Progress and Potential

A profile of women inventors on U.S. patents

PROGRESS AND POTENTIAL:
A Profile of Women Inventors on U.S. Patents

PROJECT TEAM:

This report was prepared by the Office of the Chief Economist at the U.S. Patent and Trademark Office, in collaboration with research teams from the University of Bordeaux (France) and Bocconi University, Milan (Italy). Any inquiries regarding this publication should be sent to economics@uspto.gov

Andrew A. Toole	Stefano Breschi	Ernest Miguelez
Amanda Myers	Edoardo Ferrucci	Valerio Sterzi
Charles A. W. deGrazia	Francesco Lissoni	Gianluca Tarasconi

INTRODUCTION

Hannah Wilkinson Slater is often celebrated as the first woman to receive a U.S. patent. In 1793, she received a patent for a new method of producing cotton-sewing thread. She was inspired in the mills run by her husband, Samuel Slater, who had left England as a young apprentice, undeterred by a ban preventing textile craftsmen from emigrating to the United States (Cameron, 1960; White, 1836). Interestingly, the United States issued Hannah Wilkinson Slater's patent to "Mrs. Samuel Slater," which has created some ambiguity regarding whether she was indeed the first American female patent inventor.[1] Some historians prefer to award this merit to Hazel Irwin for a cheese-press invention in 1808 (Khan, 1996) or to Mary Dixon Kies, who in 1809 was granted a patent on a new technique for weaving straw with silk and thread to make hats (United States Government, 1888). All these women, without a doubt, were exceptional for their era. Only 72 U.S. patents were credited to women inventors between 1790 and 1859, while men obtained 32,362 patents (Khan, 1996).

Even today, women comprise a small minority of patent inventors. This fact suggests that their innovative potential is underutilized. Recent research from Opportunity Insights, a research team based at Harvard University, shows disparities in opportunity across gender, race, and income. The researchers find that women are among the "lost Einsteins" — people who would contribute valuable inventions had they had early exposure to innovation and inventor role models (Bell et al., 2017). Their research suggests that harnessing underexploited talent in these groups would be valuable to spurring innovation and driving growth.[2]

To learn more about the progress and potential of women in patenting, this report studies U.S. women inventors named on U.S. patents granted from 1976 through 2016 and examines the trends and characteristics of their patents. The analysis uses new data from PatentsView (www.patentsview.org), a web-based data resource supported by the U.S. Patent and Trademark Office (USPTO) Office of the Chief Economist.[3] The key findings are summarized on the sidebar.

KEY FINDINGS

- The number of patents with at least one woman inventor increased from about 7% in the 1980s to 21% by 2016.

- Despite this increase, the percentage of all patent inventors that are women, or the annual "women inventor rate," reached only 12% in 2016.

- Notable differences in the number of male and female patent inventors persist despite greater female participation in science and engineering occupations and entrepreneurship.

- Women inventor rates are higher in technology-intensive states, but also in states where more women participate in the overall workforce.

- Women inventors are increasingly concentrated in specific technologies and types of patenting organizations, suggesting that women are specializing where female predecessors have patented rather than entering into male-dominated fields or firms.

- Women are increasingly likely to patent on large, gender-mixed inventor teams, highlighting the growing importance of understanding the relationship between gender and innovative collaboration.

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1   See: http://blogs.britannica.com/2011/03/10-key-dates-womens-history-early-modern-period/ (accessed January 3, 2018). There is ambiguity among historians regarding the first American women to receive a U.S. patent, in part, because the relevant documents were destroyed by a fire at the U.S. Patent Office in 1836. Additionally, well before the U.S. patent system was created, Sybilla Master, who devised a method for processing corn into cornmeal, was granted an English patent in 1715. Because women were not allowed to hold property at that time, the patent was issued in her husband's name. See http://www.womenhistoryblog.com/2016/01/first-women-inventors.html (accessed March 1, 2018).

2   According to Bell et al. (2017), if women, minorities, and low-income children were to invent patented technology at the same rate as white men from high-income (top 20%) households, the rate of innovation in America would quadruple. See http://www.equality-of-opportunity.org/assets/documents/inventors_summary.pdf (accessed March 1, 2018).

3   Appendix II provides a detailed description of the methodology applied to identify the gender of patent inventors based on their names and a combination of data extracted from PatentsView and other resources. Unless otherwise indicated, all graphs and figures reflect data on inventors residing in the United States. as specified on the patent grant. Key findings and trends are consistent if both U.S. and foreign resident inventors are considered.

Figure 1. Forty-Year Trends in Women Patenting
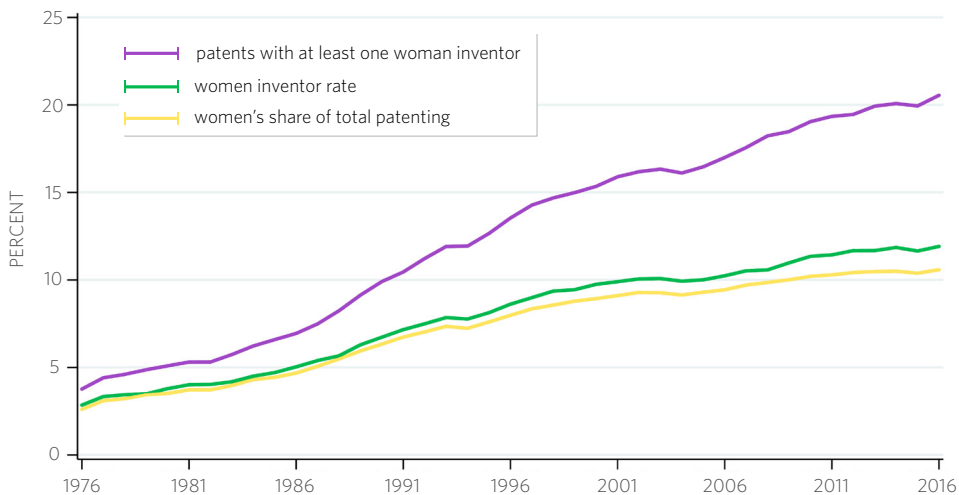
Legend:
- patents with at least one woman inventor
- women inventor rate
- women's share of total patenting

> Rather than female-only teams, mixed-gender teams are driving most of the growth in granted patents with at least one female inventor.

MORE WOMEN PARTICIPATE IN PATENTING BUT GROWTH IS SLUGGISH

Patent data can be used to construct three alternative metrics to illustrate different aspects of women's participation in invention and patenting. The main metric used throughout this analysis is the "women inventor rate." The women inventor rate is the percent of unique women inventors across all patents granted in a given year. It answers the question: What share of patent inventors are women in a given year? The other two metrics focus on patent counts to provide a "patent output" perspective on women inventors. One metric simply measures the percentage of patents granted in a given year that have at least one woman inventor.[4] The third metric, women's share of total patenting, attributes credit for patents by using the patent's inventor team. All inventors on a patent are given an equal share when the patent has multiple inventors. The resulting "fractions" of patents are summed across men and women to provide total patent output by gender for each year.

Figure 1 presents forty-year trends for the three metrics. Each measure has increased over time, but the percent of patents with at least one woman inventor (top line in Figure 1) has grown fastest, climbing from roughly 7% in the 1980s to about 21% in 2016. While this trend is promising, it should be viewed in combination with two less favorable patterns. First, growth in the percentage of patents with at least one woman inventor has slowed through most of the past 20 years (1998–2016) compared to the prior decades.

Between 1978 and 1997, the share of patents with at least one female inventor nearly tripled from 5% to 14%. Such a rapid increase is reasonable considering the share was quite low in the mid-1970s, making it easier to achieve high growth rates. Likewise, women's opportunities to invent expanded rapidly as more women entered the labor force over the period.[5] Since 1998, however, the share of patents with at least one female inventor has only increased from 15% to 21%, suggesting the pace of entry into patenting by women has slowed.[6]

Second, even though more patent inventor teams include women, the gender composition among all inventors has not changed significantly. As shown by the women inventor rate (middle line in Figure 1), through the mid-1980s women comprised less than 5% of all patent inventors. The women inventor rate only reached 10% in 2000. And in 2016, more than a decade and a half later, only 12% of patent inventors were women. Notice the women's share of total patenting (bottom line in Figure 1) follows a similar trend, but at lower levels. This difference reflects fewer patents granted per female inventor compared to males.
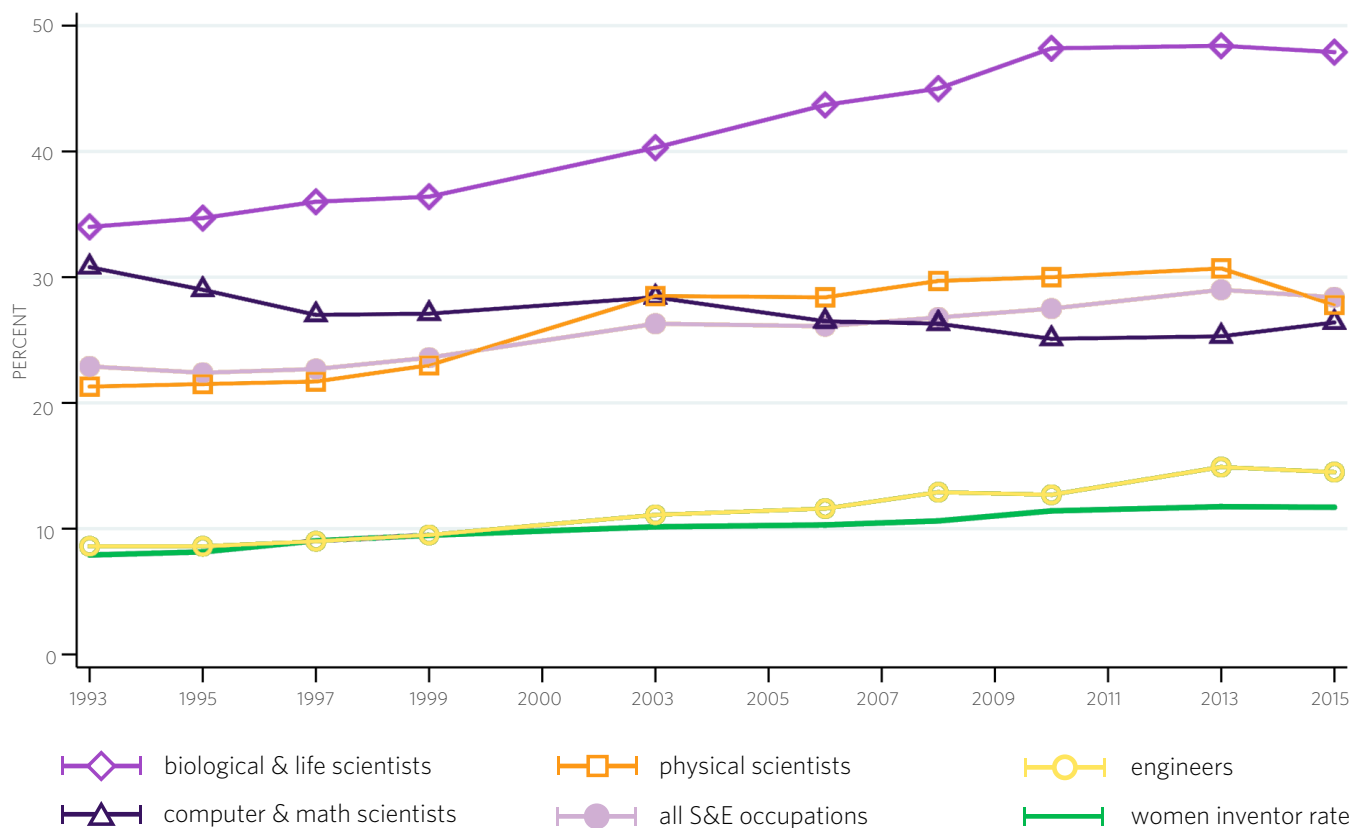
Figure 1 also shows a growing gap between the percent of patents with at least one woman inventor and the other two series, women inventor rate and total patents attributable to women inventors. This reflects overall trends in patent inventor teams. Rather than female-only teams, mixed-gender teams are driving most of the growth in granted patents with at least one female inventor. Additionally, compared to men, women are more likely to work on larger patent inventor teams. Subsequent sections consider each of these factors in more depth.

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4   Throughout the report, the percentage of patents that have at least one woman inventor is calculated for all patents with at least one U.S. resident inventor. Patents with all inventors residing outside the U.S. are excluded.

5   The percentage of women employed increased from roughly 46% in 1978 to 57% in 1997. In 2015, about 54% of women were employed. See https://www.bls.gov/opub/reports/womens-databook/2016/pdf/home.pdf (accessed March 1, 2018).

6   A series of Wald and likelihood-ratio tests indicate the annual growth rate of the percentage of patents with at least one woman inventor experienced a time-series structural break in 1998. The mean annual growth rate after 1998 was 1.9%, significantly lower than the pre-break mean of 6.2%. Simple projections suggest that maintaining the pre-break growth rate would have increased the percent of patents with a female inventor to 25% by 2006 and 30% by 2009.

Figure 2. Women Patent Inventors vs. Women in Science and Engineering Occupations

Legend:
- biological & life scientists (purple diamond)
- physical scientists (orange square)
- engineers (yellow circle)
- computer & math scientists (dark purple triangle)
- all S&E occupations (light purple filled circle)
- women inventor rate (green line)

WOMEN INVENTOR RATE REMAINS BELOW WOMEN'S SHARE OF SCIENCE AND ENGINEERING JOBS

It is widely recognized that many factors shape the opportunities for women to become patent inventors. Educational and occupational choices are two important influences.[7] Historically, science and engineering fields produce the most patentable inventions (Marco et al., 2015). Naturally, when fewer women pursue careers in science and engineering fields, they will make up a smaller share of patent inventors. To explore this further, Figure 2 compares the women inventor rate with the percentage of women in science and engineering occupations based on periodic national surveys.[8]

In 2015, women made up about 28% of the total science and engineering work-force (all S&E occupations in Figure 2) but only 12% of inventors on granted patents (women inventor rate in Figure 2). Across nearly all science occupations, women participate at a much higher rate than they invent patented technology. It is only in engineering that women's workforce participation rate (yellow, hollow circle line in Figure 2) resembles the overall women inventor rate.

> Across nearly all science occupations, women participate at a much higher rate than they invent patented technology.

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7   Observed gender differences among patent inventors reflect a wide variety of influences that ultimately shape the opportunities for men and women to become inventors. One such factor is educational background. Women make up 31% of science, engineering, technology, and mathematics (STEM) college graduates, even though they account for 60% of graduates across all degree fields (Munoz-Boudet, 2017). Within STEM fields, women comprise 18% of graduates in computer science and engineering versus 40% in life science.

8   Data on the percentage of women in science and engineering occupations is from the National Science Foundation (NSF) National Center for Science and Engineering Statistics (1993–2013) and National Survey of College Graduates (2015). Figure 2 percentages are compiled from the National Science Board Science & Engineering Indicators 2018 Report. See https://www.nsf.gov/statistics/2018/nsb20181/report/sections/science-and-engineering-labor-force/women-and-minorities-in-the-s-e-workforce#women-in-the-s-e-workforce (accessed February 16, 2018).

While biological and life science fields approach workforce gender parity (purple, hollow diamond line in Figure 2), there have not been comparable improvements in the women inventor rate for patents. In 2015, women occupied roughly 48% of biological and life scientists but represented only about 25% of inventors on biotechnology patents and 23% of inventors on pharmaceutical patents.[9]

Many patented inventions are developed by entrepreneurs that pursue their endeavors outside of traditional science and engineering occupations. Women also appear to pursue such entrepreneurial activity at a higher rate than they invent patented technology. According to national survey data, women accounted for 39% of new entrepreneurs in 2016[10], well above the women inventor rate (12%).[11] Overall, that rate remains low despite higher female participation in the scientific workforce and entrepreneurship. This suggests a potential underutilization of high-skilled, innovative talent,

particularly if various factors that prevent scientific professionals and entrepreneurs from becoming patent inventors disproportionately affect women. For example, prior research has found that female scientists face more difficulty securing funding and lack social networks that can be critical to patenting and commercializing innovations (Ding et al., 2006; Hunt et al., 2012; Meng, 2016; Murray and Graham, 2007; Rosser, 2012; Whittington, 2009).

WOMEN INVENTOR RATE IS HIGHER IN TECHNOLOGY-INTENSIVE STATES

Figure 3 illustrates how the women inventor rate differed across states during the last half-decade (patents granted 2012–2016). The figure presents an adjusted women inventor rate that takes into account the fact that women have different opportunities to invent across states.[12] In all states, the

Figure 3. Adjusted Women Inventor Rate by State, 2012-2016

0.102 – 0.144
0.145 – 0.160
0.161 – 0.182
0.183 – 0.245

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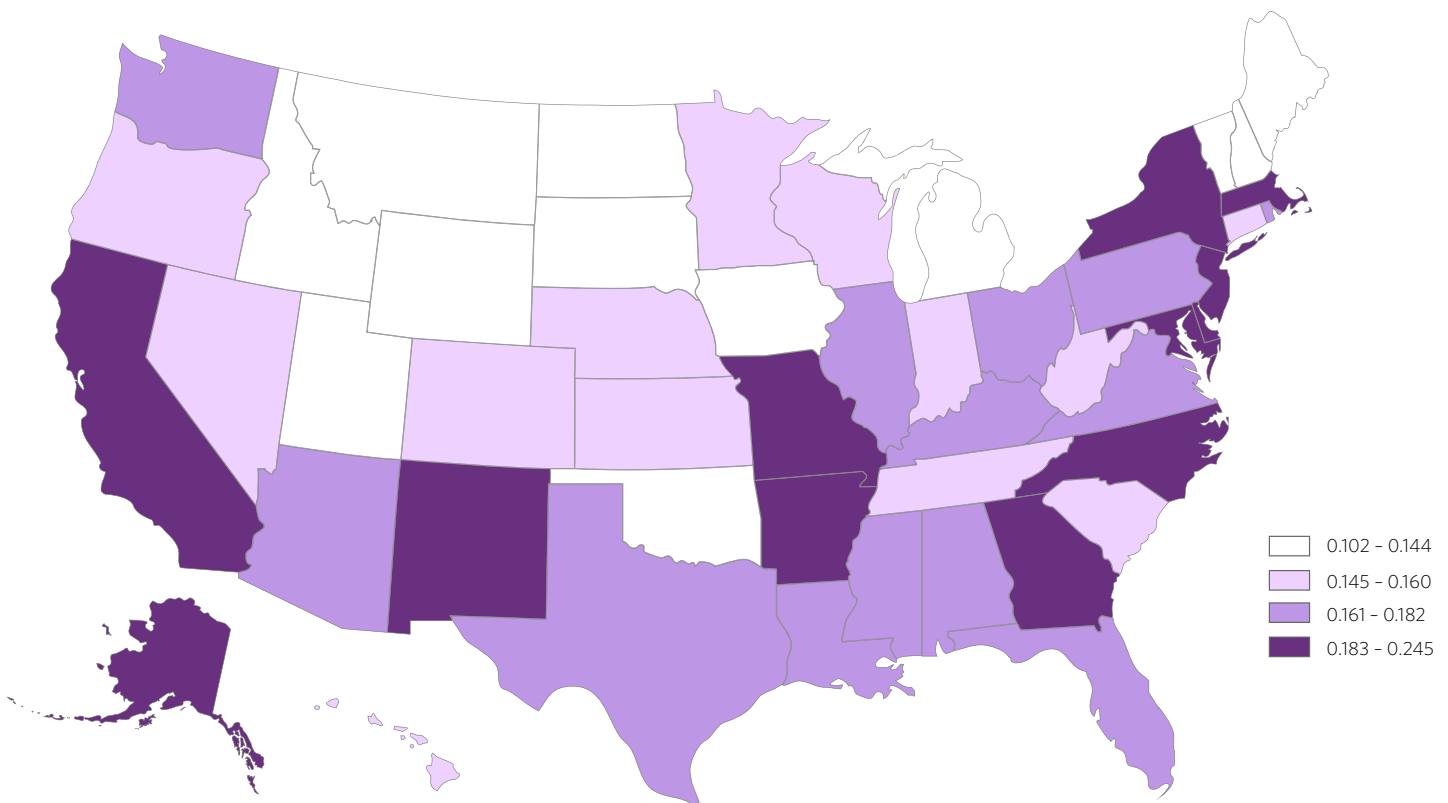
9   Based on supplemental analysis not shown.

10 Based on gender composition of new entrepreneurs as calculated by the Kauffman Foundation from the U.S. Census Current Population Survey. See Figure 2A (page 12) https://www.kauffman.org/kauffman-index/reporting/~/media/b27f0b8eb4a8414295f23870538e5372.ashx (accessed March 1, 2018).

11 There is generally a lag between entry into entrepreneurial activity and a patented invention. However, the share of new entrepreneurs that are women has consistently been well above the women inventor rate. According to the Kauffman Foundation startup activity index, women constituted roughly 35–40% of new entrepreneurs in the 2014–2016 period and 44% in 1996. See https://www.kauffman.org/kauffman-index/reporting/startup-activity (accessed March 1, 2018).

12 Being a patent inventor is strongly associated with being employed. To account for state differences in the opportunities for women to become patent inventors, Figure 3 reports the average state-adjusted women inventor rate calculated as the state's women inventor rate over the state's share of women in the labor force. When a state's adjusted women inventor rate is equal to one, the female proportion of patent inventors is equal to the proportion of women in the state's workforce. This is one concept of gender parity. A value below one indicates that a smaller share of patent inventors are women relative to the share of women in the workforce.

Figure 4. Actual Women Inventor Rate by State, 2012-2016

Figure 4. Actual Women Inventor Rate by State, 2012-2016
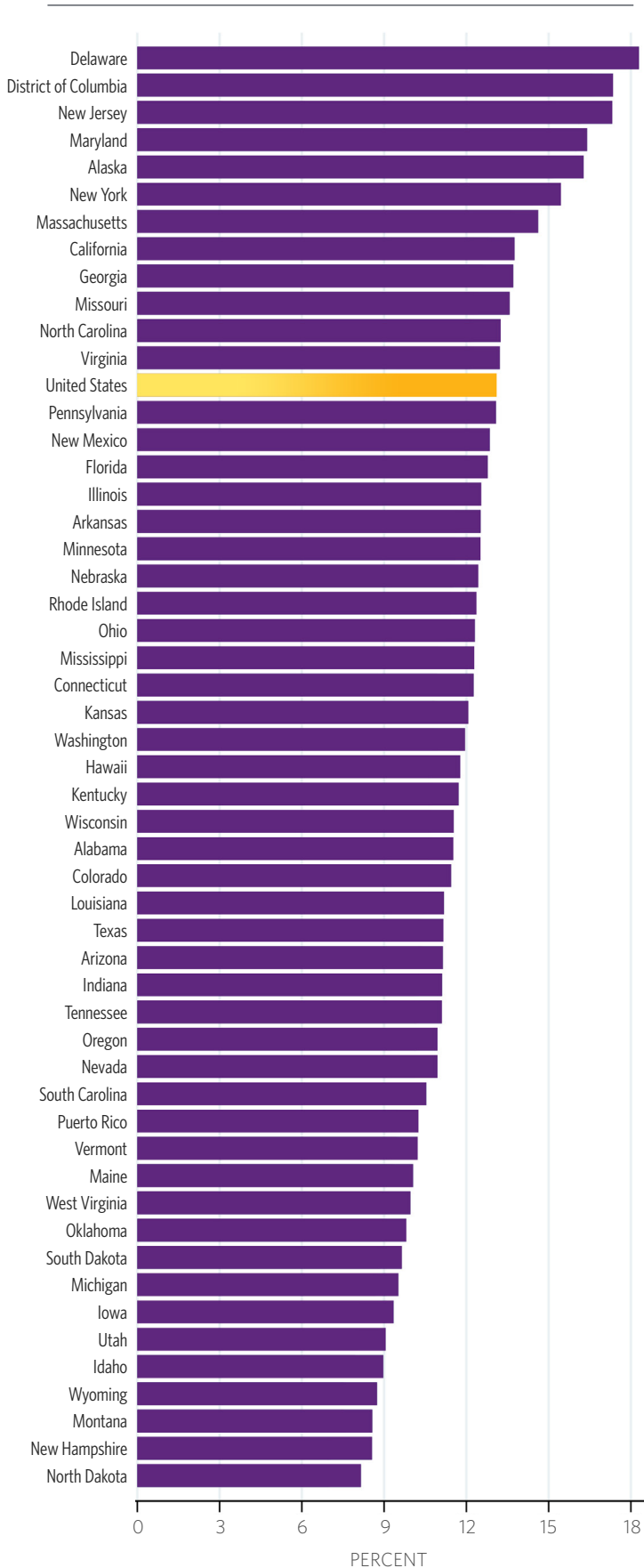
adjusted women inventor rate is below one, indicating that the female share of patent inventors is lower than the share of women in the state's workforce. Figure 4 shows the actual women inventor rate in each state for patents granted 2012–2016.

Patenting activity in the United States is heavily concentrated in a few geographical clusters, reflecting both workforce size and technological specialization (Feldman and Francis, 2004). States on both coasts, which host important technology clusters, exhibit higher adjusted and actual women inventor rates. Women comprised a relatively high share of patent inventors residing in New York (just over 15%), Massachusetts (nearly 15%), and California (14%) during the 2012–2016 period. The women inventor rate in California is particularly important because that state is, by far, home to the most patent inventors.[13]

Delaware, the District of Columbia, and New Jersey actually exhibit the highest women inventor rates (both actual and adjusted). For 2012–2016 patent grants, women accounted for just over 18% of inventors residing in Delaware and 17% of inventors residing in each of the District of Columbia and New Jersey.

In many locations with comparatively more women in the workforce, such as Alaska and Maryland, the high adjusted rates in Figure 3 reflect actual women inventor rates well above the national rate. However, Figure 3 also shows relatively high adjusted rates for Kentucky, Louisiana, and Arizona, where the female share of patent inventors is below the national rate (as shown in Figure 4) but comparatively large when accounting for lower female labor force participation in these states.

Most states with low adjusted women inventor rates in Figure 3 produce relatively few patents. Michigan, however, accounts for a sizable volume of total U.S. patents and has a low adjusted rate. Figure 4 shows that the actual women inventor rate in Michigan (nearly 10%) is well below the national rate, which may reflect the industry composition in that state.

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13   Roughly 22% of the U.S. resident inventors on patents granted 2012–2016 resided in California.

Figure 5. Women Inventor Rate by Technology Sector

Legend:
- chemistry
- design
- electrical engineering
- instruments
- mechanical engineering
- other fields

WOMEN INVENTORS ARE CONCENTRATED IN SPECIFIC TECHNOLOGIES AND TYPES OF ASSIGNEES

Figure 5 presents the women inventor rate across broad technology categories[14] for each of the past four decades. Although the female share of patent inventors has increased over time in each sector (moving from left to right), there is considerable variation in growth patterns. Women's inventive participation has improved the most in chemistry and design patents. While women accounted for only 6% of inventors on chemistry patents issued 1977–1986, they comprised roughly 18% in the last decade (2007–2016).[15] Within chemistry, certain subcategories exhibit even higher women inventor rates. In 2016, for example, women accounted for more than one-fifth of inventors granted patents in biotechnology (25% women inventor rate), pharmaceuticals (23%), and organic fine chemistry (21%).

Women's participation on patents in instruments[16] and electrical engineering[17] has also improved but to a lesser extent. Women comprised only 12% and 11% of inventors on patents in instruments and electrical engineering, respectively, in the 2007–2016 decade.

Among mechanical engineering patents,[18] where inventors are the most disproportionately male, there has been the slowest improvement in women's participation. The female share of inventors on such patents was 3% in the 1977–1986 decade and only reached 8% in the last decade observed.

> Overall, women inventor participation is improving. However, trends suggest that women are specializing in technology fields and sectors where female predecessors have patented before rather than entering into male-dominated fields or firms.

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14 Utility patents are grouped into the "WIPO technology categories" suggested by Schmoch (2008) based on the International Patent Classification. The categories reflect 5 sectors which can be further disaggregated into 35 fields. Design patents are added as a sixth sector.

15 Chemistry includes technology related to organic fine chemistry, biotechnology, pharmaceuticals, macromolecular chemistry, food chemistry, basic materials chemistry, etc.

16 Instruments include technology related to optics, measurement, analysis of biological material, control, and medical technology.

17 Electrical engineering includes telecommunications, digital communication, computer technology, IT methods for management, semiconductors, etc.

18 Mechanical engineering includes technology related to machine tools, engines, pumps, turbines, mechanical elements, transport, thermal processes and apparatus, etc.

Figure 6. Women Inventor Rate by Patent Assignee Type

UNIVERSITIES & HOSPITALS

PUBLIC RESEARCH ORGANIZATIONS

INDIVIDUAL

BUSINESS
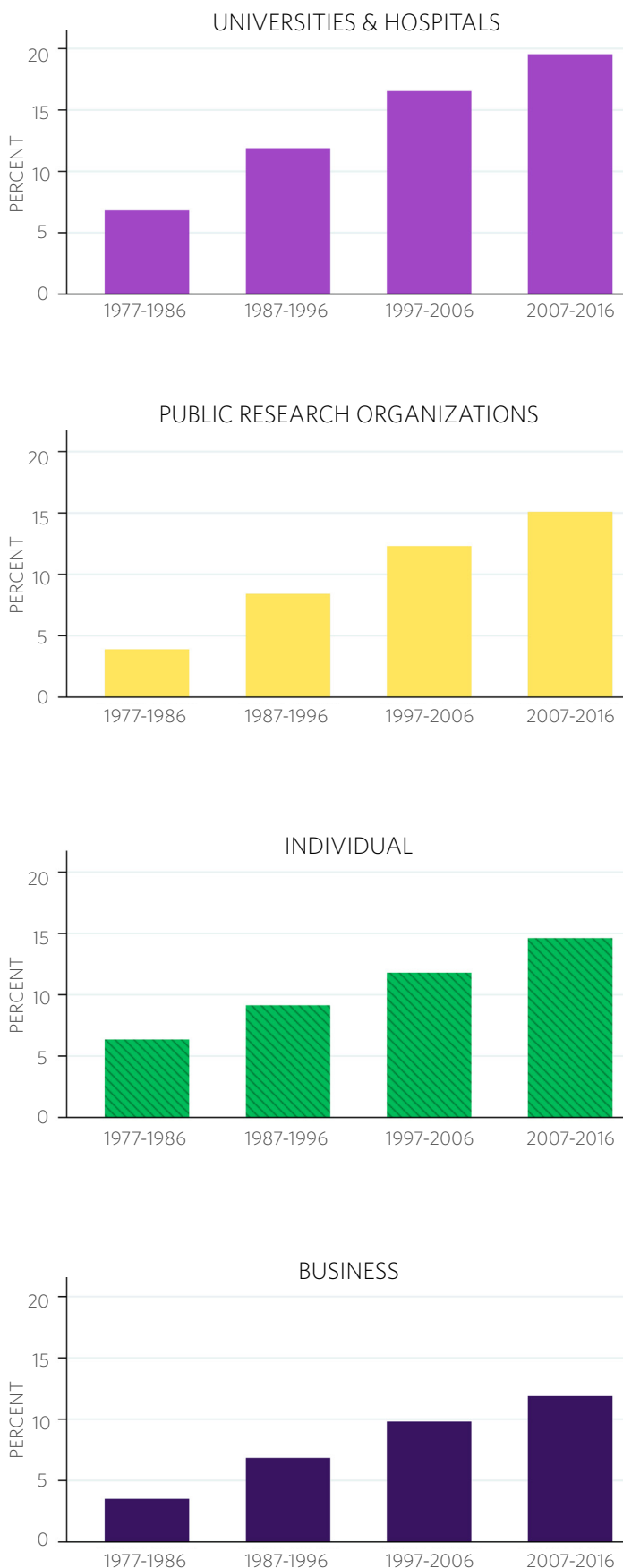
Differences in the women inventor rate across technologies are similar to those observed in the science and engineering occupations (see Figure 2). Thus, lower rates for mechanical engineering patents may merely reflect women comprising a smaller share of the workforce in that field. Still, across fields, the share of women that invent is systematically lower than the share of women working in that field.

When a patent is granted, a company, university, or other entity is assigned ownership and identified as the "assignee" of the patent. Figure 6 presents the women inventor rate for different types of assignees.[19] Once again, the female share of patent inventors is trending up across assignee types, but universities and hospitals[20] and public research organizations[21] show the largest and most continued improvement.

In the 1977–1986 decade, women accounted for only 7% and 4% of inventors on patents granted to universities and hospitals and public research organizations, respectively. In the last decade observed, just under 20% of inventors on patents assigned to universities and hospitals and 15% of inventors on patents granted to public research organizations were women. Among individual-owned patents, women constitute just under 15% of inventors in the last decade, with fairly consistent increases in the women inventor rate decade-over-decade. While the women inventor rate on patents granted to business firms is persistently the lowest, it has climbed from only 4% in the 1977–1986 period to 12% in the last decade. Overall, women patent inventor participation is improving, but most of the growth is in the technologies and organizations where women have historically been more likely to innovate. Such trends suggest that women are specializing in technology fields and sectors where female predecessors have patented before rather than entering into male-dominated fields or firms.

The women inventor rates reported in Figure 6 are consistent with the results of prior research. Previous studies find that women are more likely to be inventors on patents granted to public or not-for-profit organizations because they offer more opportunities to women than private firms (Sugimoto et al., 2015; Martinez et al., 2016). Still, since businesses account for the majority of patenting in the United States, expanding women's participation in innovative activity within firms is important to improving the women inventor rate.

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19 Patent assignee type is determined based on the method proposed by Van Looy et al. (2006) and sourced from the PATSTAT dataset. This method uses text string analysis of patent assignee names based on keyword occurrences such as "University," "Government," "Hospital," "Limited," etc. Patents with multiple assignee types were allocated to a single assignee type. Starting with all patents with multiple assignee types, those that had a university or hospital co-assignee were classified as a university and hospital assignee type. Removing these, if any of the remaining multiple assignee type patents had a public research organization co-assignee, they were classified as a public research organization assignee type. After that, all others were classified as business assignee type.

20 Universities and hospitals are considered jointly due to the large number of university hospitals among assignees.

21 Public research organizations are identified as any assignee coinciding with a governmental body.

Figure 7. Women Inventors at Select Top Patent Assignees, 2007-2016

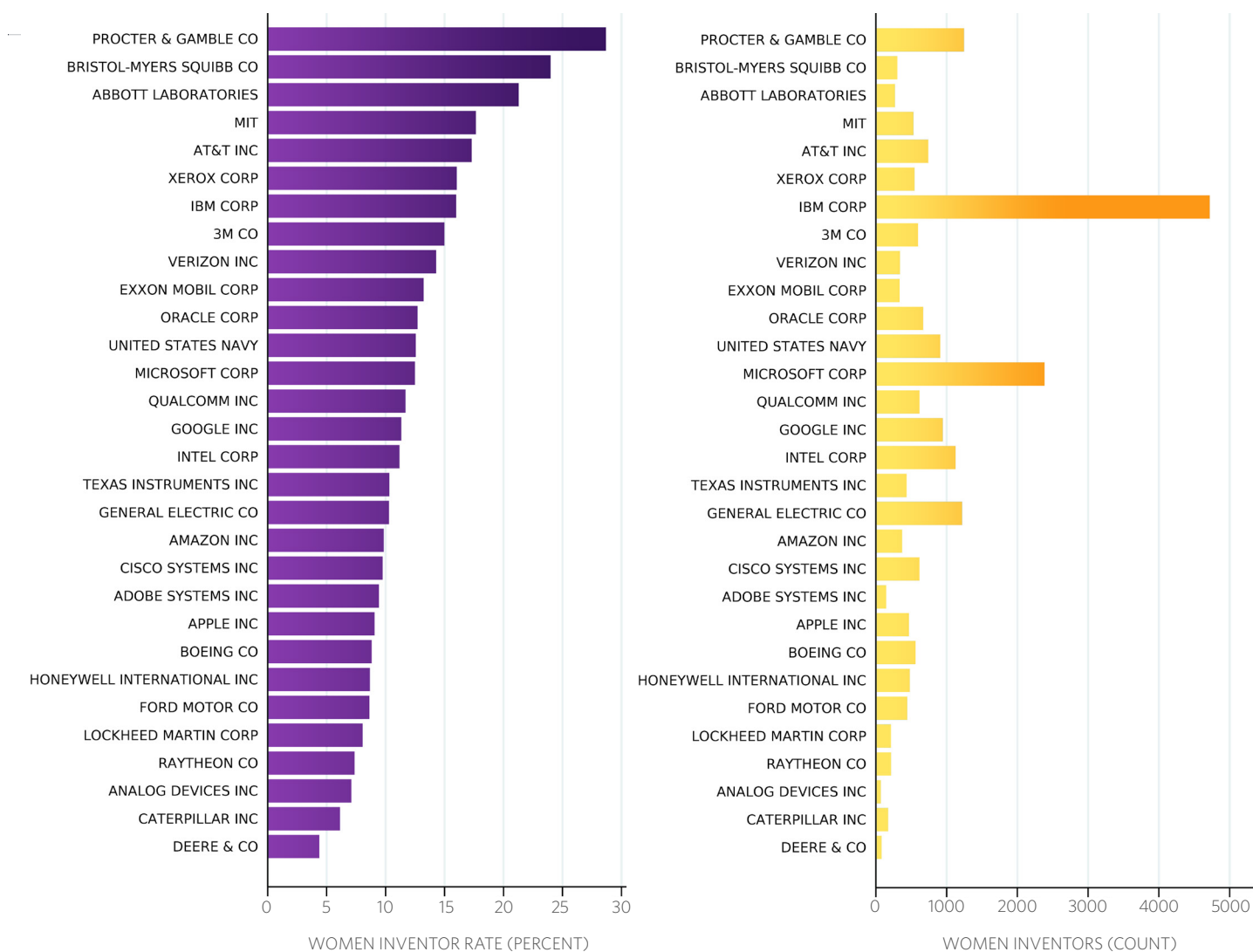WOMEN INVENTOR RATE (PERCENT)

WOMEN INVENTORS (COUNT)

Figure 7 shows the women inventor rate (left panel) and a count of the number of unique women inventors (right panel) for select top patent assignees for the 2007–2016 decade.[22] Procter & Gamble stands out as having the highest women inventor rate (nearly 29%). Likewise, IBM maintains, by far, the largest women patent inventor workforce (with over 4,500 female inventors) and has a relatively high women inventor rate (16%). Microsoft also employs a relatively large number of female inventors (more than 2,300 over the decade) though the firm's women inventor rate (just over 12%) is roughly the same as the average for all entities in Figure 7.
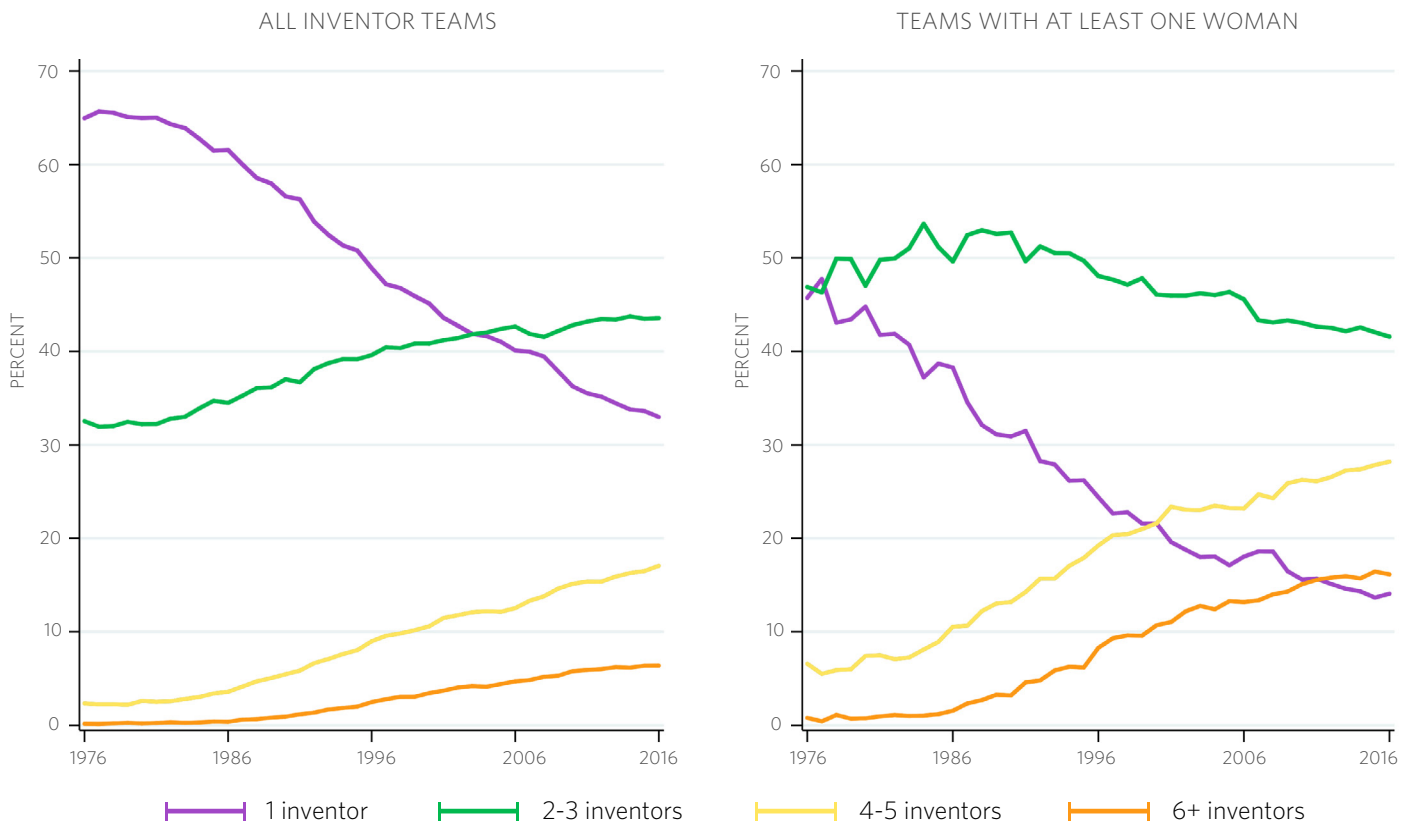
Differences in women inventor rates based on the technology and organization type are also evident for the top patent assignees. The female share of patent inventors is highest among chemical and pharmaceutical companies, like Procter & Gamble, Bristol-Myers Squibb (24%) and Abbott Laboratories (21%), as well as research universities such as M.I.T. (Massachusetts Institute of Technology) (18%). The only government entity on the list, the U.S. Navy, also has a relatively high women inventor rate (nearly 13%).

Women comprise the smallest share of patent inventors at firms with largely electrical and mechanical engineering technology, such as Deere & Co (4%) and Caterpillar (6%). Interestingly, there is considerable variation in women inventor rates across firms within the same technological sectors, such as IBM (16%) versus Qualcomm (12%) and Apple (9%).

22 Appendix III provides a detailed description of the methodology applied to calculate the women inventor rate for top patent assignees. Figure 7 presents the rate for each assignee for the entire 2007-2016 period. For most assignees included, the trend in the women inventor rate is relatively flat over this decade. The firms with upward or volatile trends are largely those with very low women inventor rates such that even their max rate over the period is comparatively low.

Figure 8. Share of Patents by Inventor Team Size

ALL INVENTOR TEAMS | TEAMS WITH AT LEAST ONE WOMAN

Legend: 1 inventor | 2-3 inventors | 4-5 inventors | 6+ inventors

WOMEN PATENT ON INCREASINGLY LARGER, GENDER-MIXED INVENTOR TEAMS

Scientific and technological production is increasingly characterized by collaboration among diversely specialized inventors (Jones, 2010; Jones et al., 2008; Wuchty et al., 2007). Accordingly, patent inventor teams have grown in size. Figure 8 illustrates how the shares of granted patents have changed over time broken out by different team sizes. The panel on the left includes all teams while the panel on the right shows trends for those patent inventor teams with at least one woman.

The left panel shows a clear decline in individual inventor patents (purple line) from comprising the majority of all issued patents in the late 1970s to 33% in 2016. Consequently, the share of patents with multiple inventors has climbed, particularly for larger teams. In 2016, over one-fifth of all patents were developed by inventor teams of four or more.

As the right panel shows, the trend toward larger patent inventor teams (yellow and orange lines) is more pronounced when women participate. Since 1976, Figure 8 shows that women are increasingly likely to collaborate with other patent inventors rather than patent alone and more likely to participate on teams of four or more inventors. In 2016, about 44% of patents with at least one woman were developed by a team of four or more inventors. Notably, in the most recent years, a larger share of patents with a woman inventor were developed by inventor teams of six or more (orange line) than by solo female inventors (purple line).

> Women are increasingly likely to collaborate with other inventors rather than patent alone and more likely to participate on teams of four or more inventors.

Figure 9. Share of Patents with at Least One Woman Inventor by Gender Composition
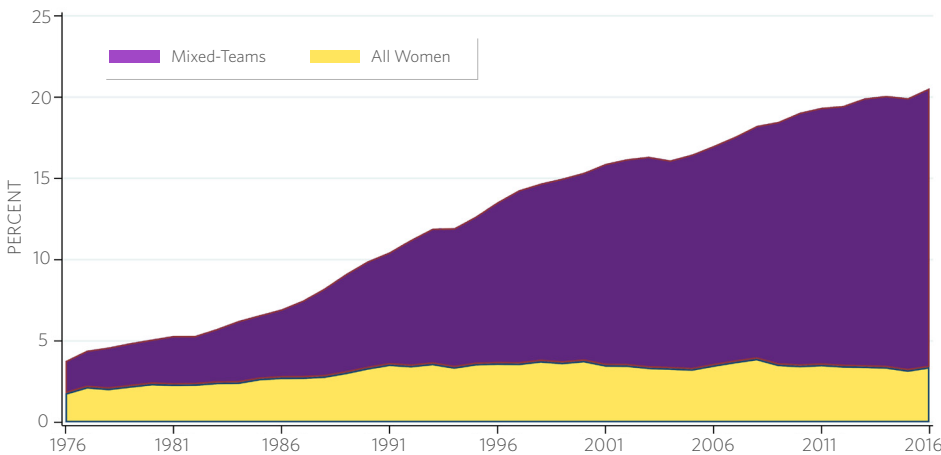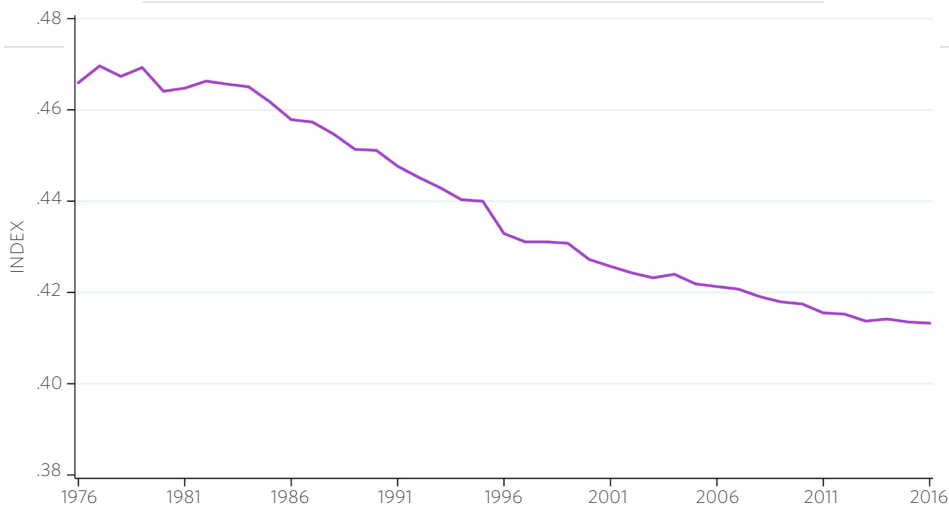

Figure 10. Gender Diversity Index for Gender-Mixed Inventor Teams

female invented patents constituted only about 4% of issued patents. Accordingly, the growth in women inventorship, as measured by the share of patents with at least one female inventor, is almost entirely due to women's participation on gender-mixed teams.

Among gender-mixed patent inventor teams, gender diversity has actually declined somewhat over time. Figure 10 reports the trend in the average value of the gender diversity index for all gender-mixed inventor teams. The gender diversity index measures the relative share of male and female patent inventors in a team such that a value of zero equates to a single-sex team and 0.5 to a team with equal share men and women.[23]

Figure 10 shows a gradual decline in the average gender diversity index for patents invented by teams of men and women inventors. Through the mid-1980s, mixed inventor teams were somewhat closer to gender equality than in the most recent years. The average index value of just below 0.47 in 1976 implies that women comprised roughly 37% of gender-mixed inventor teams, on average.

Over time, the index value has declined. The index value of just above 0.41 in 2016 indicates that women accounted for roughly 29% of gen-der-mixed inventor teams, on average. Thus, as the average size of gen-der-mixed patent inventor teams has grown over time (see Figure 8), women account for a shrinking minority of inventors on those teams.

Overall, these trends emphasize the growing importance of understanding the relationship between gender and team dynamics (Crescenzi et al., 2016; Jaravel et al., 2017) and collaborative networks (Meng, 2016) of inventors. The impact of these factors on the professional performance and career trajectories of women is increasingly focal and significant.[24]

There are a number of factors that may contribute to women being more likely to work on large patent inventor teams, relative to men. Women inventor rates are higher in technology fields where teamwork is more important, such as chemistry (see Figure 5). Higher female inventor participation at academic and publicly-funded institutions (see Figure 6) suggests that women may specialize in more fundamental research, which tends to be concentrated in these organizations and requires larger collaborative teams.

The gender makeup of patent inventor teams affects the women inventor rate. Relatively more patents with only women inventors will increase the women's share of inventors and patents, but the impact of gender-mixed teams is more ambiguous. Figure 9 shows the share of patents with at least one female inventor broken out between patents invented by mixed teams (including both men and women inven-tors) and those invented only by women.

Perhaps surprisingly, the share of patents by individual woman inventors and teams of all women (yellow area) shows little growth between 1976 and 2016. In the last decade, all

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23   The gender diversity index is calculated as 1 — (share of men squared + share of women squared) for each team, averaged over the grant year.

24   For example, women are rarely the most experienced patent inventors on teams. Even in the last decade observed, 2007-2016, the share of patents where a woman was the most experienced inventor (based on the total number of prior patents) has been largely unchanged at 6% (supplemental analysis not shown).

APPENDIX I: DEFINITIONS

Women inventor rate: The percentage of unique inventors with a patent granted in a given year that are women. The women inventor rate is calculated only for inventors residing in the United States based on the information disclosed in the patent. Inventors residing outside of the United States are excluded.

Women's share of patenting: The total number of patents attributable to women inventors is based on factional counts that give each inventor an equal share when patents are granted to multiple inventors. Women's share of patenting is calculated only for patents with at least one inventor, male or female, residing in the United States. Further, we report this number only for inventors who reside in the United States, excluding any inventors with non-U.S. addresses based on the information disclosed in the patent.

Adjusted women inventor rate: Calculated at the state level as the women inventor rate over the share of women in the labor force. An adjusted women inventor rate equal to one indicates that the proportion of women inventors is equal to the proportion of women in the workforce. A value below one indicates that the share of inventors that are women is smaller than the share of women in the workforce.

Gender diversity index: A measure of the relative share of men and women inventors on a team, calculated as 1 — (share of men squared + share of women squared). The index ranges from a minimum value of zero, indicating a single-sex team, to a maximum value of 0.5, indicating a team with equal share men and women.

APPENDIX II: METHODOLOGY FOR CLASSIFYING INVENTOR GENDER

The USPTO collects limited information on the inventors of patented technology. Only the full name and city and state or country of residency are collected and recorded on the front of the U.S. patent document. The USPTO does not collect information on the gender of patent inventors. Thus, to study women's participation in patenting, it is necessary to develop a method for classifying inventors as men or women based on their names. This appendix describes the method applied in this report to attribute gender to inventors listed on the front of patents. An online appendix provides additional detail.[25]

The vast majority of prior literature on gender diversity in patenting identifies the gender of inventors by comparing inventors' first names with a list of national or worldwide names for which various sources assign a feminine or masculine characterization.[26] Previous studies have leveraged baby name books (USPTO, 1990, 1999); the U.S. Social Security Administration (SSA) database of the most popular baby names by gender (Ashcraft and Breitzman, 2012; Jensen et al., 2018), or combinations of such sources as dictionaries, books, internet sites, and files from record offices in different countries (Naldi et al., 2004; Frietsch et al., 2009; Ashcraft and Breitzman, 2012; Sugimoto et al., 2015; UKIPO, 2016) to construct name-gender linked data. Inventors are then classified as female or male based on whether their first name is solely or predominantly linked to women or men, respectively, in the name-gender linked data. While conceptually straightforward, implementation of such methods involves three major challenges.

First, gender may vary for the same first name depending on the inventor's language spoken or country of origin. For

example, "Andrea" is an Italian masculine name but a feminine name in most other languages. An inventor's linguistic origin can be critical to assigning the correct gender based on first name. Some recent studies have attempted to address this challenge by developing country-specific gender-name linked data, which allows gender to vary for the same first name depending on the language spoken (Naldi et al., 2004; Frietsch et al., 2009; Sugimoto et al., 2015; UKIPO, 2016). These studies infer an inventor's linguistic origin from the country or region of residence disclosed on the patent document. The country of residence, however, may not reflect the linguistic origin for foreign-born inventors nor second and subsequent generation migrant inventors whose first name's gender may reflect the parents' or grandparents' language. Extensive and continuous growth in migration of highly skilled labor to the United States suggests that residency is a limited proxy for linguistic origin. Recent estimates suggest that one in four inventors with a U.S. address are foreign nationals (Miguelez and Fink, 2013). These considerations indicate the importance of accounting for an inventor's country of residence as well as their potential migratory background when classifying gender based on first names.

A second challenge is gender-neutral first names. Names such as "Yannick" in French or "Tracy" in English are used interchangeably for men and women with some variation by region or birth cohort. Some prior research attempts to mitigate this issue by leveraging gender-name linked data sources with gender attribution that varies over time. However, because inventors' age is not disclosed in patent documents, such data sources have limited value in classifying inventors with gender-neutral first names.

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25 See http://data.patentsview.org/documents/On-line+Appendix+-+Gender+Attribution+of+USPTO+Inventors.pdf

26 Alternative methods include matching inventors' records to Social Security registers (Jung and Ejermo, 2014), surveys of inventors (Hoisl and Mariani, 2016; Walsh and Nagaoka, 2009), and semantic analysis of names and titles (e.g. men's names ending with "o" and women's names ending with "a").

Lastly, difficulty arises from the English transliteration of names with non-Latin origin, especially East Asian names. Transliteration can render the original name's gender ambiguous. This issue affects inventors residing abroad as well as migrant inventors (or any subsequent generation) residing in the United States. The sizable volume of inventors with Asian names makes this challenge particularly problematic.

The methodology applied here addresses the first challenge by leveraging novel data on first and family names, nationality, and gender. However, similar to prior studies, our method has limited success in mitigating the second and third challenges. While the analysis and findings presented in this report should be viewed with these limitations in mind, the extent to which they introduce bias is unclear and cannot be reasonably assessed with available data. Our methods and results are consistent with prior studies, suggesting that bias is negligible.

To assign gender to inventors, we used two different sources of name-gender linked data:

1) The Global Name Recognition system, a name-search technology produced by IBM (hereafter, IBM-GNR). The IBM-GNR leverages a database produced by U.S. immigration authorities in the first half of the 1990s. It contains first and family names, nationality, and gender for foreign citizens entering the United States. The IBM-GNR includes roughly 750,000 full names and country-sensitive orthographic and abbreviation rules (Breschi et al., 2017a, 2017b). Each first and family name is associated with one or more countries of likely origin (c_i, with $i=1...n$) and the within-country frequency. The IBM-GNR also associates first names with gender in probabilistic terms (probability p to be feminine and $1-p$ of being masculine), irrespective of the countr(ies) of likely origin (c_i), and provides the worldwide frequency of first names.[27]

2) The WIPO worldwide gender-name dictionary (hereafter, WGND), produced by the World Intellectual Property Organization (WIPO). The WGND includes 6.2 million names from 182 different countries. It was constructed using country-specific information sources, including national public statistical institutions, Wikipedia lists, and manual labeling.[28]

Patent data were compiled from PatentsView, a data repository and visualization tool made available by the USPTO. PatentsView provides detailed data on granted U.S. patents, including inventor name(s), assignee organization(s) (or owner), and technology classification(s). This analysis

relied on a sample of all 6.4 million (6,366,664) U.S. patent documents granted in the 1976–2016 period.[29] PatentsView performs a series of entity resolution algorithms designed to disambiguate inventors' names. Disambiguation involves identifying an individual inventor whose name appears in varying forms on patent grants. For example, Jonathan Smith may appear as J. Smith on one patent grant and Jon Smith on another. Disambiguation also attempts to ascertain when inventors with the same name are distinct individuals. PatentsView uses a discriminative hierarchical co-reference method to disambiguate inventors based on other data elements appearing on patent documents (Monath et al., 2015). Disambiguation allows for identifying unique inventors, which is necessary for calculating women inventor rates. After inventor name disambiguation, there were 3,482,305 distinct inventors identified from the sample of U.S. patent grants. On average, each inventor was listed in 1.83 patent documents.

Using patent inventor name and name-gender linked data, we applied a "baseline method" consisting of the following steps:

1) We classified inventors based on first names with high probability of being feminine or masculine, regardless of country of origin, in the IBM-GNR. All inventors with a first name that had a probability of being feminine (p) equal to or greater than 97% were classified as women, and all inventors whose first name's probability of being male ($1-p$) was equal to or greater than 98% were classified as men. The different threshold values for classifying inventors' names as women or men were identified based on visual inspection of the distribution of p and ($1-p$), respectively. We applied a similar method for inventors with middle names when the first name was majority male or female but not exceeding the established thresholds.[30] In this way, we classified gender to roughly 73% of inventors (2,538,580 cases).

2) For the remaining 27% of inventors (943,725 cases), we first identified the most likely country of origin based on inventors' name and surname in the IBM-GNR. This provided a better indication of country of origin than inventors' residence or nationality, which could be misleading in the presence of migration flows. When an inventor's name and surname was associated with multiple countries of origin, we extracted from IBM-GNR the share of observed instances for each country. We collapsed the share of observed instances into linguistic groups (e.g. English, German, French, etc.) and retained the top linguistic group per inventor as a proxy for country of origin. For a relatively small number of inventors with rare surnames, we were unable to identify a likely

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27 Roughly 5% of worldwide first names are too rare for any statistics to be reliable. We excluded such rare names from our method.

28 See Martínez et al. (2016) for details.

29 Data extracted from www.patentsview.org was updated as of August 8, 2017.

30 When the first name's probability of being female was more than 50% and the probability of the second or middle name being female is 97% or more, the inventor was classified as a woman. Similarly, when the first name's probability of being male was greater than 50% and the probability of the second or middle name being male was 98% or more, the inventor was classified as a man. We applied this approach for roughly 1% of inventors (38,581 cases) in the sample.

country of origin in the IBM-GNR and relied on the country of residence identified on the patent document.[31] We then matched inventors' name-country pairs to the WGND dataset to classify inventors as women or men based on the country specific gender-name linked data. This method classified gender for about 14% of inventors (498,620 cases).

3) For inventors without a name-country match to the WGND data, we assigned gender where the following two conditions were satisfied. First, the first name appeared in the WGND dataset without being linked to the country or countries associated with the inventor's surname. Second, the first name was identified as solely male or solely female in all instances throughout WGND and as the same gender in the majority of instances in the IBM-GNR data. This approach classified another 5% of inventors (169,405 cases).

After applying these three steps of the baseline method, we classified gender for roughly 92% of inventors (3,206,605 cases). The remaining 8% of inventors (275,700 cases) unclassified by the baseline method consisted of inventors residing (based on address reported on the patent document) in the United States (about 82,200 cases) and East Asian countries (Japan 54,400 cases, China 34,600 cases, and the Republic of Korea 28,300 cases). To gauge the extent to which these unclassified inventors may affect results, we examined the number of unclassified cases as a percentage of the total number of inventors residing in each country. Inventors unclassified by the baseline method

accounted for only 5% of all inventors with a U.S. address. They comprised a much larger percentage of all inventors residing in the Republic of Korea (31%), India (29%), and China (62%). This suggested that the baseline method suffers from the same limitations of prior studies that have attempted to assign gender to Asian names (Park and Yoon, 2007; Yu et al., 2014).

To remedy this limitation and increase coverage, we applied a less restrictive version of the baseline method to inventors whose surnames originate from China, Singapore, Taiwan, Macao, Hong Kong, the Republic of Korea, and India (even if they reside elsewhere). We repeated step 1 of the baseline method but applied a lower probability of first names being feminine or masculine.[32] This approach classified gender for an additional 1% of inventors (38,188 cases) in the sample.

In total, our method classified gender for roughly 93% of inventors (3,244,813 cases). We exclude inventors for which our method did not provide a gender classification from the inventor-level analysis presented in this report. We also only include patents in the patent-level analysis if all inventors have a gender classification.

The analysis presented here is predominantly limited to the subset of inventors residing in the United States. For this subset, our methods classified gender for roughly 96% of inventors. These coverage or attribution rates are consistent with or exceed those of prior studies on women in patenting.[33] By leveraging U.S. immigration records, we are more confident in our gender classification for migrant inventors residing in the United States.

APPENDIX III: WOMEN INVENTOR RATE FOR TOP PATENT ASSIGNEES

This appendix describes the methodology used to calculate the women inventor rate for select top patent assignees between 2007 and 2016.

To identify an initial set of candidate organizations, we relied on the annual lists of the top 300 patent owners published by the Intellectual Property Owners Association (IPO).[34] We aggregated patent grant counts for each firm or organization from the annual lists to generate each assignee's count

of total U.S. patents granted from 2007 to 2016. We then restricted our sample of entities to those headquartered (firms) or located (non-firms, e.g., universities) in the United States, based on manual searching of internet and financial records. Additionally, we reduced the sample to the top 100 patenting firms, as measured by total U.S. patents granted 2007-2016.

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31 We used the country of residence for approximately 1% of inventors (37,003 cases).

32 For inventors with a surname associated with China, Singapore, Taiwan, Macao, or Hong Kong, those with a first name that have a probability of being feminine (p) equal to or greater than 60% were classified as women, and those whose first name's probability of being male ($1-p$) was equal to or greater than 60% were classified as men. A threshold of 80% and 90% was applied for inventors whose surname originate from the Republic of Korea and India, respectively. Different thresholds were identified based on visual inspection of the distribution of p and ($1-p$) for each surname country of origin.

33 Another large-scale study of inventor gender on U.S. patents by Sugimoto et al. (2015) classified gender for 90.8% of inventors residing in the United States. A worldwide analysis released by the UK Intellectual Property Office (UKIPO) classified gender for around 80–90% of inventors residing in the United States, Japan, the UK, Germany, France, or Italy. Coverage declined to around 75% for Switzerland and the Netherlands and was even lower for China (27.9%), the Republic of Korea (29.1%), or Taiwan (11.6%).

34 See https://www.ipo.org/index.php/publications/top-300-patent-owners/ (accessed 17 January 2018).

We pre-processed the names of firms and other entities in our sample[35] for matching to the population of assignees listed on U.S. patents granted 1976-2016.[36] Using proprietary software, we applied various fuzzy matching methods to match the cleaned names of entities to those of assignees.[37] Generally, the software generates scores for each potential match based on the co-occurrence of words, where words are weighted by their inverse frequency. We retained all potential matches with a score greater than or equal to 95 (out of a possible score of 100).

We then had multiple individuals independently conduct a manual evaluation of each potential match for accuracy. Evaluators also identified matches that indicated a joint venture, subsidiary, or international branch of the firms and other entities in our sample. We reconciled any differences between evaluators and removed inaccurate or low quality matches. We made extensive efforts to avoid errors; however, we cannot fully guarantee the accuracy of all matches.

Next, we generated two sets of matched assignee names for each entity: 1) assignee names of the entity itself as well as the IP branch or holding company, excluding joint ventures, subsidiaries, and international branches, and 2) all matching assignee names. The second set, while more expansive, does not represent a firm's entire corporate structure because additional subsidiaries with names that vary significantly

from the corporate name would not be captured. It should be noted that the women inventor rate may differ if the entire corporate structure is considered. However, the effort required to identify all entities within the corporate structure of the top 100 assignees for the 2007-2016 period is beyond the scope of this report.

We then linked the assignees included in sets 1 and 2 to their respective patents, retaining only those patents granted in the 2007-2016 period. For each entity's matched patent sets 1 and 2, we retrieved the inventor and gender classification data (see Appendix II) and calculated the women inventor rate for the set of unique inventors (see Appendix I). The women inventor rates were consistent across the matched patent sets 1 and 2 because the vast majority of matched patents fall into both groups. Given this similarity, throughout the report, we provide only the women inventor rate for the patents linked to assignees matched in set 1, excluding joint ventures, subsidiaries, and international branches.

For inclusion in Figure 7 of this report, we reduced the number of entities in our sample to 30 unique assignees. To select these 30 firms, we first ranked the assignees by the women inventor rate for set 1 and grouped them by decile. Within each decile, we manually chose three assignees to include in the figure.

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35 We manually searched the patent assignee data for possible variants of the official name of each entity in our sample. An individual firm name can appear in a variety of ways on different patents. For example, International Business Machines may be abbreviated as IBM or Massachusetts Institute of technology to MIT. We compiled a list of such name variants for each entity and then cleaned and standardized the variants using a firm name standardization software package (stnd_comp) in Stata.

36 We restricted PatentsView assignee file to all organizational assignees (i.e., no individuals) with at least one patent granted between 1976 and 2016 and then cleaned and standardize each assignee name using a firm name standardization software package (stnd_comp) in Stata.

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