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The institutional dynamics of inequality for women inventors who break with conventional thinking

Tara Sowrirajan[a,b], Ryan Whalen[c], and Brian Uzzi[a,b,d,1]

Affiliations are included on p. 6.

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Though women comprise a growing share of the scientific workforce, the gender innovation gap in patenting between men and women inventors persists, potentially limiting innovation output and equity. We study millions of scientific and technological innovations and find that the innovation gap faced by women is not universal. No gap exists for highly conventional innovations, which combine ideas in familiar ways. Rather, it exists when women inventors attempt to patent unconventional inventions, which combine ideas in surprising ways and drive scientific advancements. Our data suggest that rather than deliberate bias, a confluence of institutional practices lower women inventor's chances of patenting unconventional innovations. We find that women examiners relative to men have less of the on-the-job experience needed to appraise unconventional innovations. Additionally, women examiners are overassigned to women applicants, reducing their odds of successfully patenting unconventional inventions. Lastly, traditional explanations weakly account for this innovation gap because men examiners grant comparably more unconventional innovations to women inventors than do women examiners. These institutional barriers reveal new factors that slow innovation, but at the same time can be more directly addressed than deeply rooted gender norms.

science of science | innovation | gender innovation gap | scientific equity

Significance

The gender innovation gap—where women's inventions are less likely to be patented or pursued—raises concerns about its potential to slow scientific progress. Our analysis of millions of patent applications reveals that the gender gap in patenting is not uniform across conventional and unconventional patents. Rather, it manifests for women inventors who attempt to patent unconventional inventions—innovations that combine knowledge in unfamiliar ways. We find the USPTO's practices overassign women inventors to women examiners who are relatively inexperienced and more likely to reject unconventional inventions due to their inexperience, not due to gender stereotypes. By identifying these institutional barriers, we propose that organizational policies can complement gender bias explanations and may more immediately address the gender innovation gap.

Breakthrough innovations often require unexpected thinking (1–10), an observation summarized in Einstein's declaration, "we cannot solve our problems with the same thinking we used when we created them." Yet, despite the breakthrough potential of innovations that employ new thinking, their novelty is often the reason for their rejection (3, 11). Because they turn away from past ideas, innovations that push against the boundaries of convention seem dubious, raising rather than reducing their rejection rate (3, 10, 12–14). Consider the laser. The US Patent Office repeatedly rejected the laser's application for more than three years because its rare combination of ideas from optics and electromagnetism impeded patent examiners' ability to recognize its value (15, 16). Notwithstanding the laser's eventual patenting and foundational contributions to many breakthroughs, science policy analysts are raising concerns that the decrease in science's innovativeness since the 1980s may reflect a host of "lost breakthrough innovations" that could address chronic problems and other grand challenges (1–3, 5–7, 10, 17, 18).

One policy approach to boost breakthrough rates is to increase the number of women involved in innovation (2, 19–22). Women are a major and growing proportion of scientifically trained talent, making up about 60% of all college graduates, but their proportional representation among inventors is low: They comprise just 21% of patented inventors (20, 22–27). Women also add new and diverse perspectives into the creative process (6, 21), as well as the review process as referees, editors, and examiners, which could be more inclusive to unconventional innovations that combine ideas in new or atypical ways (19). The fact that the gender innovation gap appears in patenting but not uniformly across other measures of innovation suggests that institutional procedures governing commercialization and IP formation may play a central role. Here, we document a gap in patenting outcomes, not in innovation per se.

Scarce data inhibit the study and policy analysis of women-created innovations that push the boundaries of conventional thought (28), leaving uncertainty about how best to foster its development. On the one hand, gender stereotypes could conceivably overpenalize new groups of women innovators' unconventional thinking (22, 23, 28, 29), inadvertently lowering innovation rates. On the other hand, more women reviewers could

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[1]To whom correspondence may be addressed. Email: uzzi@kellogg.northwestern.edu.

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mitigate gender stereotypes, thereby increasing innovation rates (30–33). However, few studies simultaneously examine the production and evaluation sides of the innovation process (28), and no studies do so in connection with innovations that break with conventional thinking.

Here, we use data on 6.6 million patent applications, as well as information on Patent Office policies, to study the assignment of innovators to evaluators by gender with respect to unconventional innovations. These data allow an in-depth analysis of the size and extent of the gender gap for conventional and unconventional innovations. They also permit research designs based on organizational arrangements that permit examination of how the gender of inventors and reviewers of innovations can explain the gender innovation gap.

We find that separating innovations into those that build on the expected combination of past ideas (i.e., conventional innovations) as opposed to innovations that build on surprising combinations of past ideas (i.e., unconventional innovations) reveals that the well-documented gender innovation gap is not universal. Rather, it is nearly nonexistent for conventional innovations and largest for unconventional innovations. Further, these analyses point to institutional factors, not traditional gender discrimination, as barriers to innovation.

Data and Methods

Our empirical materials include diverse data sources. The three datasets concern scientific and technology patent applications. Patent dataset one includes 6,185,556 patent applications from the United States (USPTO) filed from 2001 to 2018. In addition to information about inventors, inventions, and patent application success, we have information about the examiners' identities and experience (measured as the number of previously reviewed patent applications). Patent examination is conducted primarily by a single, independently assigned examiner whose gender and experience we use throughout the analyses. Patent datasets two and three use Canadian and U.K. patents that contain comparable data to the UPSTO data but fewer applications, 280,128 and 224,365, respectively (34–37) (see *SI Appendix*, section S2 for a list of variables).

Across these data, we quantify the likelihood of being granted or denied a patent as a function of the invention's innovativeness and the inventor's gender accounting for many covariates. Following prior work, we define an invention's level of "unconventionality" depending on how much it incorporates new thinking (1–4, 11, 21, 38). At one end of the continuum, conventional innovations combine past ideas in familiar ways that have been done before. Unconventional innovations combine past ideas in unexpected ways that have never or only rarely been observed before, thereby pushing the boundaries of accepted thinking (1, 3, 8, 39).

The degree to which an innovation incorporates new thinking can be quantified using patent CPC codes (8, 9), which categorically group related ideas into separate technology domains. For instance, CPC subclass A01B is used for inventions relating to "Soil Working in Agriculture or Forestry" and B29C is used for inventions that involve the "Shaping or Joining of Plastics." The average number of CPC subclass designations per patent application in our dataset is 2.21 (SD = 1.40). Methodologically, our unconventionality measure aggregates all pairs of CPC codes over all previous patent applications for each year to compute an observed frequency of CPC code pairings. The measure is annually updated and is cumulative to capture changes in activity and relationships among CPC codes, allowing us to compare the unconventionality of inventions from different years. To determine whether the observed frequency of a patent's CPC code combinations represents conventional or unconventional thinking, we compare a patent application's observed frequency of each CPC code pair to the frequency expected by random pairing, which gives us a z-score statistic for each pair (8). Pairs of CPC codes that occur together less often than expected by chance reflect statistically unconventional combinations of prior ideas. By contrast, pairs of CPC codes that occur together more often than expected by chance reflect statistically conventional combinations of ideas. To get an overall score for an application, we aggregate the z-score pairs (*SI Appendix*, sections S3 and S4 provide computational details and robustness checks using different methods of aggregation of z-score pairs).

Our measure has been shown to have face validity (8, 13, 21, 40), and in our data we confirmed that it correlates appropriately with other measures of unconventionality (1, 9) and impact (11, 41). For example, an unconventional patent is 52.1% more likely than a conventional patent to be in the top one percentile of cited patents ($P < 0.001$) controlling for grant year, team size, and CPC code. Unconventional patents are economically more impactful too, as indicated by their owners being more likely to pay patent maintenance fees ($P < 0.001$) (see *SI Appendix*, section S11 for computational details). Our regression analyses use a wide variety of covariates and fixed effects, which are defined in *SI Appendix*, Table S1. Following prior research, we used Genderize to algorithmically estimate an inventor's gender as man, woman, or undetermined (i.e., only the inventor's initials are recorded or the name is unisex) (21, 42). Descriptively, in our data, when unconventionality is defined as an invention with an unconventionality score > 0, male majority teams are somewhat more likely to file applications for unconventional patents (31.8%) than women-majority teams (25.9%). Much of the difference in unconventionality dissipates when assessed within technical fields. At the CPC subclass level only, 6% of subclasses show statistically significant differences in unconventional application filing levels by men and women, and the differences in those fields go both ways and tend to be substantively small.

Fig. 1 provides examples of conventional and unconventional innovations for inventions within similar technical areas to illustrate how the same type of innovation can be approached from the perspective of conventionality or unconventionality. Both inventions were granted patents in 2007, are from the same technological domain, "Medical Procedures" (CPC code A61B), and combine the focal technology area (A61B) with three other technological areas (depicted in separate boxes).

Fig. 1 lists the unconventionality score between each pair of CPC code categories and the focal category. The length and width of the arrow between categories is proportional to the level of unconventionality. The unconventional invention combines CPC codes A61B (focal) with H04N, G08B, and H04Q, which are all atypical pairwise combinations with the most uncommon link being between the pair A61B and H04N, combining areas related to medical procedures with information technology, with an unconventionality score of 25.9. The conventional innovation combines CPC codes A61B (focal) with G21K, G01N, and H05G, which are all frequently co-occurring CPC codes pairings that are conventional. The unconventional invention is much more highly cited (citation count of 107) compared to the conventional invention (citation count of 2),

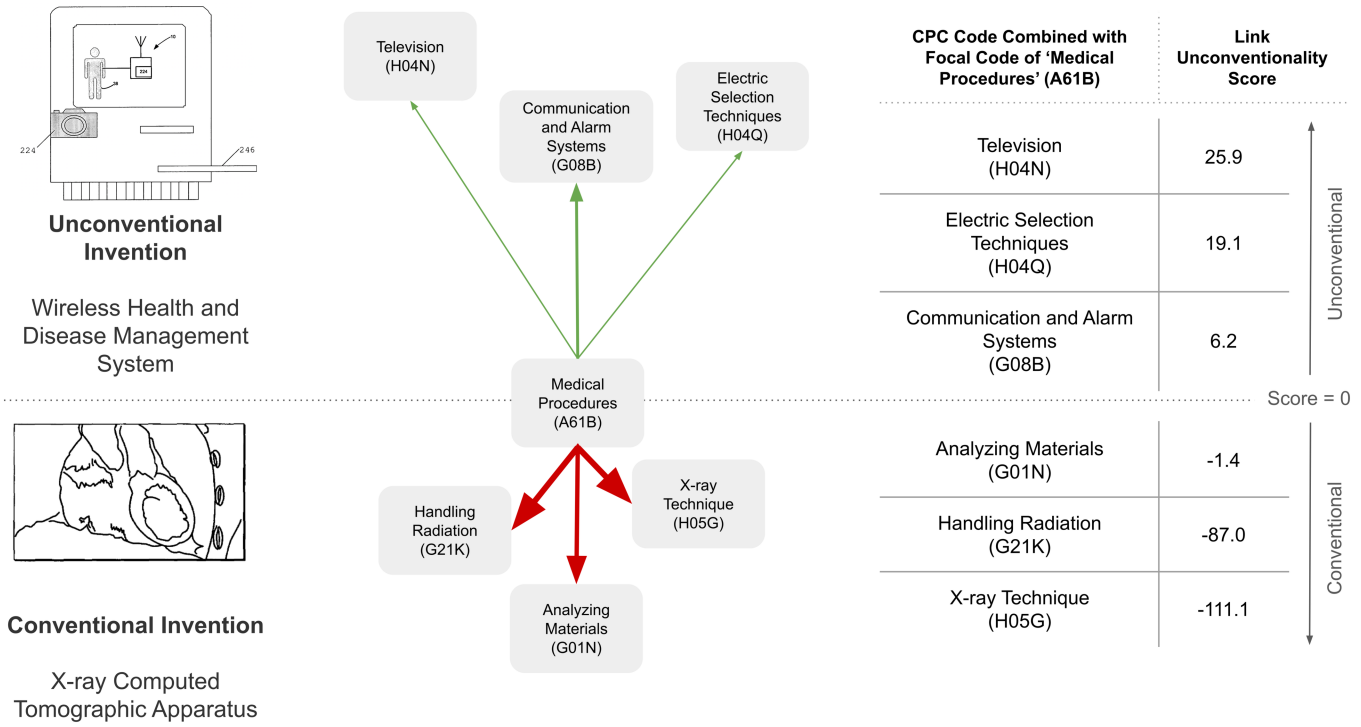

Fig. 1. Illustrative example of how the same type of innovation can be approached from the perspective of conventional and unconventional thinking. This example illustrates a comparison between unconventional (top, Pat. App. No. 11/156177) and conventional (bottom, Pat. App. No. 11/367461) inventions, both having the same focal CPC code. It highlights the combined CPC codes and summarizes the invention titles and code description. Network diagrams in the center display combinations of categories in each invention, with proximity indicating commonality and distance indicating rarity. The top network depicts the highly cited unconventional invention "Method and apparatus for health and disease management combining patient data monitoring with wireless internet connectivity," linking rare pairwise combinations of CPC codes H04N, G08B, and H04Q with focal code A61B. The bottom network depicts the conventional invention "X-ray computed tomographic apparatus, image processing apparatus, and image processing method," using frequent pairwise combinations of CPC codes G21K, G01N, and H05G with focal code A61B. The table quantifies unconventionality, showing relationships ranging from highly unconventional (positive, green) to conventional (negative, red).

exemplifying the association between unconventionality and impact.

Results

Men and women inventors have similar patenting experiences with regard to conventional innovations and divergent patenting experiences for their unconventional innovations. Fig. 2*A* depicts the relationship between patenting grant rate and an invention's unconventionality using the USPTO data, which is binned into 85 quantiles represented by a scatter point of the average grant rate of that bin. The regression line is fit to the scatter points, controlling for team size and 141 separate technological domains as determined by their primary CPC codes with clustered SEs by year to further control for heterogeneity in the data. The plot shows that when innovations are conventional in nature (indicated by negative z-scores), the difference in the grant rate for men and women inventors is small. Conversely, for unconventional innovations (positive z-scores), the gender innovation gap steadily widens up to over 14.9 percentage points.

To further understand the link between grant rate, inventor gender, and unconventionality, we regressed an application's probability of being granted on an interaction between the majority gender on the inventing team and the patent's level of unconventionality along with controls for an inventor's previous number of patent applications and affiliation (whether part of a corporation), the examiner's gender and experience (number of previously reviewed patent applications), and fixed effects for inventor team size, 141 CPC codes, and application year (see *SI Appendix*, Table S2 for regression details and *SI Appendix*, section S5 for robustness to several gender composition operationalizations). Fig. 2*B* is a margins plot summarizing the regression's estimates. The y-axis measures women's average probability of patenting grant minus the men's grant rate, with the dashed line showing the point of no gender difference. Values below the line show the women's innovation gap.

Contrary to prior work, we find that for conventional applications the well-documented gender innovation gap largely disappears (43–47). Rather, the gender innovation gap appears and enlarges in proportion to the innovation's unconventionality ($P < 0.001$). In the United States alone, we estimate the value of unconventional "lost patents" that would have been granted to women at over $234 million (1992 USD) by inferring that 2,238 more unconventional patents would be granted if women and men had the same grant rate (*SI Appendix*, section S12). Robustness checks using the U.K. and Canadian datasets indicate that the unconventionality penalty for women inventors is a pervasive phenomenon. U.K. and Canadian women inventors ($P < 0.001$) experience a significant drop in their probability of success when their creations push against conventional thinking (see *SI Appendix*, section S10 and Table S17 for details).

Explanations for the patenting gender gap often focus on gender stereotyping, bias, and discrimination (24, 28, 30, 44). However, our evidence only weakly supports the claim that men patent examiners underrate women inventors relatively more than women examiners do (24). The USPTO data demonstrates that the opposite is true. Women inventors have their highest patenting rates with men examiners and their lowest patenting

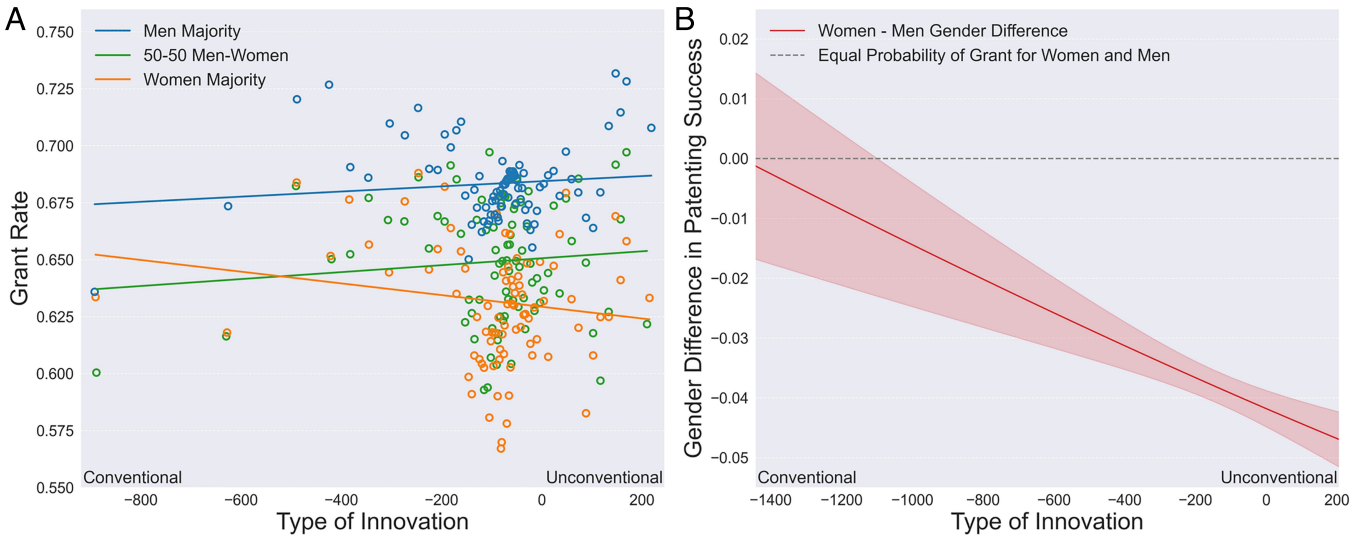

Fig. 2. The gender gap exists primarily for innovations that incorporate unconventional thinking. (*A*) This plot shows the relationship between the type of innovation and grant rate by team gender composition in the USPTO data. The gender composition of the team was defined following prior work (24). It depicts a binned scatterplot, showing averages within bins, with regression lines by team gender composition over the full range of data with controls for heterogeneity in CPC codes and team size along with standard errors clustered by year to account for intracorrelation. Women's grant rates decrease as their innovations become increasingly unconventional. (*B*) The residual margins plot (with 95% CIs) shows the estimated patent grant rate on the interaction of team gender majority and unconventionality from a logit model that includes controls for team size, year, CPC class, examiner gender, examiner and inventor experience, and applicant entity size in the USPTO data. The plot indicates that the innovation gap for women scales with the level of innovation unconventionality. The gender gap appears and widens the more that innovations from women inventors push the boundaries of convention. Innovations that stay within the confines of conventional thinking show less difference in grant rate for women and men innovators. Regression fit and cross validation statistics are reported in *SI Appendix* and generalizations of the gender gap-unconventionality scaling relationship are reported for international patents.

rates with woman examiners. Women examiners are 8.1% less likely than men examiners to grant patents to women inventors.

Examiner experience is critical for correct grant review decisions. This relationship between examiner experience and correct grant review decisions is especially important for unconventional innovations, which rely on unexpected combinations of prior ideas that require expert judgment to spot their potential (48). Consistent with this claim, USPTO data show that experience is positively related to accurate patent decisions. Our first evidence comes from data on appeals of rejected patent applications. Rejected patent decisions can be challenged, which results in a new panel of expert judges who conduct a formal reassessment of the patent review that confirms or rejects the original patent examiner's decision.

Fig. 3*A* shows that examiner experience is positively correlated with accurate assessments. In appeals, inexperienced examiners are overturned significantly more than experienced examiners—a relationship that is especially pronounced when they evaluate unconventional innovations (49). Moreover, Fig. 3 *C* and *D* show that across the board, more experienced examiners, irrespective of their gender, have higher grant rates, especially for unconventional inventions ($P < 0.001$, *SI Appendix*, Table S9).

Fig. 3*B* shows that men inventors are assigned significantly more experienced examiners than women inventors, which suggests that women's unconventional innovations are at higher risk of mistaken rejection because they are assigned to less experienced examiners. Furthermore, Fig. 3 *C* and *D* present heatmaps indicating that men and women examiners of equivalent experience accept unconventional patents at the same rate (Pearson correlation coefficient between heatmaps is 0.98, $P < 0.0001$), and that higher examiner experience and higher unconventionality are associated with higher grant rates.

Institutionally, women examiners on average have less experience than men examiners (t test $P < 0.0001$), a difference that is strongly related to the higher dropout rate of USPTO women examiners relative to men examiners (*SI Appendix*, section S9). The lower average experience levels of women examiners can affect women inventors because women inventors are overassigned to women examiners who systematically have lower experience. The data indicate that women examiners are 16.9% "overassigned" to women inventors relative to what is expected by chance (see *SI Appendix*, section S8 for details). Further, patent applications are not assigned to examiners at random. Rather, they are assigned to specific "art units" within the Patent Office that have expertise in the substance of the invention. The gender composition of examiners in a technical field is correlated with that of inventors. At the CPC class level the unweighted correlation between the proportion of female inventors and examiners is $r^2 = 0.46$ ($P < 0.001$). When weighted by the number of applications within CPC classes that correlation grows to $r^2 = 0.80$ ($P < 0.001$). The overassignment of women inventors to women examiners means that on average their applications are reviewed more often by less experienced examiners who grant patent protection for unconventional applications less often, partially accounting for the gender innovation gap for unconventional innovations. Evidence indicates that the assignment of women inventors to less experienced examiners is especially pronounced when women file unconventional patent applications (*SI Appendix*, Table S10).

The combined impact of these institutional practices can account for why fewer unconventional patents are granted for women inventors than they are for men. The institutional practices include overassigning women inventors to women examiners who have less experience than men examiners because women examiners have higher dropout rates. The data show that less experienced examiners accept unconventional patents

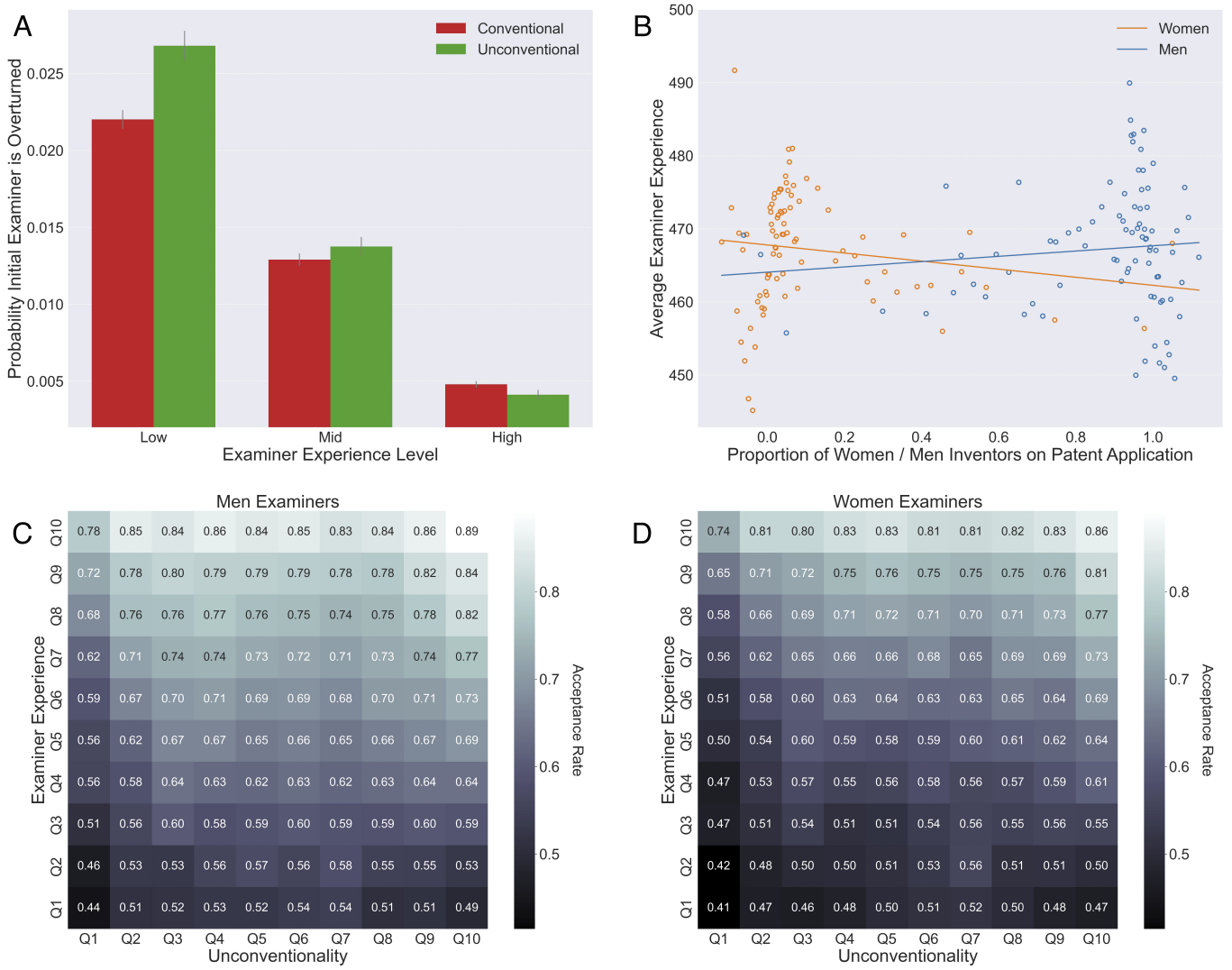

Fig. 3. Examiner experience and assignment impacts grant rates and decision accuracy, and examiner gender is not a factor in evaluation decisions. (*A*) In appeals of patenting decisions, experienced examiners' decisions are reversed less frequently than those of inexperienced examiners, suggesting experienced examiners' decisions are more accurate. For each level of examination experience, the global reversal rate within appealed patent applications for unconventional and conventional innovations is shown. (*B*) Depicts a binned scatterplot of the proportion of women and men inventors on a patent application and examiner experience (measured in patent applications examined) with regression lines included that control for year, team size, entity, examiner gender, and CPC class. The more women on an application, the less experience their patent examiners have; the more men on an application, the more experience their examiners have. (*C*) Heatmap of acceptance rate for men examiners by examiner experience quantile and unconventionality quantile (ten quantiles each) on USPTO data. (*D*) Heatmap of acceptance rate for women examiners by examiner experience quantile and unconventionality quantile (ten quantiles each) on USPTO data. Experience drives openness to unconventionality for both men and women examiners, with similar acceptance rates across experience and unconventionality quantiles.

at lower rates than experienced patent examiners, and less experienced examiners are more likely to wrongly reject patent applications, especially because experience helps to correctly review unconventional patents that are outside of the norm. Quantitatively, an all-women inventor team assigned to a woman examiner of low experience has a 37.1% chance of being granted a patent built on unconventional thinking. Conversely, an all-male inventor team assigned to a male examiner of high experience has an 81.8% chance of being granted an unconventional patent, representing a stark 44.7 percentage point gender gap in success. To help quantify the magnitude of the potential association between examiner experience and the rate of patent granting for women, we estimate that if only half of the unconventional patent applications from women majority teams had been originally assigned to women examiners with high experience, this could conceivably result in 13% more unconventional patent grants (*SI Appendix*, section S12.1).

Discussion

Unconventional innovations are drivers of scientific advancement and cultural expression (1, 3, 10). They are also an important factor in understanding who is most likely to have success at the patent office. When innovation respects the boundaries of convention, building on known and taken-for-granted combinations of existing innovations and ideas, men and women have nearly equal chances of the successful adoption of their ideas and inventions. Conversely, when innovation pushes against the boundaries of convention, combining preexisting innovations and ideas in ways that are never or rarely seen before, men and women have starkly different chances of patenting. This is true even though women and men are equally likely to attempt unconventional innovation.

Contrary to prior work that has explained patenting differences by emphasizing gender stereotyping or bias (24, 50), our data

indicate that women inventors have their highest patenting rates when assigned to a man examiner. Evidence suggests that the difference in successfully patenting unconventional innovations is explained by a confluence of institutional practices that lower women examiners' experience and overassign them to women inventors. The higher rejection rate for women's unconventional innovations is explained by the systematic overassignment of examiners who have less of the experience needed to correctly judge patents that combine past knowledge in surprising and unfamiliar ways. The examiner experience gap means patent applications by men inventors are more likely to be examined by experienced examiners who grant patent applications more often, especially for unconventional patents, and are less likely to have their decisions overturned on appeal (Fig. 3*A*). Future study could expand beyond the context of science and technology studied here to assess the universality of this phenomenon.

Taken together, these findings indicate that the gender gap in patenting unconventional innovations operates through institutional arrangements rather than differential evaluation standards by examiner gender. Women examiners, on average, have lower levels of examination experience, a pattern largely driven by differential retention within the Patent Office. At the same time, women inventors are disproportionately assigned to women examiners. Because examiner experience is especially crucial for accurately evaluating unconventional inventions, this confluence of assignment practices and experience disparities systematically reduces women inventors' likelihood of successfully patenting unconventional work.

The unconventionality penalty that women experience has broad implications for innovation policy. Many proposals aimed at ameliorating the more general gender innovation gap focus on increasing the number of women creators (26, 51) with reason, but our work focuses points of policy on innovators who create the unconventional patents that tend to be higher impact and are important for addressing grand challenges (3, 14, 52, 53).

First, by identifying institutional practices that worsen outcomes for unconventional women innovators, our findings both complement and add to the innovation gender gap research while providing concrete policy responses that may help close the gap through actionable organizational changes rather than through addressing culturally ingrained stereotypes. Although gender stereotypes affect gender inequality (28, 30), intrapsychic biases are difficult to address. They can arise well before women become innovators, by factors outside the control of organizations, and are apt to change slowly. A focus on institutional arrangements supports the work on stereotypes with interventions that allow measurable and potentially direct changes in outcomes and can help evaluators recognize the merits of innovations that break with conventional ideas (13, 14).

Second, the findings also raise the policy speculation that institutional practices employed to decrease gender discrimination, such as gender matching of innovators and examiners, may ironically result in unintended consequences, negating the practice's potential benefits. The USPTO and other analogous assessment bodies could address this issue by striving not just for diverse gender representation among assessors, but also by trying to ensure that assessors acquire equivalent experience and are distributed across groups of applicants in ways that simultaneously address multiple assignment biases.

Third, other institutions that play a vital role as gatekeepers of innovative success should ensure gender parity in resources allocated to making those decisions. For example, new administrative policies may help ameliorate the gender innovation gap by helping facilitate longer careers for women, both on the side of creators and evaluators. Moreover, systematic efforts to expose junior evaluators to unconventional creations and train them in how to assess unconventional innovations, which have a sparse historical record from which to extrapolate, may help reduce the grant rate gap associated with experience and consequently reduce the gender innovation gap. Broadly, future research that focuses on gender should strive to better understand how gender correlates with an array of organizational factors, rather than one issue—such as gender stereotypes—which may exacerbate other issues.

A limitation of our research is that while patenting serves a core function for turning ideas into useful innovations worldwide, and represents organizational practices that are likely to be present in many types of organizations, we do not have direct data on the generalizability of our findings to other patent offices or organizations that differ from the USPTO in critical ways. Thus, in contexts like the USPTO, the centralized organization of the system may prove more amenable to reform than other creative domains. While the USPTO Director can institute reforms to address biases in the patent examination system, successfully reforming decentralized institutions needs more research. Nevertheless, our work remains a potentially informative line of future research that can complement current approaches to the gender innovation gap that emphasize gender stereotypes or increases in women's participation. Additionally, it adds insights into institutional analyses that could help develop not-before-considered policies aimed at closing the gender innovation gap and better recognizing the merits of innovations that break with convention, both of which can aid in increasing innovation and advancing science and technology.

Data, Materials, and Software Availability. Previously published data were used for this work. Data for the primary analyses are available from the USPTO (34, 35, 49). Data used for robustness checks and supplementary analyses are available via Google Patents (36) and CIPO (37).

Author affiliations: [a]Kellogg School of Management, Northwestern University, Evanston, IL 60208; [b]Northwestern Institute on Complex Systems, Northwestern University, Evanston, IL 60208; [c]Faculty of Law, University of Hong Kong, Hong Kong Special Administrative Region; and [d]Ryan Institute of Complexity, Kellogg School of Management, Northwestern University, Evanston, IL 60208

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