees, Khan, 'Women inventors'; eadem, *Democratization*.

characteristics. Exhibitions and award-granting institutions did not require potential exhibitors to pay entry fees or meet technical standards, and thus potentially provide information on a more diverse population of innovations.

³⁰ '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*, 51 (1874), p. 396.

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be expected, British women were more likely to engage in multiple patenting after the fall in filing fees. Between 1895 and 1915, Lavinia Lenton, a widowed trimmings manufacturer in Coventry, obtained almost a dozen patents for a range of 'feminine articles' such as hair curlers, rational cycling dress and velocipedes, which she assiduously marketed at exhibitions. More often, families and family businesses functioned as quasi-apprenticeship institutions in providing know-how, resources, and a social context that had the potential to increase women's investment in inventive activities.³³ However, by the end of the nineteenth century, women inventors were increasingly gaining specialized training through apprenticeships and formal technical education, which was reflected in their commitment to inventions. A number of women were drafted into technical apprenticeships during the war, which facilitated the development of career patentees such as the engineer Verena Winifred Holmes.³⁴

Foreign patenting similarly signals a portfolio of more significant discoveries, as the highestvalued inventions tended to be patented in international markets.³⁵ It is worth noting that 18.3 per cent of the women inventors whose patents were granted in Britain actually came from overseas, primarily from the United States and Germany. Between 1899 and 1908, Mrs. Anna Helwig, an American patentee and partner in the Helwig Manufacturing Company of St. Paul, Minnesota, obtained patents in Britain and other countries for her impressive array of mechanical inventions in pneumatic metal cutters, steam motors, and pneumatic hammers. Elizabeth Barnston Parnell, a successful professional metallurgist, was initially from Sydney, Australia and moved to live in Surrey. She 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 Parnell process of refining ores proved successful in trial experiments, and she was subsequently backed by a syndicate who funded her applications for more than a dozen patents in different countries.³⁶

The data on co-inventors in table 1 shed further light on some of the mechanisms that promoted inventive activity by women. The majority of both British and American women patentees had no co-inventors (76.5 and 92.4 per cent, respectively), indicating the independent nature of female inventive activity.³⁷ However, women often were 'invisible partners' in family enterprises, and the records reveal that many family members worked together on their inventions and innovations.³⁸ The Birmingham family team of Elizabeth Whitehead and John and Herbert Whitehead,

³⁴ Holmes (1889–1964) worked at a propeller company during the First World War, and this apprenticeship as well as night classes encouraged her to go on to engineering college. Between 1921 and 1958, she successfully applied for 15 British patents, as well as several foreign patents from the United States, France, and Canada.

³⁵ Khan, 'Selling ideas'.

³⁶ 'In the Matter of Parnell's Patent', *Reports of patent, design, and trade mark cases decided by courts of law in the United Kingdom*, 5 (1889), p. 127.

³⁷ The higher fraction of inventor teams in Britain likely was related to the greater transaction costs of filing for patents, and the ability under the law to add individuals to the patent who were not actually inventors of the idea.

³⁸ Henrietta Vansittart (1833–83) is often featured as a prominent inventor (and an engineer, in the *Dictionary of National Biography*), but she described herself as a 'mechanical artist'. In 1868, she patented her own improvements on a ship's propellor devised by her father, James Lowe.

³² Guppy patented a suspension bridge in 1811, a tea urn in 1812, bedroom furniture in 1831, and a method of caulking ships in 1844.

³³ Women patentees often benefitted from family resources, especially in the case of wealthier households. However, familial apprenticeships and resources were also useful for working class women. Khan, 'Invisible women', found that many French women inventors demonstrated greater productivity at both invention and commercialization because they were able to exploit family connections.

art metal and glass workers, used glass crystals and 'imitation jewels', for their 1902 patent for 'illuminated devices for advertising and decorative purposes'. The Prest siblings – Thomas, James, and Mary – of Blackburn, Lancashire, were all joint applicants for an 1898 patent to protect their improvements in cycle tyres. Most notable was the long-term collaboration between sisters Eva and Cecilia MacKenzie of Inverness, who completed numerous inventions from 1895 until Eva's death in 1917.³⁹ In the twentieth century, more family businesses were involved in patenting discoveries, such as George, Mary Ann, and Eliza Jane Fowler, trading as the manufacturing firm of Welcome & Co on Leadenhall Street in London, who invented a portable solidified fuel that reduced the risk of fire and explosion, in 1901.

A significant fraction of co-invented patents included unrelated males, typically from the same geographical location.⁴⁰ In the 1930s, Nina Benita, Duchess of Hamilton, obtained six highly technical patents for improvements in telephone instruments with co-patentee Douglas Stuart Spens Steuart (a mining engineer who held his own prior telephone patents, and provided the specialized knowledge for realizing the inventive ideas). British women inventors shared their property rights for a number of reasons beyond joint inventive activity. Co-inventor status could provide a means of compensating intermediaries who helped to mobilize venture capital, advised about marketing and commercialization, and engaged in litigation about property rights and related issues. The Honourable Maude Agnes Lawrence joined Frederick Arthur Cole, a coach builder, in applying for a patent in 1893 for an improvement in four-wheeled vehicles, and the extremely wealthy Lawrence provided the funding for the invention.⁴¹ Patentees could secure the services of agents on a risk-sharing basis by assigning part of their patent. When Alberta Mary Caspar, a London artist, filed for an American patent for imitation stained glass in 1884, she transferred half of her rights to Eugene Pearl, her patent lawyer in New York.

Table 2 suggests that participation in business and in the labour market provided advantages for women that promoted their ability to appropriate returns from their creativity. More than a quarter of these British inventors were manufacturers and corset makers. Many women successfully founded firms to produce their patented discoveries, while owners of business enterprises could benefit from the technical insights and assistance of their employees.⁴² In 1894, after the deaths of her husband and father-in-law, Eliza Rippingille became the head of a 'world renowned' lamp and stove manufacturing company, and she subsequently registered some 15 patents with employee coinventors, including the foreman of the Birmingham branch of the firm. Manufacturers were also likely to apply for patents whose subject matter was related to their enterprises, such as Martha Kerr, a manufacturer of washing machines in Liverpool, who obtained two washing machine patents in 1896 and 1902.

Inventors had to exercise entrepreneurial abilities to commercialize their discoveries by selling the patent rights, licensing the invention, manufacturing, defending their rights, and pursuing

³⁹ Two of their patents, for hairpins, included their mother Mrs. Georgina MacKenzie. Cecilia and Jessie (Eva) Mackenzie obtained more than a dozen patents between 1895 and 1920, for inventions which were sold even in the United States, with the help of the first female US patent attorney, Edith Griswold. By 1911, when they applied for another patent to protect their apparel design for women and children, the sisters were adept at manufacturing and commercializing their inventions.

⁴⁰ Many of the co-inventor listings testified to women's collaborations with machinists, engineers, pattern makers, toolmakers, manufacturers, and artisans, who likely made a substantive contribution to the invention.

⁴¹ Lawrence (1864–1933) was a single woman living in Kensington, who employed a butler and 14 servants in 1911. Her probated estate in 1933 was valued at £172 382.

 $^{^{42}}$ This is especially evident in the French context, where manufacturers accounted for a disproportionate number of women's occupations (47.4% of patentees and 62.6% of exhibitors).

Britain	United States	France
8.8	26.9	10.6
7.0	6.4	0.0
5.3	18.4	9.0
7.0	9.7	9.8
24.6	19.3	47.4
5.3	3.5	0.0
35.1	11.1	17.9
7.0	4.7	5.3
45.7	33.7	38.0
	Britain 8.8 7.0 5.3 7.0 24.6 5.3 35.1 7.0 45.7	BritainUnited States8.826.97.06.45.318.47.09.724.619.35.33.535.111.17.04.745.733.7

TABLE 2 Occupational distribution for women patentees in Britain, France and the United States (percentages).

Notes: 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), from 1840 through 1900. Occupations in the United States were obtained by matching inventors' name and residence with records from city directories and manuscript population census. British occupations were included in patent documents and in the population census. French occupations were drawn from the patent documents and from exhibition reports.

Source: See Appendix.

better employment opportunities. Mrs. Annie Matilda Wood took out 11 patents, including one in 1885 for the widely used 'woodite', a light, flexible, and impermeable rubber-based material. Woodite was of interest to the navy in Britain as well as other countries because it lessened the impact of cannon shots by rendering the penetrated hull watertight, and increased the ship's buoyancy, making lifeboats in particular 'practically unsinkable'.⁴³ In 1887, the A. M. Wood's Ships' Woodite Protection Company Limited was wound up, and the next year a new firm, Woodite Company Limited, was capitalized at £50 000. This firm bought out the worldwide rights to Annie Wood's patents, as well as the trademarks Woodite and Whaleite, and all associated trade secrets. As a major shareholder in the new company, she was appointed one of the nine directors, and paid an annual salary of £750.

Successful inventors like Wood had to be prepared to defend their valuable inventive rights from potential infringement, as illustrated by the lawsuit *In the Matter of Griffin's Application for Patents*, 3 August 1888.⁴⁴ In 1887, Colonel J. T. Griffin applied for two patents to secure the rights for 'improvements on India-rubber compositions', which he claimed had been communicated to him by an unspecified American inventor. Griffin had actually been the Chairman of the Wood company, where he took down detailed notes about Annie Wood's inventions at meetings, and then proceeded to apply for related patents on his own account. Despite her objections, the Comptroller General of Patents approved Griffin's applications, and she appealed against the decision to the Solicitor General. The matter was ultimately decided in her favour in the appellate court, Griffin's patent application was denied, and her legal costs were refunded.

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⁴³ The influential US publication *Scientific American* [supplement, 26 (1888), p. 10556], devoted almost an entire page to Wood's improvements to 'Mechanically propelled boats'.

⁴⁴ Patentees such as Annie Wood faced manifest gender discrimination in the prosecution of their rights. The Comptroller General was reluctant to deny the claims of a Colonel Griffin in favour of a Mrs. Wood. In his address before the Institution of Naval Architects, Captain Penrose Fitzgerald declared, 'We have also heard lately something of a substance called "woodite," but as this is a patent composition and invented by a lady, I must speak of it with the greatest reserve'," *Transactions of the Institution of Naval Architects*, 29 (1888), p. 169.

Towards the end of the nineteenth century, women inventors became more proficient in enforcing their rights, and in the professional marketing and commercialization of their ideas. Mary McMullin, a manufacturer, patented her 'electro-glacial applicator' in Britain in 1883, and also obtained American, German, Belgian, and French patent rights. According to her advertisement in the first volume of the Lancet, in 1884, her invention was 'invaluable in Neuralgia, Headaches, Rheumatics', and she successfully applied for an award from the National Health Society. Agnes Bertha Marshall exploited synergies between her patented inventions and her professions of celebrity chef, entrepreneur, and cookbook author. In 1885 she patented an ice cream maker that could make a pint in 3 minutes, and many of her cookbook recipes directly incorporated this machine as well as her other patented appliances. At her cooking school in Cavendish Square, she marketed an extensive range of her own branded products such as gelatine, icing sugar, almond flour, and even curry powder. Her popular public lectures and cooking demonstrations were attended by 500-600 devotees at a time, and she published The Table, a weekly magazine, all of which helped to increase market demand for her products. As one of the numerous newspaper testimonials noted, Marshall drew on skills and knowledge in which 'science and art blended'.

Over the same period, Doris Sophie Munn, from Bayswater, London, invented close to a dozen apparel and household articles, and realistic artificial flowers which emanated a perfume. Like many other entrepreneurial women inventors, she was the director of her own company, and successfully pursued intellectual property rights protection overseas, including in developing countries such as India, Cuba, and Brazil. In the 1920s and 1930s, Dorothy Blanche Miller from the Isle of Wight designated her occupation as inventor, and devised numerous improvements for bicycles, printing, and lamps. Her experiences obviously conferred confidence in her innovative abilities, as she even wrote a book in 1937 instructing others on *How to patent and commercialize your inventions*.

Cross-country comparisons support the view that the design of patent institutions influenced the composition of patentees. Fully 35.1 per cent of British women inventors belonged to the professional and elite class, due in part to the high fees and administrative costs of patenting.⁴⁵ The roster of patent applications by peers of the realm and members of the landed gentry is particularly lengthy, and many among these privileged groups obtained multiple patents. For example, the Duchess of Hamilton obtained six patents for telephones, and her daughter, Mary Louise Douglas-Hamilton, Duchess of Montrose, patented a frame that facilitated the turning of eggs.⁴⁶ Another family member, Flora Marie Douglas, Duchess of Touraine, filed British patents for a wardrobe that could be used as a travelling trunk in 1903, and a combined hinge and stay for boxes and doors in 1905, along with several more patents in France. By contrast, patenting activity by the artisanal and working classes in Britain (8.8 per cent) and France (10.6 per cent) remained significantly lower than in the United States (26.9 per cent), where patents were cheaper and better enforced. Women inventors in this socio-economic group rarely filed more than one patent. An early example is Martha Gibbon, a dressmaker who was granted a patent in 1800 for 'anatomical stays' for women and children; while Eleanor Hughes, a lady's maid from Lancashire, patented a bag for keeping knitting materials, in 1902. Of course, not all innovative women were formally employed

⁴⁵ 'In the world there is no lack of female inventors of useful articles for personal and domestic use, but the heavy expense of taking out a patent prevents a great many novelties from being brought to perfection', 'Ladies' Column', 10 February 1891, *Bury and Norwich Post* (England).

⁴⁶ The Montrose estate was noted for innovative poultry rearing, and was awarded several trophies, according to *Modern Poultry Keeping* (13–14, 1926), p. 366.

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	Britain		United States		France	
Industry	Patented	Unpatented	Patented	Unpatented	Patented	Unpatented
Agriculture	1.8	1.1	2.1	1.8	1.7	0.3
Apparel	20.7	6.5	17.3	20.3	19.0	25.0
Chemicals, medical	7.8	0.0	8.3	3.6	12.0	5.0
Machines, engines, and transport	17.2	1.5	21.3	1.2	7.6	1.7
Food	4.7	0.0	0.7	2.7	10.3	3.1
Household, building	23.0	0.0	32.1	31.7	17.8	9.0
Industrial	13.6	1.5	4.2	2.4	8.6	11.9
Arts and education	5.4	86.7	5.4	32.7	5.0	14.6
Textiles	3.6	2.7	5.8	1.1	15.3	28.9
Miscellaneous	2.3	0.0	2.8	2.6	2.7	0.5

TABLE 3 Industrial distribution of women's patented and unpatented inventions and innovations, in Britain, France and the United States (percentages).

Notes: Patented inventions and unpatented entries at prize-giving institutions were allocated to the industry of final use. *Source*: See Appendix.

outside the home. In Britain, 45.7 per cent of female patentees whose details could be traced were listed as keeping house or without any stated occupation, relative to 33.7 per cent of American patentees.

Prior research indicates that the majority of ordinary and 'great inventors' tended to produce job-related inventions, suggesting a correlation between occupation and industry.⁴⁷ The industrial distribution of patents filed by British working women (table 3) yields evidence that their creativity was likewise related to perceived market demand and experience acquired in the course of their jobs. 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. Elizabeth Rowland, a nurse and 'Specialist of the British and Continental Women's Hospitals', protected intellectual property rights for six inventions, including a means of treating a malpositioned uterus, and a commercially successful inhaler which was patented in several foreign countries. Ann Young, a pianoforte player and music teacher from Edinburgh, filed an unusually long 23-page specification in 1801 setting out the details of her game (which was marketed for several decades) to amuse and educate children about the principles of music. In Bristol at the turn of the century, Mrs. Mary Isabella Wilkins, a bicycle manufacturer, invented two improvements in cycle brakes, and Rosalie Riddick Powell applied her knowledge as a chemist to aid two relatives in discovering a better way to manufacture vinegar. A productive collaboration between Edith Mary Lawton, 'cinema operator', and Ernest Harding, an electrical engineer living in the same town, resulted in a 1920 patent for cinema film spools that reduced wear and tear on the film material.

As economic actors, nineteenth-century women have a visible presence largely as unskilled workers in factories, as sole proprietors, petty producers, and as passive investors in markets for 'safe' securities. 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

restrictive social norms.⁴⁸ The records for women inventors reveal a much more complex reality, in which women of all backgrounds were engaged in creative endeavours that encompassed the entire range of technological discovery, from conception through commercialization. Contemporary feminists drew attention to women's inventions that were technically sophisticated, and those that made lasting contributions to the annals of industrial machines and production innovations. Nevertheless, since all women participated in the market as consumers and household managers, it is not surprising that, regardless of their formal occupations, a significant fraction of their contributions were related to their role in the home and the family. This household-orientation was especially evident in the case of award-granting institutions, where women tended to display unique works of arts and craft, clothing, household appliances, and other forms of unpatentable domestic enterprise. In short, the majority of women's inventions exploited and demonstrated their comparative advantage in household activities and consumer-oriented products.

III | HOUSEHOLD AND CONSUMER-ORIENTED INNOVATIONS

The information in section II showed that the subject matter of feminine technologies tended to vary significantly from those of male inventors, just as their employment experiences differed. According to some historians, a specialization by gender was evident in the nineteenth century, whereby men were associated with 'production, competition, and material gain' and women belonged to a sphere that encompassed 'ideal virtues, beauty, and consumption'.⁴⁹ However, such claims have not been subjected to systematic empirical analysis. This section therefore tests the hypothesis that the patterns of inventive activity and innovation varied by gender in terms of their industrial distribution and their contributions to consumer final goods and improvements in designs.⁵⁰ If this were indeed the case, the results would suggest that a better understanding of 'feminine ingenuity' requires a broader perspective than the conventional focus on production technologies, steam engines, and heavy-industry machine inventions that usually dominate accounts of the history of technology during the British Industrial Revolution.

The lack of empirical research into women's contributions to invention and innovation during the British Industrial Revolution largely owes to the dearth of readily available data sources. This study supplements patent documents with original archival data from prize-granting institutions such as the Royal Society of Arts (RSA), which offers information on a more diverse population of innovations and imitations.⁵¹ Since there were minimal rules, no application fees, and no examination process, prize-oriented institutions were functionally equivalent to an unfiltered open-access registration system. Panels of judges in decentralized committees granted awards in a demonstrably idiosyncratic fashion, on the basis of a wide array of demonstrably arbitrary criteria that ranged from novelty to aesthetics and even characteristics of the entrants.⁵² The

⁴⁸ For a discussion, see Steinbach, 'British history'.

⁴⁹ Owen, 'Rookwood', p. 16. This echoes an earlier declaration that 'woman is not undeveloped man but diverse' ('Another Woman's Year', *Morning Post* (London, England) 29 December 1893). See also <u>Blaszczyk</u>, *Imagining consumers*.

⁵⁰ The law of product designs and commercial art requires a precarious balance on the borders of patent, copyright, and trademark laws. In England, designs were first covered by the copyright protection laws of 1787.

⁵¹ Further details appear in Khan, 'Royal Society of Arts'.

⁵² Khan, 'Inventing prizes'; eadem, 'Premium inventions'. The Centennial Exhibition rules, for example, provided that 'awards should be based upon ... considerations relating to originality, invention, discovery, utility, quality, skill, work-

organizers encouraged women to submit entries, expecting that their visually appealing displays would attract more visitors.⁵³ These often unpatentable innovations cannot be usefully counted with patented inventions, but rather illustrate the diverse types of creativity that fell outside the defined and exclusive boundaries of the formal patent system.

The conventional approach to the economics of technology centres on inelastic supply-side advances in producer goods and inputs that cause outward shifts in the production possibility frontier of a society. Allocative efficiency, on the contrary, reflects movements along the production possibility frontier that improve consumer welfare without increasing productive possibilities, holding other things constant. A small number of theorists have recently started to explicitly incorporate consumer goods in their models of economic growth.⁵⁴ Although it is acknowledged that improvements in the nature and quality of consumer products and design innovations might have a direct impact on household and social utility, such innovations are difficult to locate, measure, and quantify at an aggregate level. In the final analysis, 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 and in hedonic models. Tratjenberg's 'Product innovations', for instance, assessed the uniqueness and degree of substitutability of one good relative to others in the same product 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 inventive activity.⁵⁵ Bresnahan and Gordon contended 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'.⁵⁶ This heuristic of approaching technological innovation in terms of broad categories – 'the' jet plane, telephone, radio, automobile, or computer – fails to accurately characterize the essentially incremental nature of the inventive process. Even more important, this approach has negative implications for the economic analysis and valuation of women's technological contributions, which tend to lie well within the boundaries of such categories.⁵⁷

It is ironic that a similar orientation was evident among nineteenth-century feminists, who were determined to prove male-female equivalence by highlighting heroines of invention, however atypical, who furthered their political objectives. They vowed 'to make no note of the

manship, fitness for the purposes intended, adaptation to public wants, economy and cost', *Report of the United States Centennial Commission* (Philadelphia, PA, 1877), p. 15.

⁵³ 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*, 51 (1874), p. 396.

⁵⁴ See, for instance, Gualerzi, 'Growth theory'.

⁵⁵ Khan, 'Premium inventions'.

⁵⁶ Bresnahan and Gordon, New goods, p. 12.

⁵⁷ The feminine approach to creativity has typically been deprecated as 'trivial': 'Most of these inventions as might be expected, are of a trivial character – dress-protectors, clothes pins, churns, milk-coolers, wash-basins, garment stiffeners, and so forth', 'Female Inventors', Monday, 11 October, 1880, *Western Daily Press* (Yeovil, England). A thoughtful examination of related issues is presented in Bianchi, 'Novelty' and Bils and Klenow, 'Variety'.

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'.⁵⁸ Accordingly, they adopted the 'great inventor' model, in which women were urged to patent technically demanding machines that could be deemed to be comparable with men's discoveries. Many leaders in the women's movement dismissed traditionally female activities such as housework and denied the importance of incremental 'feminine technologies'.⁵⁹ The organizers of the Women's Pavilion at the 1893 World's Columbian Exposition, for example, were appalled to find that the submissions predominantly consisted of ordinary household products such as kitchen tools, furniture, and apparel.

The patent system's focus on novel ideas further fits awkwardly with the mercantilist approach that was evident in early British technology policies. The definition of novelty in technological innovation was restricted to within national boundaries, and the objective was often to re-create, or offer patents of importation for, foreign technologies that could have been obtained more cheaply through free trade. The stated intent of the Royal Society of Arts and allied 'encouragement' institutions was to 'embolden enterprise, enlarge science, refine art, improve our manufacturers and extend our commerce', and they offered awards for the domestic production of verdigris, Turkey red dyes, laces, madder, and marbled paper whose quality and design matched already-existing consumer goods from Europe.⁶⁰ Within the context of a closed economy, the recreation or adaptation of foreign goods increased domestic consumption possibilities. Moreover, this form of import substitution was often directed towards industries where women's innovations were disproportionately represented.

The allocation of patents by industry of final use (figure 3) in part reflects comparative advantage among women inventors. This graph indicates that the overall sectoral ranking of women's patenting was largely invariant over time, even in the context of such major changes as the 1884 fall in costs in the patent system. Nevertheless, the patterns after the shift to cheaper patents suggest that the lower fees induced more inventive activity from women inventors who were producing improvements related to the household, clothing, and the arts. In other words, technologies disproportionately associated with female inventiveness such as apparel and kitchen appliances were more elastic in supply with regard to the cost of patenting. Conversely, it was just such inventions that had been deterred by the higher fees and administrative costs prior to the reforms in the patent laws.

At the same time, a stark distinction existed between the industrial allocation of inventions that had been patented, and the predominantly unpatentable items submitted elsewhere to exhibitions and prize-granting institutions such as the Royal Society of Arts (table 3). This was most evident in the 86.7 per cent of women's entries in the category of arts and education. Many of these innovative women who were responsible for the patenting of such items as corsets, tapestries, and apparel inventions also devised improvements at the boundary of design, art, and technology. In 1883 Alberta Caspar, the founder of Caspar's Original Crystoleum Company, invented and commercialized a popular 'crystoleum' method of painting coloured photographic images onto glass, a process which one reviewer termed 'art mechanical work'. Lisbeth Lindemann claimed patent protection in 1898 for the creation of decorative glass panels with 'the purpose of obtaining an extraordinarily favourable gay light and colour effect'. Mary Eunson, a china and porcelain decorator from Glasgow, invented a furnace or oven in 1901 that would more effectively burn the colours onto the fired wares.

⁵⁸ Cited in Weiman, Fair women, p. 429.

⁵⁹ Siegel, 'Home as work'.

⁶⁰ Khan, 'Royal Society of Arts'.



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FIGURE 3 Industrial distribution of women's patents before and after 1883 fall in filing fees (percentages). *Notes and sources*: see Appendix. Patents were allocated to industry of final use.

The majority of women's inventions invariably related to clothing and improvements for the home and household. For instance, in 1737, Jane Vanef, a widowed maker of petticoat hoops, patented 'a way of compressing the hoops of skirts to allow for entry and exit into carriages, churches and other enclosed spaces'. The apparel category received a new direction and impetus towards the end of the nineteenth century, when the mania for cycling inspired and induced over 5000 patents for related inventions in 1897 alone, many of which were by women.⁶¹ Female inventors applied for 702 patents, 21.1 per cent of which were for clothing and 15.1 per cent related to bicycles. There was an upsurge in applications to protect 'rational dress' that was fit for female cyclists, as well as inventions for the machinery of the bicycles themselves. The Pease sisters from Yorkshire – Mary Elizabeth and Sarah Anne – obtained an 1895 patent for a skirt that could be transformed into a cape for 'lady cyclists' that allowed for a more modest garment to conceal the figure after dismounting from the machine. Elizabeth Ann Williams submitted two applications at the end of 1897 for a metal tubing for the frame of the cycle and a material to resist punctures on pneumatic tyres. The following year, Katharine Norie invented an improved version of handlebars for velocipedes.

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). A few of these grants were for machinery and producer inventions, but the majority of the improvements in clothing (broadly defined) typified the sort of consumer final goods that were difficult to distinguish from designs. When

⁶¹ According to Lady Mabel Howard, whenever the cycling fad seemed to wane, the appearance of a new patent 'will still cause excitement and be run after', 'Some Practical Notes on Cycling', *Badminton Magazine*, 6 (1898), p. 161. See also Gray and Peteu, 'Cycling attire'; Shephard, 'Dress patents'; Jungnickel, *Bikes and bloomers*.

Beatrice McMaster of Surrey, England, obtained patent no. 15 739 (1916) for a glove for waiters, she used the word 'elegant' four times to describe her invention, adding that she preferred to add a border of lace when the item was for a woman. Ethel Eva Levien's 1900 patent for 'improved women's cycling knickers', were 'more graceful in appearance and more convenient in every way from a hygienic point'. Other women's patents similarly frequently conflated the item's appealing appearance with its functional utility.⁶² Such inventors were clearly responding to the nature of demand in the market for these items, since variation in style and look for women's clothing offered a commercially valuable form of product differentiation. Moreover, because the potential market was large, 'small feminine technologies' could prove to be extremely profitable, encouraging several professional women inventors to specialize in such creations.

According to contemporaries, 'Nine-tenths of [women's] patents have for their object the making of household life pleasanter'.⁶³ The fractions might not be entirely accurate, but it was undoubtedly the case that household-oriented discoveries occupied the attention of a large number of women inventors, accounting for 23 per cent of all patents. Mary Jane Arch, a London housewife, came up with the idea of designing compact combination furniture in 1907 because she had noticed that in small flats 'a bed of large size occupies so considerable an amount of space that... the room when fully furnished presents an extremely crowded appearance'. In 1910, another married woman, Emma Stevens, patented a secreted 'detective camera', that would automatically capture a photograph of any burglars entering a home and further turn on all the lights in the building. In 1910 Lady Amy Baker used ceramics techniques to devise a means of making artificial marble which could be polished to a high gloss. Such inventions might not have been on the technical frontier, but they still had the potential to generate significant economic value because they met the needs and concerns of householders.

Table 4 presents evidence regarding the hypothesis that inventive activity and innovation covaried with gender and by institution. The entries from both the patent records and exhibitions were categorized to identify consumer-goods inventions and designs integrating art and technology. Women who obtained patents were already engaging in the marketplace for ideas. As might be expected, the proportion of utility patents that were related to changes in designs was lower than in the case for consumer final goods, and these patterns were more similar across countries. About 43.4 per cent of the patented inventions in Britain were made up of consumer final goods, and only 15.5 per cent consisted of novel designs. At the same time, female creativity extended well beyond the boundaries circumscribed by formal intellectual property, and such records offer valuable evidence regarding the nature of female innovativeness within the household, much of which was unpatentable. Moreover, the difference between the inventive activity of men and women is especially striking in terms of items displayed at exhibitions and prize-granting institutions.

The Royal Society of Arts archives offer a prominent and reliable sample of unpatented inventions, since applicants for RSA awards were prohibited from obtaining patents.⁶⁴ Some

⁶² Textual searches of patent specifications for terminology regarding aspects of beauty or appearance results disproportionately in those by female inventors. For example, Sarah Jane Pacey, a 'Hotel Manageress' in Liverpool, invented an ornamented set of fasteners that would hold back curtains in folds to 'produce a gracefully draped appearance'. As a contemporary article noted, 'the world of labour is already indebted to them to an almost unknown extent for new comforts and facilities for beautifying and smoothing the ways of life', *The Englishwoman's review*, 1885, p. 398.
⁶³ Ibid.

⁶⁴ The RSA was founded in 1754 and adopted progressive policies towards women. It was the first such institution in Britain to directly solicit participation by women: 'The ingenious, of both sexes, are invited to submit their works and their inventions to the inspection of the Society', *Transactions of the Society of Arts*, 16 (1798), p. xvii.

	В	ritain	United States	
Patents	Number	Percentage	Number	Percentage
Women				
Consumer final products	1340	43.4	704	30.7
Design innovations	480	15.5	458	19.9
Unpatented Innovations	Number	Percentage	Number	Percentage
Women				
Consumer final products	243	92.4	2250	74.4
Design innovations	246	93.5	2468	81.6
Men				
Consumer final products	1210	54.9	593	19.1
Design innovations	1190	54.3	380	12.2

TABLE 4 Consumer final goods and design innovations in Britain and the Unit	ted States
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Notes: See previous tables.

Source: See Appendix, and notes to previous tables.

10 per cent of total awards were given out for contributions by women, for technological inventions as well as excellence in producing handmade goods such as spinning, knitting threads for lace, and the making of starch. In 1824, for example, numerous awards were granted to women from various parts of the United Kingdom who had made bonnets using local materials. Other inventions included a waterwheel and a lever that could be used for raising earth in building, but these were atypical. Almost all of the items women submitted were consumer final products and improvements in design, which can be compared with approximately half of the innovations for which men received awards.⁶⁵

The contrast between men's and women's activity at exhibitions is even more evident among the participants in US cities, as presented in table 4. Only 19.1 per cent of US men's exhibits consisted of consumer final products, and even fewer of them related to product design. By way of contrast, three-quarters of the women's exhibits were consumer goods, and designs comprised an even larger proportion. The variance in the technical inputs of women's entries was extremely high, ranging from decorative wall hangings, pleated rugs, lace tatting, and artificial flowers to improvements in dishwashers and sewing machine components. Many of these changes in materials or designs or new colours would not have met the rules for patentability, but the reports of the juries testify to the notable degree of creativity evinced by these contrivances by women. However, relative to female patentees and to male exhibitors, women at both domestic and international exhibitions were significantly less likely to receive gold medals and other forms of recognition, in part due to the type and quality of their inventions. The proportion of women exhibitors who earned medals approximated patenting rates: just 25 (0.5 per cent) obtained a gold medal, 157 (3.1 per cent) silver medals, and 86 (1.7 per cent) received bronze medals. Still, such recognition provided valuable advertisement and publicity that could enhance social and business reputations and lead to more profits for traders.

Graeme Gooday has similarly demonstrated the need to address aesthetic elements when analysing the interaction between gender and technology, and his study of 'decorative electricity'

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⁶⁵ Female recipients predominantly obtained awards in 'the Polite Arts', for creations such as Hannah Chambers' candelabra design.

identifies how 'female voices promoted artistic lighting in the cause of domestic electrification'.⁶⁶ Moreover, in addition to actively engaging with electrical products as innovative users, women were committed to 'aestheticizing electricity' as inventors of new goods. The specification of Ethel Burrell's 1926 patent for electric light shades emphasized that the invention was 'constructed in an effective and artistic form ... which will at the same time give a translucent and crystalline effect closely resembling that of expensive artistic glass ware'. In 1930, Alice Avery Price of New York, the co-owner of the Display Lighting Company, applied for a British patent for 'improvements in decorative lighting', involving a prismatic chandelier that produced multi-coloured spots of light.⁶⁷ This aesthetic sensibility characterized women's creativity, both within and especially beyond the patent system. As the 1897 catalogue of the Victorian Era Exhibition noted, the display for women inventors 'excels in matters of taste, such for instance as dresses, decorations, and other devices for beautifying the home'.

IV | CONCLUSION

Technological change and its role in generating economic growth and social transformation have been well studied, but feminist researchers point to the continued lack of attention regarding gender biases in the history of technology. According to Bray, 'in the Western nations which pioneered industrialization ... technology is firmly coded male'.⁶⁸ Historians have called for more inclusive approaches that can expand the scope of technology research beyond industrial hardware to encompass the application of women's specialized skills and knowledge.⁶⁹ Such scholars reject conventional assumptions that men are producers of machines and valuable discoveries whereas women feature predominantly as consumers of technology. These concerns are reflected in the dissatisfaction of a number of economists with the current state of theoretical and empirical approaches to technology, especially in the existing need to account for innovations that transform or adapt characteristics of existing products into differentiated goods with higher market demand.

This paper presents the first comprehensive empirical study of women inventors in Britain during the first and second industrial revolutions. The panel dataset of several thousand inventors and inventions was compiled from patent records, prizes, and exhibits at industrial fairs and related institutions, as well as biographical information from city directories, probates and population censuses, among others. The analysis addresses major facets of inventive activity by capturing machine-oriented discoveries that were likely to be protected by patents, as well as the unpatentable inventions and innovations that women were disproportionately devising to exploit their comparative advantage. Although it is inherently impossible to determine the representativeness of such a sample relative to the entire population of innovators, the results offered broader insights than could be obtained from case studies of individuals and inventions,

⁶⁶ Gooday Electricity, p. 187, outlines the efforts of Alice Gordon in promoting 'Decorative Electricity'.

⁶⁷ This patent was cited by 19 other inventors, an indicator of its technical value.

⁶⁸ Bray, 'Gender', p. 38.

⁶⁹ According to Wajcman, 'Feminist theories', p. 144, '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'.

as well as providing a more systematic assessment of women's creativity in both the market and nonmarket household sector.

These findings challenge the standard conclusions about the nature of women's economic and social involvement in the nineteenth century and, more broadly, their role in industrialization. Middle-class women did not choose to retreat away from the marketplace and from participation outside the domestic sphere, as many have claimed. The experience of women inventors and innovators highlights the hidden nature of their extensive participation in business, entrepreneurship, and management oversight of sole proprietorships as well as large-scale enterprises. Women in the household, notably, were also directing their efforts towards improvements in familial wellbeing and social welfare. It is worth noting that their inventive and commercial endeavours were not limited to any particular age, 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 difficulties in accounting for the role of women in technological progress arises because their contributions defy conventional categorizations and lie at the intersection of male-defined boundaries. Perhaps the most noteworthy finding from the empirical investigation of women's creativity is that it reveals the widespread prevalence of innovations in consumer goods and designs, well beyond the capital goods sector. 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. These extensive quantitative records, which 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 technology embedded in new varieties of standard goods, as well as in subtle changes in function and perceived value that accompanied improvements at the interstices of art and technology. As such, this study of women's inventive activity and innovation suggests that economic research currently significantly underestimates the extent of technological progress and advances in consumer welfare attained within households and the market economy.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Allen, R. C., The British industrial revolution in global perspective (Cambridge, 2009).

- Bianchi, M., 'Novelty, preferences and fashion: when goods are unsettling', *Journal of Economic Behavior & Organization*, 47 (2002), pp. 1–18.
- Bils, M. and Klenow, P. J., 'The acceleration in variety growth', American Economic Review, 91 (2001), pp. 274– 280.
- Blaszczyk, R. L., Imagining consumers: design and innovation from Wedgwood to Corning (Baltimore, MD, 2000).

Boehm, K. and Silberston, A., British patent system, vol. 1, Administration (Cambridge, 1967).

- Bottomley, S., The British patent system during the industrial revolution 1700–1852: from privilege to property (Cambridge, 2014).
- Bray, F., 'Gender and technology', Annual Review of Anthropology, 36 (2007), pp. 37-53.
- Bresnahan, T. F. and Gordon R. J., eds., The economics of new goods (Chicago, IL, 2008).
- Bruton, E., 'The life and material culture of Hertha Marks Ayrton (1854–1923): suffragette, physicist, mathematician and inventor', *Science Museum Journal*, Autumn(2018) online: http://doi.org/10.15180/181002
- Combs, M. B., 'Cui bono? The 1870 British married women's property act, bargaining power, and the distribution of resources within marriage', *Feminist Economics*, 12 (2006), pp. 51–83.
- Cordato, M. F., Representing the expansion of woman's sphere: women's work and culture at the world's fairs of 1876, 1893, and 1904 (New York, 1989).
- Crafts, N., 'Steam as a general purpose technology: a growth accounting perspective', *Economic Journal*, 114 (2004), pp. 338–351.
- Darney, V. G., 'Women and world's fairs: American international expositions, 1876–1904' (unpub. Ph. D. thesis, Emory University, Atlanta, GA, 1982).
- Dublin, T., Transforming women's work: New England lives in the industrial revolution (Ithaca, NY, 1994).

Dutton, H. I., *The patent system and inventive activity during the industrial revolution*, *1750–1852* (Manchester, 1984). Edgerton, D., *Science, technology and the British industrial 'decline'*, *1870–1970* (Cambridge, 1996).

- Federico, P. J., 'Historical patent statistics 1791-961', Journal of Patent Office Society, 46 (1964), pp. 89-171.
- Gooday, G., Domesticating electricity: technology, uncertainty and gender, 1880-1914 (Abingdon, 2015).
- Gray, S. H. and Peteu M. C., "Invention, the angel of the nineteenth century": patents for women's cycling attire in the 1890s', *Dress*, 32 (2005), pp. 27-42.
- Griliches, Z., 'Patent statistics as economic indicators: a survey', *Journal of Economic Literature*, 28 (1990), pp. 1661–1707.
- Gualerzi, D., 'Growth theory, structural dynamics and the analysis of consumption', in R. Arena and P. L. Porta, eds., *Structural dynamics and economic growth* (Cambridge, 2012), pp. 181–203.
- Jordan, E., 'The exclusion of women from industry in nineteenth-century Britain', *Comparative Studies in Society* and History, 31 (1989), pp. 273–296.
- Jungnickel, K., Bikes and bloomers: Victorian women inventors and their extraordinary cycle wear (Cambridge, MA, 2018).
- Kay, A. C., The foundations of female entrepreneurship: Enterprise, home and household in London c.1800–1870 (2009).
- Khan, B. Z., 'Married women's property laws and female commercial activity: evidence from United States patent records, 1790–895', *Journal of Economic History*, 56 (1996), pp. 356–388.
- Khan, B. Z., "Not for ornament": patenting activity by nineteenth-century women inventors', Journal of Interdisciplinary History, 31 (2000), pp. 159–195.
- Khan, B. Z., The democratization of invention: patents and copyrights in American economic development (New York, 2005).
- Khan, B. Z., 'Premium inventions: patents and prizes as incentive mechanisms in Britain and the United States, 1750–930' in D. L. Costa and N. R. Lamoreaux, eds., Understanding long-run economic growth: geography, institutions, and the knowledge economy (Chicago, 2011), pp. 205–234.
- Khan, B. Z., 'Selling ideas: an international perspective on patenting and markets for technological innovations, 1790–930', *Business History Review*, 87 (2013), pp. 39–68.
- Khan, B. Z., 'Inventing prizes: a historical perspective on innovation awards and technology policy', *Business History Review*, 89 (2015), pp. 631–660.

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ECONOMIC HISTORY REVIEW

- Khan, B. Z., 'Invisible women: entrepreneurship, innovation and family firms in nineteenth-century France', *Journal of Economic History*, 76 (2016), pp. 163–195.
- Khan, B. Z., 'Prestige and profit: the Royal Society of Arts and incentives for innovation, 1750–1850', *NBER WP no. w23042* (Cambridge, MA, 2017).
- Khan, B. Z., 'Human capital, knowledge and economic development: evidence from the British Industrial Revolution, 1750–1930', *Cliometrica*, 12 (2018), pp. 313–341.
- Kuegler, A., 'The responsiveness of inventing: evidence from a patent fee reform,' *Cambridge University Working Paper* (Cambridge, 2016).
- MacLeod, C., Inventing the industrial revolution: the English patent system, 1660-1800 (Cambridge, 2002).
- MacLeod, C., Heroes of invention: technology, liberalism and British identity, 1750-1914 (Cambridge, 2007).
- MacLeod, C. and Nuvolari A., 'The pitfalls of prosopography: inventors in the dictionary of national biography', *Technology and Culture*, 47 (2006), pp. 757–776.
- MacLeod, C. and Nuvolari A., 'Inventive activities, patents and early industrialisation: a synthesis of research issues', *Rivista di storia economica*, 32 (2016), pp. 77–108.
- Marçal, K., Mother of invention: how good ideas get ignored in an economy built for men (New York, 2001).
- Martineau, R., 'Science and technology: where are the women?', Techno-Innovation, 38 (1998), pp. 12-18.
- McGaw, J. A., 'Reconceiving technology: why feminine technologies matter', *Gender and Archaeology* (1996), pp. 52–75.
- McGaw, J. A., 'Inventors and other great women: toward a feminist history of technological luminaries', *Technology* and Culture, 38 (1997), pp. 214–231.
- Ó Gráda, C., 'Did science cause the industrial revolution?' Journal of Economic Literature, 54 (2016), pp. 224-239.
- Oldenziel, R., Making technology masculine: men, women and modern machines in America, 1870–1945 (Amsterdam, 1999).
- Owen, N. E., 'On the road to Rookwood: women's art and culture in Cincinnati, 1870–1890', *Ohio Valley History*, 1 (2001), pp. 4–18.
- Palliser, B., History of lace (London, 1865).
- Pennington, S. and Westover B., A hidden workforce: women homeworkers in Britain, 1850–1985 (New York, 1989).
- Romney, C., 'Women as inventors, and the value of their inventions in household economics', *Journal of Industrial Education*, 9 (1894), pp. 1–11, 22–6.
- Shephard, A. J., 'Waterproof dress patents as evidence of design and function from 1880 through 1895', *Clothing and Textiles Research Journal*, 30 (2012), pp. 183–199.
- Siegel, R., 'Home as work: the first woman's rights claims concerning wives' household labor, 1850–1880', Yale Law Journal, 103 (1994), pp. 1073–1217.
- Sokoloff, K. L., 'Inventive activity in early industrial America: evidence from patent records, 1790–1846', *Journal of Economic History*, 48 (1988), pp. 813–850.
- Sokoloff, K. L. and Khan, B. Z., 'The democratization of invention during early industrialization: evidence from the United States, 1790–1846', *Journal of Economic History*, 50 (1990), pp. 363–378.
- Steinbach, S., 'Can we still use "separate spheres"? *British history 25 years after Family fortunes*', History Compass, 10 (2012), pp. 826–837.
- Styles, J., 'Product innovation in early modern London', Past and Present, 168 (2001), pp. 125-131.
- Sullivan, R. J., 'Estimates of the value of patent rights in Great Britain and Ireland, 1852–1876', *Economica* (1994), pp. 37–58.
- Summers, L., Bound to please: a history of the Victorian corset (Oxford and New York, 2001).
- Swanson K. W., 'Getting a grip on the corset: gender, sexuality and patent law', Yale Journal of Law and Feminism, 23 (2011), pp. 23–57.
- Trajtenberg, M., 'The welfare analysis of product innovations, with an application to computed tomography scanners', *Journal of Political Economy*, 97 (1989), pp. 444–479.
- Wajcman, J., 'Feminist theories of technology', Cambridge Journal of Economics, 34 (2010), pp. 143–152.
- Warner, D. J., 'Women inventors at the Centennial', in M. M. Trescott, ed., Dynamos and virgins revisited: women and technological change in history (Metuchen, NJ, 1979), pp. 102–119.
- Weiman, J., The fair women (Chicago, 1981).

Official publications

Catalogue Officiel, Exposition des produits de l'industrie de toutes les nations (Paris, 1856).

- Great Britain Patent Office, Annual report of the Comptroller General of patents, designs, and trade marks (various years).
- UK Intellectual Property Office, Gender profiles in UK patenting: An analysis of female inventorship (Cardiff, 2016).
- United States Patent Office, Annual report of the Commissioner of Patents (Washington DC, various years).
- Women's Bureau, Women's contributions in the field of invention, *Bulletin of the Women's Bureau*, no. 28 (Washington, DC, 1923).

Woodcroft, B., Titles of patents of invention chronologically arranged, 1617-1852 (1854-1856).

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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