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ABSTRACT

Do stronger intellectual property rights incentivize female participation in innovation? We provide new evidence on this question using a unique database of artificial intelligence patents publicly shared by the USPTO. Our identification strategy leverages China's WTO TRIPs accession, which led to stronger intellectual property rights in 2002. We find a significant rise in the number of female inventors and an increase in the number of patents with females on inventor teams vis-a-vis a control group of countries. We also find that after stronger intellectual property rights, the quality of Chinese artificial intelligence patents with female inventors on the team improved. Results are robust controlling for unobserved heterogeneity at the country, technology class, and over time. Additional robustness tests with synthetic controls, coarsened exact matching, randomized inference and alternative control groups support our benchmark findings. Our results highlight that stronger intellectual property rights can be helpful in improving gender division of labor thereby benefiting society and innovation.

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1. Introduction

Is there a relationship between stronger intellectual property rights (IPR) and the labor market for inventors? An understanding of this question is essential given that governments decide the strength of IPR for their country. The trade-off in this decision-making lies between static inefficiencies due to market power and dynamic gains due to innovation (Allred & Park, 2007; Arrow, 2015; Nordhaus, 1969). The arguments from advocates remain that strengthening intellectual property will accelerate technology transfer between countries, ensuring a relatively equal distribution of gains (Branstetter, Fisman, & Foley, 2006). In contrast, policymakers in lesser developed countries debate innovation expansion policies of the World Trade Organization (WTO) such as TRIPS[1] as it may crowd-out domestic innovation efforts (Lanjouw, 1998; McCalman, 2001; Motari et al., 2021).

We offer new evidence on this debate from a gendered lens. Stronger intellectual property protection is known to spur innovation (Intarakumnerd & Charoenporn, 2015; Maskus, Milani, & Neumann, 2019) and gives a thurst to high-tech R&D (Brown, Martinsson, & Petersen, 2017; Hu, 2010). While all inventors are likely to be affected by a change in innovation-related policy, the effect is not likely to be similar across all genders.

The differences between gender groups arise not due to their identity as male or female but due to disparity in access to a suitable innovation environment, tangible investments (finance), and intangible assets (knowledge, training, network ties, examinations) (Aneja, Reshef, & Subramani, 2022; Biscione, Boccanfuso, Caruso, & de Felice, 2021; Del Carpio & Guadalupe, 2022; Frietsch, Haller, Funken-Vrohlings, & Grupp, 2009; Pairolero, Toole, DeGrazia, Teodorescu, & Pappas, 2022). Multiple studies have laid out evidence that when endowed with an innovation-supportive culture and optimal resources, women are just as likely to have a positive or even stronger contribution to a field as men (Marvel, Lee, & Wolfe, 2015; Mendonça & Reis, 2020; Wu, Dbouk, Hasan, Kobeissi, & Zheng, 2021). Thus, structural changes through stronger IPR have the potential to support female participation in innovation races.

Using novel data from artificial intelligence (AI) patents in China, we show how stronger

[1] Trade-Related Aspects of Intellectual Property Rights (TRIPS)

IPR incentivizes the participation of female inventors. China joined the WTO on December 11, 2001, and this decision by the government offered not only tremendous challenges for its industries but also unprecedented opportunities with the strengthening of IPR (Li, 2002). In our data, we find clear evidence of a spike in the share of artificial intelligence patents in China (Figure 1, Panel (a)).[2] This observation is in line with the findings of Fisch, Block, and Sandner (2016) who found that patent applications by China's inventive labor increased by 1400% from 2001 to 2011.[3] The more interesting question that remains to be explored is whether the expansion of the innovation market incentivizes the participation of female inventors.

As visible through Panel (b) in Figure 1, we find a sharp increase in the share of female inventors in China for AI patents compared to the rest of the world (ROW). An increase in female inventors with an overall spur in innovation is not so obvious. As we show in Figure 2, in many industrialized nations like Japan, USA, Canada, and Germany, the increase in number of total inventors is not accompanied by an increase in the number of total female inventors. This descriptive evidence calls for a careful investigation of the variation in participation in inventive labor by gender with stronger IPR.

Our study hypothesizes that accession to the WTO by China should have a positive impact on the participation of females in innovation activity. This hypothesis is strongly motivated by Gary Becker's model of discrimination (Becker, 2010). The model suggests that an exogenous shock (i.e., competition from trade) drives out labor market discrimination in the long run. Becker's model has been used extensively by economists to empirically demonstrate the effect of competition on reducing the gender wage gap, differences in employment of male and female workers, and improvement in the occupation status of women (Black & Brainerd, 2004; Black & Strahan, 2001; Ederington, Minier, & Troske, 2009).

To empirically evaluate the impact of IPR changes in China, we obtain information on patents across eight technology classes[4] from the Artificial Intelligence Patents Database (AIPD) by the United States Patent and Trademark Office (USPTO) that were recently made available

[2] Share of AI Patent is the total number of AI patents across eight technology classes in China divided by the total number for the rest of the world (see section 3).

[3] In the same duration, patents by U.S. applicants increased by 150% and those by Japanese applicants decreased by 7%.

[4] Machine Learning (ML), Natural Language Processing (NLP), Evolution, Knowledge Reasoning, Hardware, Planning, Speech, and Vision.

to researchers for public use.[5] We map the AI patents with inventor information from 1997-2011 for 123 countries. We use this longitudinal data to obtain information on the number of female inventors and patents with at least one female inventor at the country-technology-year level.

Our identification strategy employs a formal difference-in-differences framework building on our descriptive evidence discussed above. We estimate the average treatment effect of the Chinese IPR policy shock post-2002 on its female inventive labor compared to the ROW. Our regression evidence suggests that in China, the number of AI patents with female inventors increased by 116.1% after 2002, and the participation of female inventors on these patents increased by 186.3% compared to the ROW. These results remain robust, controlling for unobserved heterogeneity at the country, technology class, and over time. We also conduct multiple robustness checks including coarsened exact matching (Iacus, King, & Porro, 2012), randomized inference testing (Rosenbaum, 2002) and synthetic controls (Abadie, Diamond, & Hainmueller, 2010); our benchmark findings remain consistent. Our results also hold when we use two alternative sets of control groups - emerging and developed nations.

We find three important mechanisms to explain why there is a surge in female innovation in China. First, in line with Becker's model of discrimination, we find evidence for an increase in the share of domestic female inventors on patent teams in China. Second, we find that there is a systematic effort from the Chinese government to promote females in higher education. This is evident from a sharp increase in the percentage of females enrollment in Ph.D. programs in scientific research institutes (Figure 3). Third, we find that after 2002, there was a surge in patents with female inventors filed by private firms compared to state-owned entities. Thus, the evidence suggests that it is a combination of government-led initiatives and an opening of the market that has led to an increase in the involvement of females in innovation in China.

Interestingly, female-driven innovation is also contributing to the improvement in the quality of patents. We utilize the Derwent Innovation database to measure the quality of patents using the number of forward citations and strategic importance of the patent obtained. We find that the quality of innovation generated by female inventors in China increased positively and

[5] https://www.uspto.gov/ip-policy/economic-research/research-datasets/artificial-intelligence-patent-dataset

significantly after China became a member of the WTO.

Our findings primarily contribute to the literature on gender, incentives for innovation, and the role played by the innovation environment in promoting female participation in national innovation ecosystems (Pellegrino & Savona, 2017). There has been a considerable amount of interest and evidence on the integral role that females can play in contributing to innovation at the regional (Griffin, Li, & Xu, 2021; Ritter-Hayashi, Vermeulen, & Knoben, 2019), firm (Marvel et al., 2015; Mendonça & Reis, 2020; Wu et al., 2021) and industry level (Kou et al., 2020). However, little is known about female inventor participation in new AI technologies and how that changes over time. Our analysis is essential as new products and processes may have differential impacts on both men and women (Koning, Samila, & Ferguson, 2021).[6] The perspective of female innovators can ensure that new technologies cater to the needs of the entire population without suffering from male biases.[7]

We also contribute to the literature on the quality of innovation generated by female inventors in China. Past work (Griffin et al., 2021; Kou et al., 2020; Le Loarne-Lemaire, Bertrand, Razgallah, Maalaoui, & Kallmuenzer, 2021; Ritter-Hayashi et al., 2019) has found that more females within the technological innovation value chain and in boardrooms impact the adoption of efficient innovation processes, greater productivity, and better results. While studies have measured the value of Chinese patents between the period 2000-2011 across types of patents (Chen & Zhang, 2019), industrial ownership (Fisch, Sandner, & Regner, 2017; Liu, Cao, & Song, 2014; Thoma, 2013), financial incentives (Dang & Motohashi, 2015) and research universities (Fisch et al., 2016), there exists a gap around understanding these heterogeneities from a gender perspective.

The rest of the paper proceeds as follows. Section 2 provides the institutional background of China related to stronger IPR. Section 3 discusses the data. Our empirical strategy is outlined in Section 4. In section 5, we discuss our findings along with robustness checks and mechanisms. Section 6 concludes with managerial and policy implications.

[6]For example, Apple had to retrieve and relaunch the health kit app due to a loss in customer base when it failed to include the feature of menstrual cycle tracking.

[7]https://www.wipo.int/wipo_magazine/en/2017/04/article_0001.html

2. Impact of China Joining the WTO

2.1. Institutional Changes

After 15 years of negotiations (since 1986), China became a member of the WTO on December 11, 2001. Accession to the WTO required China to make significant changes to its laws and regulations to gain access to the world market. It was expected to increase transparency standards, limit domestic trade-distorting subsidies, and protect IPR.

To kickstart the process, China made sweeping but important and long-lasting changes to its patent and trade laws between 2000-2002 (see Appendix Table A1). The Chinese government made amendments to its patent law in 2000 to align it with the requirements of TRIPS.[8] TRIPS is an integral component of the WTO trade rules which requires member countries to "enact substantive legislation to protect against counterfeiting and ensure that critical enforcement procedures will be available in each member country to safeguard IP" (Evans, 2002; Stoianoff, 2012; Thomas, 2017).[9] By modeling the requirements of TRIPS, China not only signaled to developed countries that it was ready to protect the rights of innovators but also altered the view of Chinese citizens on IP rights and innovation that likely led to a broad expansion in the labor market for inventors (Evans, 2002; Giuliani & Macchi, 2014; Stoianoff, 2012).

While the changes to patent law set the stage for innovators to be incentivized by new ideas, accession to the WTO along with a series of new laws in 2002 ensured patent holders of their IP rights (Li, 2002; Representative, 2002). Regulations on administration, registration, and prohibition of imports or exports of technologies, along with amendments to computer software protection came into force on January 1, 2002. Rules related to creative innovation combining publications, motion pictures, sound and video recordings came into effect February 1, 2002. The implementation of regulations for copyright law and trademark law started on September 15, 2002. Finally, trademark examination guidelines were revised in October 2002 (Thomas, 2017).

[8] The changes were made in three strata: a) judicial and administrative procedure, b) patent application procedure c) streamlined enforcement mechanism.

[9] TRIPS covers all aspects involved in the protection of IP, from patents, trademarks and copyright laws to the proper adjudication of disputes.

Before its membership, the focus of science and technology policies in China was on promoting state-owned enterprises (SOE). This sector saw minor progress despite massive investments and continuous revitalization (Prime, 2002). To promote domestic innovation through the entry of private-owned enterprises, research universities and the pool of human capital, China had to shift its role from being a provider to a promoter of innovation. According to the patent right index (Park, 2008), China climbed from 69th in 1995 to 34th in 2005 among 123 countries, making remarkable progress in patent protection. With the change in focus on the type of ownership, liberal regulations, a stronger domestic knowledge base and pro-patent-holder legal environment, innovation witnessed an upsurge in China (Eberhardt, Helmers, & Yu, 2016; Prud'homme & Zhang, 2019).

2.2. *Innovation Environment of China*

In addition to the above discussion on gender participation in innovation, one associated question remains, which is about institutional reforms. We believe that the innovation environment in China led its economy to evolve into a global technological leader, particularly in AI adoption and production. Important in the innovation environment is promoting gender diversity. A 2016 WIPO report mentions that "The Republic of Korea (50%) and China (49%) had the greatest gender equality in international patenting via the PCT in 2015, whereas the greatest gender gaps among the top PCT countries of origin are found in Germany (19%), Japan (19%), Italy (18%) and South Africa (16%)".[10] Clearly, much therefore remains to be understood on what institutional environment drives these findings around co-evolution of female inventors in the national innovation ecosystem.

Extant work has explored the role of financial support, such as subsidies, attracting FDI and R&D support that may have led to the patent explosion in China. Chen and Zhang (2019) provide a perspective on this effect by disentangling the heterogeneity by patent types. They find that although financial benefits increase the number of applications filed in China there is heterogeneity in quality. Along similar lines, other researchers suggest that R&D explains only a fraction of the growth in patenting. Eberhardt et al. (2016), Guan and Yam (2015) & Hu

[10] See https://www.wipo.int/pressroom/en/articles/2016/article0015.html

and Jefferson (2009) attribute the explosion to state incentives, such as the second amendment of Chinese patent law in 2000 and the exit of state-owned enterprises which led to the entry of non-state entities. Dang and Motohashi (2015), Lei, Sun, and Wright (2012) & Li (2012) credit patent subsidies across regions as a positive policy shock-inducing firms and individuals to innovate more. Finally, Tiwari, Anjum, Chand, and Phuyal (2017) & Lundvall and Rikap (2022) show that significant investments in human capital, education and research universities may explain evolution of innovation in China.

There is also a strand of literature that questions institutional homogeneity and gives evidence of spatial variation in innovation across regions and industries in China. Innovation is found to be restricted to a few locations with higher populations and more industrialization (Crescenzi, Rodríguez-Pose, & Storper, 2012; Prud'homme & Zhang, 2019). There also seems to be a skew towards a few clusters of active industries with better technological capabilities (Eberhardt et al., 2016; Guan & Yam, 2015; Prud'homme & Zhang, 2019) and to regions with positive knowledge spillovers generating agglomeration externalities (Kafouros, Wang, Piperopoulos, & Zhang, 2015; Li, 2009; Ma, Lee, & Chen, 2009; Shang, Poon, & Yue, 2012).

Overall, while micro-policy and industrial changes may have played a role (Hu & Jefferson, 2009), the question of whether structural changes like stronger IPR incentivize female participation in innovation remains under investigated. Relatedly, whether stronger IPR also relates to an increase in the quality of patents with female participation in innovation also needs to be addressed. Our study provides some of the first evidence on these two important questions.

3. Data

We obtained data on inventors participating in patenting activity between 1997 and 2011 using PatentsView, a publicly available repository of the United States Patent Trademark Office (USPTO).[11] The raw USPTO data files are widely used for conducting studies related to patenting activity and innovation. These files offer researchers several advantages. First, the PatentsView data aggregation process incorporates a built in algorithm that predicts an inventor's gender. It builds on prior gender classification methods using country-specific names

[11] https://patentsview.org/download/data-download-dictionary

associated with males and females (Caviggioli & Forthmann, 2022; Giczy, Pairolero, & Toole, 2024). Second, it also deals with problems from misspellings and other errors found in raw text fields (Toole, Jones, & Madhavan, 2021). These nuances and attention to detail make the attribution results more accurate and reliable. Using this database, we identify the inventors participating in patenting activity over our study period across 123 countries such as China, Japan, USA, South Korea, UK and India.[12]

To identify the patents that our sample of inventors have worked on, we merge the inventor data with the artificial intelligence patent database (AIPD) published by the USPTO.[13] This crossover data gives us an understanding of the participation of inventors in patents granted between 1997 to 2011 that had a component of AI. The AIPD data allows us to identify each patent's AI component across eight technology classes, including machine learning, natural language processing, evolution, knowledge reasoning, hardware, planning, speech, and vision technologies (Giczy, Pairolero, & Toole, 2022). Through a machine learning algorithm based on patent text, claims, and citations each patent is given a probability score between 0.0 and 1.0 indicating the degree of presence of the eight AI components. The AI probability scores are translated into binary variables taking value of one if the score is greater than or equal to 0.50 and zero otherwise. This allows us to categorize each patent according to its dominant technology component.

Using patent and gender information, we generate a panel at the country, technology class, and year level from 1997-2011. Table 1 describes the construction and definition of the main variables used in our study. There are two main dependent variables assessing female participation in innovation activity. First is the number of patents with female inventors, defined as the total number of patents in a country in a given year in each technology class with at least one female inventor on the patenting team.[14] Second is the total number of female inventors participating in innovation activity at the country-technology-year level.[15] For both these dependent

[12] We used the patent-inventor crosswalk dataset containing identifying location id, inventor id and patent id to map the inventor information (such as name, gender, patent, country of residence or inventor location).

[13] https://www.uspto.gov/ip-policy/economic-research/research-datasets/artificial-intelligence-patent-dataset

[14] A patent can be classified into technology-year category for more than one country due to international collaborations.

[15] Since we cannot capture the level of contribution of a female inventor in each technology component of a patent distinctively, we consider a female as an inventor across multiple technology classes if a patent falls under

variables, we also create share variables by dividing the patents with female inventors by the total number of patents and the number of female inventors by the total number of inventors.

Further, we use the information on citations and strategic importance from the Derwent Innovation Database to understand the quality of innovation activity.[16] From our crossover dataset, we identify the patents for each year in a country across technology classes that had non-zero female inventors. We take this information and collapse mean values at the country-technology-year level to calculate patent quality. The number of citations or forward citations refers to "the number of times a patent has been cited by subsequent patents, indicating that these newer patents are technologically built upon the cited (previously filed) patent" (Fisch et al., 2017). Strategic importance is a unique score generated by Derwent Innovation based on machine learning algorithms for every patent. Table 2 presents the summary statistics for the main variables in our study.

Table 3 provides descriptive estimates from a simple difference-in-differences framework concerning the impact of China joining the WTO. The table highlights the mean value of the log of patents with female inventors and the log of female inventors in the pre- and post-period for China and the ROW. We define 1997-2001 as the pre-shock period and 2002-2011 as the post-shock period. The estimates from first difference indicate a significant increase for both outcome variables as China strengthened its intellectual property regime after the accession to the WTO.

Table 3 also highlights the difference-in-differences estimate (first minus second difference) of raw means. We find a significant increase in both of our main dependent variables. We also find similar results for both the share variables. The t-test and the p-values confirm the significance of the mean difference. These preliminary results from the simple difference-in-differences setup are merely suggestive and require the inclusion of fixed effects and robustness checks to establish a stronger causal inference.

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this ambit. For example, if patent xyz invented by a Chinese female in 2001 had three AI components (ML=0.3, NLP=0.7, Vision=0.6), this female inventor will be included as an AI inventor of ML, NLP and Vision equally.

[16] The measure of the quality of innovation has been at the center of debate in research involving patents. Measures such as patent claims (Harhoff & Wagner, 2009; Régibeau & Rockett, 2010; Tong & Frame, 1994), forward citations (Gambardella, Harhoff, & Verspagen, 2008; Hagedoorn & Cloodt, 2003; Harhoff, Scherer, & Vopel, 2003), citation lag (Fisch et al., 2017; Gay, Le Bas, Patel, & Touach, 2005) and patent renewals (Bessen, 2008; Chen & Zhang, 2019; Liu et al., 2014) have all been used in the extant literature.

4. Empirical Specification

We evaluate the average treatment effect of China's membership in the WTO on the participation of female inventive labor and their patenting activity by using difference-in-differences as our identification strategy. To study the causal relation, we use the following regression specification

$$\mathbf{y_{ity}} = \beta_0 + \beta_1 \mathbf{China_i} \times \mathbf{Post2002_y} + \theta_i + \theta_t + \theta_y + \nu_{it} + \phi_{ty} + \epsilon_{ity} \tag{1}$$

where y_{ity} is the outcome variable measured at the country (i)- technology (t)- year(y) level. y_{ity} is used as the number of patents with at least one female inventor and the number of female inventors in two separate estimates (in the log). $China_i$ corresponds to a dummy for our treatment group, which equals one when country i is China and zero for the ROW (control group). $Post2002_t$ equals one if the year is after 2002, zero otherwise. θ_i, θ_t ,θ_y represent country, technology class and year dummies respectively. ν_{it} & ϕ_{ty} represent paired dummies of country-technology and technology-year respectively. These allow us to control for simultaneous events such as the SkyNet[17] and Smart Cities[18] projects launched in China during the sample period which may confound our results otherwise. Standard errors are clustered at the country level.

The main coefficient of interest in our study is β_1. This estimate captures the effect of China's membership in the WTO on the participation of females in innovation activity at the technology level as compared to the ROW exogenous to the regulation. In other words, it measures the change in female inventors and their patenting activity due to Chinese accession to the WTO, net of change post-2002, and net of possible permanent difference across the ROW .[19]

Our control group comprises 123 countries, which are termed the ROW in this study. The

[17] Launched to ensure public security by rolling out technology(such as facial recognition) to monitor anti-social behavior.

[18] Central government-funded project, encouraged firms to build new technology-integration with facial recognition, big data and AI to monitor anti-social behavior.

[19] Equation 1 represents the reduced form estimation. We test for effects at the first stage using the same specification with total patents as the dependent variable. The results from this estimation have been summarized in Table A2. The positive and significant coefficient in column (3) suggests that after the strengthening of IPR in 2002, the total number of patents in China increased by 82% compared to the ROW. This specification is inclusive of country-technology and year-fixed effects.

preferred counterfactual would have been to identify an exact country with a similar institutional innovation regime and characteristics as China to act as the suitable control group. We recognize that the ROW may not be the perfect comparison group to test the validity of the policy change hence we satisfy the assumption for parallel trends and run numerous validation checks.

Additionally, we run our regression specifications with an alternative control group that has only developed countries and emerging economies in two separate specifications. We perform robustness checks using coarsened exact matching for estimating the true effects of treatment and conduct randomized inference tests to ensure that our results are not obtained by a matter of chance. Finally, we use a data-driven procedure to identify a comparison group based on synthetic controls by Abadie and Gardeazabal (2003).

5. Findings

5.1. *Increasing Female Led Innovation in China After WTO Accession*

5.1.1. *Baseline Findings*

Table 4 presents our baseline results by estimating Equation 1. The dependent variable in Panel A is the log of the number of patents with at least one female inventor and in Panel B is the log of the number of female inventors. In both the panels, columns (1) shows baseline estimation without any fixed effects. Column (2) includes the fixed effects at the country and technology level and in column (3) we introduce year fixed effects and an interaction dummy for country-technology and technology-year along with the existing fixed effects. Standard errors in all estimations are clustered at the country level.[20]

The interaction coefficients in Table 4 represent the impact of China becoming a WTO member on its female inventors and their involvement in AI patenting activity (compared to the ROW). We use column (3) for interpretation since they are the most conservative with all fixed effects. In column (3) of Panel A, where we consider patents with at least one female inventor,

[20]Estimations with standard errors clustered at the country-technology level also follow the same sign and significance as our baseline results. Results are shown in Table A3.

we find a positive and significant interaction coefficient (β = 1.161). This indicates that China's WTO accession caused an increase in the number of patents with at least one female inventor by 116% as compared to the ROW. Similarly, findings in column (3) of Panel B, where we consider the number of female inventors, indicate a positive and significant interaction coefficient (β = 1.836). This indicates that the number of female inventors in China increased by 183.6% compared to the ROW after 2002.[21]

There could be a concern that these results are obtained because of an overall increase in patenting activity, and an increase in female innovators is just part of the overall growth in innovation in China. To overcome this concern, in Table 5, we present results on the share of patents with female inventors and the overall share of female inventors using Equation 1. We find that across model specifications the interaction coefficient remains positive and significant. This indicates that with China joining the WTO the share of female inventors involved in AI-based innovation increased compared to the ROW.

5.1.2. Alternate Control Group

We perform robustness checks by altering our control group (i.e., the ROW). The purpose of these checks are to ensure that our results are not confounded and that the treatment effect holds for our outcome variables in China after the policy shock. Following the IMF's classification of countries, we divide our control group sample into developed and emerging economies. We compute this estimation to ensure that our results are not driven by a control group comprising a pooled set of diverse countries. We repeat our analysis using these two separate control groups and present our findings in columns (4) and (5) of Table 4.[22]

The coefficient of interest remains significant and positive for both outcomes of interest in column (4) of Panel A and B (Table 4), where the control group comprises only emerging economies. These results suggest that as China joined the WTO in 2002, its innovation environment became more friendly for female-led innovation when compared to the group of other emerging economies. By analyzing the gendered perspective, these findings not only support

[21]We also find an increase in male inventors during the same time using the same regression model but the coefficient is much smaller.

[22]We also use as a control group those countries that joined the WTO after 2002 and were classified as emerging countries. All our results hold and are available upon request.

but contribute to the literature that studies the factors and policies that led to differences in the evolution of innovation between emerging economies (Crescenzi & Rodríguez-Pose, 2012; Crescenzi et al., 2012; Tiwari et al., 2017).

Next, we estimate the same regression specification by changing the control group to developed countries. The findings in column (5) of Panel A and B (Table 4) reveal that the percentage of patents with at least one female inventor and the percentage of female inventors in China increased by 110% and 168.7%, respectively. This is suggestive of an increase in innovation by female inventors in China after 2002 compared to developed countries. Overall, the effect in China is stronger when compared against emerging economies as opposed to developed ones.

5.1.3. Coarsened Exact Matching (CEM)

We use the non-parametric technique of coarsened exact matching (CEM) to reduce imbalances between the treatment and the control group. The basic idea of CEM is to coarsen each variable by re-coding so that substantively indistinguishable values are grouped and assigned the same numerical value (Iacus et al., 2012). We match the treatment and control groups based on the total number of inventors and patents in a country in a year. In matching weights, a limited number of unmatched units receive zero and get dropped from the estimation.

CEM has gained attention as a robustness check for the validity of the control group in a causal estimate framework due to its multitude of advantages (Chen, Zaiyan, & Xie, 2022; Fry, 2021; Galasso & Simcoe, 2011; Iacus, King, & Porro, 2011; Wang & Zheng, 2022; Zervas, Proserpio, & Byers, 2017). For example, it can reduce estimation error, bias, model dependence, and imbalances between the treatment and the control group. Moreover, it is easily automated and has improved statistical properties (Blackwell, Iacus, King, & Porro, 2009; Rathi, Chakrabarti, Chatterjee, & Hegde, 2022).

Column (6) of Panel A and B in Table 4 gives the estimates from the CEM technique. Our coefficient of interest remains significant and positive for both outcome variables. We observe that there is slight drop in the number of observations as compared to our baseline analysis. However, the results show that post-CEM, with proper matching, our baseline results for both the outcome variables improve. We find a 117.0% increase in the AI patenting activity including female inventors and a 184.3% increase in participation by female inventors in China after 2002.

5.1.4. Alternate Sample - Extended Period

Our baseline analysis period is 1997 to 2011 which is five years before the policy shock in China. There were two reasons for the selection of this time frame. First, we intend to have enough years in the pre-intervention period for observing pre-trends. Second, this period was marked by the onset of changes in the IPR regime within China. Now, to ensure that our results are not driven by selecting a particular time frame, we extend the pre-period of our analysis. As a part of this robustness check we estimate the results for our baseline model with the extended period from 1990 to 2011.

The results obtained from the regression analysis are presented in column (7) of Panel A and B in Table 4. The coefficient for the number of patents with female inventors (in log) and the number of female inventors (in log) remains positive and significant. After the strengthening of the IPR regime in China, we find that patents with at least one female inventor and the number of female inventors increased by 101% and 178%, respectively. These estimates further support and strengthen our baseline findings.

5.1.5. Non Existent Pre-Trends

To validate the assumption of parallel trends, we plot the coefficients using an event study design. This test implies that in the absence of treatment, the changes in outcome for the treatment group would be similar to the changes in the outcome in the control group. In other words, without the policy shock, outcomes for China and the ROW should follow parallel trajectories over time. The estimation is based on the following specification:

$$\mathbf{y_{ity}} = \beta_0 + \sum_{\mathbf{y=1998}}^{\mathbf{2011}} \beta_{\mathbf{y}}(\mathbf{China_i}) + \theta_i + \theta_t + \theta_y + \nu_{it} + \phi_{ty} + \epsilon_{ity} \tag{2}$$

where $Year_y$ ranges from 1998 to 2011, with 1997 as the base year. We plot the coefficients obtained from Equation 2 for both outcome variables: (1) log of the number of patents with at least one female inventor and (2) the log of the number of female inventors. Insignificant coefficients in the pre-period (until 2001) would satisfy the assumption of parallel trends between the treatment and control group in our estimated results.

In Panel (a) of Figure 4, where the dependent variable is the log of the number of patents with at least one female inventor, we find that the coefficients in the pre-treatment period are near zero and insignificant. This indicates that in the absence of the treatment, the outcome for the control group and the treatment group follows a parallel trend. Importantly, the figure shows significant and positive coefficients for the year following the policy shock in 2002. This suggests that there was an increase in innovation involving female inventors following the strengthening of IPR in China.

Next, in Panel (b) of Figure 4, we show event study results where the dependent variable is the log of the number of female inventors. We find that except for 2001, all interaction coefficients in the pre-period are insignificant. Panel (b) also shows a significant jump starting in 2003, indicating an increase in female inventors in China after WTO accession.[23]

5.1.6. Synthetic Control

The ideal counterfactual for our identification strategy would be to observe the outcome for China in the absence of treatment. To obtain a control group that resembles China, we create a synthetic China by using the estimation strategy outlined by Abadie and Gardeazabal (2003). We use a data-driven procedure that reduces the researcher's discretion in choosing a comparison group. We use the synthetic control method to obtain an artificial control group through the weighted average of the available control units. This provides a better comparison for the unit exposed to intervention.

This approach creates a combination of comparison units matched to the characteristics of the treated group in the pre-treatment period. This data-driven technique has become more widespread due to its advantages (Adbi, Chatterjee, Drev, & Mishra, 2019; Aggarwal, Chakrabarti, Chatterjee, & Higgins, 2021; Billmeier & Nannicini, 2013; Green, Heywood, & Navarro, 2014), as it highlights two things. First is the percentage of contribution of each control unit to the counterfactual and its similarity with the treated group. Second, the sum of the weights is

[23] We corroborate these findings of pre-period empirically in Table A4.

one and is restricted to be positive (Abadie et al., 2010). Hence, the synthetic control method saves from extrapolation (Abadie et al., 2010).

Using this approach for identifying a valid counterfactual, weights are assigned to the countries from the ROW to create an artificially matched sample of China.[24] Figure 5 shows the plots for both of our dependent variables between 1997 and 2011. The figure shows that our benchmark findings hold when the control group is substituted with synthetic China. As with the non-parametric analysis, the number of patents with at least one female inventor and the number of female inventors follow similar trends in the pre-intervention period. This shows that synthetic China provides a sensible approximation for female inventor participation in inventive labor and their patenting activity. Immediately after the policy shock in 2002 the two trends diverge noticeably. Thus, China joining the WTO changes the trajectory of the outcome variables for the treated group in a positive and significant direction, therby confirming and providing further support for our baseline results.

5.1.7. Randomized Inference

Next, we utilize a randomized inference (RI) test to asses if the treatment effects are just a matter of chance. Originally developed by Fisher (1936) and taken forward by Rosenbaum (2002) to perform exact tests for experiments, RI is increasingly being applied to non-experimental data (Bharadwaj, Johnsen, & Løken, 2014; Chakrabarti, Kishore, & Roy, 2018; Nagler, Piopiunik, & West, 2020). The RI test can also be considered a falsification exercise. We use the 'ritest' command developed by Heß (2017) in STATA to conduct the RI test.

We compare the coefficients from our baseline specification shown in column (1) and column (3) of Table 4 to a distribution of coefficients. We follow a three-step process. First, we reallocate a country-technology-year combination of the two groups (treatment and control) randomly, ensuring that the sample sizes match with that of our baseline model. Second, we use the baseline specification Equation 1 to estimate the treatment effect using these new treatment and control groups. Third, we repeat this exercise 10000 times. The idea is to compare

[24]Synthetic China comprises Ireland - 68.2% and Israel - 31.8% when the dependent variable is the number of patents with at least one female inventor. When the dependent variable is the number of female inventors, synthetic China is made up of Ireland - 47.4%, Australia - 29.7%, Belgium - 22.8% and US - 0.2%.

the coefficients we obtain from this random reorganization to those from our baseline specification. The p-values obtained from RI, clustered at the country level, are shown in Table 6. The p-values suggest that the effects of China joining the WTO on the increase in female-supported innovation is unlikely to be observed simply by chance.

5.1.8. Heterogenities Across AI Technology Sub-Classes

We wish to explore if there are any underlying heterogeneities at the technology sub-class level that may explain our results. Thus, we split the sample across the eight AI technology sub-classes as defined by Giczy et al. (2022) in the AIPD dataset. The purpose of this exercise is to observe if within AI there are specific technologies that may be favoured by female inventors. To evaluate this we use Equation 1 without technology-fixed effects and generate estimates on technology-based sub-samples. Table 7 presents our results for both of our dependent variables. The dependent variable in Panel (a) is the log of the number of patents with at least one female inventor and in Panel (b) it is the log of the number of female inventors. In both the panels, columns (1)-(8) show sub-sample analysis across different AI technology sub-classes. All models include year, country, country-technology and technology-year fixed effects. Standard errors in all estimations are clustered at the country level.

We find that the interaction coefficient, in all sub-samples, for both dependent variables is positive and significant. There is, however, stark differences in involvement of female inventors in different technologies. One can see a significant increase in participation of female inventors in less complex and established technologies like computer vision and knowledge processing and a smaller increase in more evolving technologies like ML and evolutionary computation. Thus, while we do find an increase in female inventors and patents with female inventors, there seems to be an underlying choice made at the technology sub-class level that is causing the large shift in female involvement.

5.2. Mechanisms

We believe three mechanisms led to the increasing participation of female inventors in the inventive labor market in China. First, there is an increase in the share of domestic female inventors on patent-inventor teams in China compared to the control group countries in our analysis. Given the heterogeneity in inventor teams and increasing international collaborations, this mechanism allows us to obtain a coherent picture of the promotion of female inventors within a country's innovation environment. Second, human capital improved after China's ascension to the WTO. This human capital channel provides us an insight into the technological skills that females in China were developing through participation in higher education. Our findings provide suggestive evidence of the growing complementarity between females pursuing higher education and subsequently participating in the innovation environment of China. Third, there is an increase in female inventors and patents with females filed by private firms after WTO accession. We study how increased competition amongst private firms after 2002 acts as a mechanism that ensures fair gendered allocation of labor in innovation.

5.2.1. *Share of Domestic Female Inventors*

To assess the change in the participation of females in the Chinese innovation environment, we obtained information on the assignee (the organization to which a patent was granted) of patents between 1997 and 2011 from the PatentsView repository of USPTO. This data file allows us to identify the assignee organization and the assignee country of the patents.[25] After using the patent ID as the unique identifier, we match the patents to their inventors and their respective locations. We then obtain the number of female inventors in each patent-inventor team. Next, using inventor location, we identify the number of domestic and international female inventors. Finally, we calculate the share of domestic female inventors on the patent team as the number of domestic female inventors divided by the total number of female inventors on each patent-inventor team. We estimate the impact of accession to the WTO on the share of domestic female inventors in China compared to the ROW, using the following equation:

$$\begin{aligned}\mathbf{y_{iy}} = \beta_0 + \beta_1\mathbf{China_i} + \beta_2\mathbf{Post2002_t} + \beta_3\mathbf{China_i} \times \mathbf{Post2002_y} \\ + \theta_i + \theta_y + \epsilon_{it}\end{aligned} \tag{3}$$

where y_{iy} is the share of domestic female inventors (in the log) measured at the country-year

[25]The type of organization allows us to identify if a patent was assigned to a country's government, a country's private firm, a public-private partnership of a country, or an international agency each year.

level. The rest of the parameters remain the same as our baseline equation.

The results from our regression estimates are presented in Table 8. In column (1), we observe a 65.7% increase in the share of domestic female inventors on patent teams in China after the strengthening of IPR compared to the ROW. Columns (2) to (4) give the coefficients obtained for $Post2002_y$ from a before and after estimation, following Equation 3. This specification does not include fixed effects for time and country. In column (2), the coefficient for $Post2002_y$ is positive and significant, suggesting a 63.2% increase in the share of domestic female inventors in China. The coefficient in columns (3) and (4) includes the estimates for developed economies and the ROW, respectively. The share of domestic female inventors on patent teams decreases by 3.3% for developed economies (column 3) and 3.4% for the ROW (column 4).

Our findings complement Tang and Zhang (2021). They find that gender discrimination was reduced in domestic Chinese firms due to cultural transfers generated by multinational firms.[26] While their findings apply to manufacturing firms, our study provides suggestive evidence for the innovation market, specifically AI. With the accession to the WTO, the strengthening of the intellectual property regime enabled non-state entities to access the innovation market of China. In response to this new competition (in line with Becker's model of discrimination) and cultural spillovers, the share of female inventors in domestic firms increased.

5.2.2. *Percentage of Women in STEM PhDs*

A number of studies focused on the gender gap in innovation suggest that increasing representation in science and engineering fields (Hunt, Garant, Herman, & Munroe, 2013), collaboration ties (Meng, 2016) and education level (Marvel et al., 2015; Mendonça & Reis, 2020) may increase the probability of patenting for female inventors. This positive impact holds even when gender equality is lower in developing countries (Attah-Boakye, Adams, Kimani, & Ullah, 2020). To assess this human capital channel, we obtain data on the number of females in higher technical education from the Ministry of Education of the People's Republic of China.[27] We

[26] A recent study by Crescenzi, Dyèvre, and Neffke (2022) also signals the role of multinational firms in boosting innovation and growth.

[27] See: http://www.moe.gov.cn/jyb_sjzl/moe_560

obtain the percentage of females in higher technical education by dividing the number of females enrolled in a Ph.D. program by the total number of students enrolled in Ph.D. programs in China.

Figure 3 depicts the percentage of female Ph.D. enrollment in scientific research institutions from 1997 to 2011. We observe a sudden increase in the percentage of female enrollment from 2004 onwards. Importantly, this increase remains persistent and never returns to the pre-WTO era. This increasing trend indicates a progression in China that supports female interest in higher technical education. Thus, our results suggest that after the strengthening of IPR, not only the share of Chinese female inventors increased significantly but it was also supported by a strong human capital pool.

5.2.3. Firm Characteristics

In China, accession to the WTO led to liberalization and openness. The regime change required China to recognize property rights of inventors. This allowed entry of private and foreign firms into innovation focused industries, which were previously concentrated by state-owned enterprises. Figure 6 shows the gradual increase in the number of patents owned by firms other than the state-owned enterprises from 1997 to 2011. The figure suggests an increase in competition in the Chinese innovation environment.

Based on the Becker model, we postulate that increased competition will increase the cost of discrimination against female inventors. When competition increases, new firms entering the market without a taste for discrimination hire the profit-maximizing number of female inventors. Whereas firms with a strong taste for discrimination end up paying more by not hiring female inventors, thus losing potential profits. As a result, competition drives out discriminatory firms as they will earn less than normal profits from the innovation market. This, in turn, should increase the participation of female inventors in the long run.

Accession to the WTO opened up the innovation environment for private firms in China (Figure 6). With this increased competition, private firms were bound to balance their gendered allocation. As shown in Figure 7, we see a clear jump in the number of patents with female inventors and the number of female inventors amongst those who are either an individual patent owner or part of a multi-national corporation. Interestingly, these same two variables show negligible change for state-owned enterprises.

We empirically evaluate the magnitude of this mechanism by creating a panel at the firm-country-year level. We identify the assignee type of the patent and code it as private if the patent is filed by an individual or a multi-national corporation. Similarly, if a patent is filed by a state-owned enterprise we code it as a government-filed patent. We present the results for the analysis with our two dependent variables in Table 9. Columns (1) and (3) show the baseline effect and columns (2) and (4) include firm, country and year-fixed effects to control for unobserved heterogeneity. As shown in column (2), we find more than a 100% increase in the number of Chinese patents with at least one female inventor. Similarly, as shown in column (4), compared to state-owned enterprises, the number of female inventors in private firms increased by 116.4 % after 2002. These findings justify our theoretical motivation that increased competition in China after 2002 led to reduced discrimination against female inventors. Private firms appear to have led this effect.

5.3. Impact on Quality of Innovation

Thus far, our results have provided evidence that the number of female inventors and the number of patents with female inventors increased after Chinese accession into the WTO. A logical next question is whether quality of innovation was impacted by the increased presence of female inventors. Patent quality is important because it generates returns for inventive firms (Boeing, Mueller, & Sandner, 2016). However, the increasing propensity of inventive labor to patent more has brought the quality of these patents into question. The evidence in the literature is mixed. On one hand, a number of studies (Chen & Zhang, 2019; Dang & Motohashi, 2015; Fisch et al., 2017) suggest that the quality of patents in China did not converge in increased patenting. On the other hand, several studies find that institutional policies promoting domestic innovation (attracting FDI, R&D) and reducing the cost of innovation (patent application fee subsidy) led to lower-quality patents (Fisch et al., 2016; Liu et al., 2014; Thoma, 2013).

To assess the value of innovation generated by female inventors in China, we evaluate the quality of patents using strategic importance and the number of patent citations. The estimates are drawn from the following regression specification:

$$\mathbf{y_{ity}} = \beta_0 + \beta_1 \mathbf{China_i} \times \mathbf{Post2002_y} + \theta_i + \theta_t + \theta_y + \nu_{it} + \phi_{ty} + \epsilon_{ity} \tag{4}$$

where y_{ity} is measured at the country-technology-year level. y_{ity} is either the number of citations or strategic importance (in the log). $China_i$ corresponds to when country i is China (one for our treatment group) or the ROW (zero for our control group). $Post2002_t$ equals one if the year is after 2002, zero otherwise. θ_i, θ_t, θ_y represent country, technology and year dummies respectively. ν_{it} & ϕ_{ty} represent paired dummies of country-technology and technology-year respectively. Standard errors are clustered at the country level.

Table 10 shows the results from Equation 4. Columns (1) to (3) have the log of the number of citations as the dependent variable while columns (4) to (6) have the log of strategic importance as the dependent variable. Columns (1) and (4) report the baseline estimation without any fixed effects. Columns (2) and (5) include the fixed effects at the country and technology level to deal with heterogeneity. Finally, in columns (3) and (6), we introduce year fixed effects and an interaction dummy for country-technology and technology-year along with the existing fixed effects.

The interaction coefficient in Table 10 indicates the impact of China's WTO accession on the quality of patents with female inventors. We find that across columns (1) to (6) the interaction term $China \times Post2002$ is positive and significant. We focus on columns (3) and (6) for interpretation since they are most conservative as they include all fixed effects. In Column (3), we find that the quality of AI patents measured by forward citations that involved Chinese female inventors increased by 135.8% compared to our control group. In Column (6) we find that the strategic importance of the patents involving female inventors increased by 33.7% compared to our control group. These results suggest that as female inventor participation increased, so did the quality and importance of patents (innovation) they worked on. Our findings are consistent with Ain, Yuan, and Javaid (2021), and Xie and Zhang (2015) who also show gender effects on the quality of innovation. Our findings support the literature which emphasizes the improvement in quality of innovation involving women.

6. Discussion

While innovation remains a social good, its generation sometimes is limited by barriers. Inventors require encouragement, protection and legal rights to create knowledge that can be diffused in society. IPR as a tool fosters the creation of this social good by providing the necessary economic incentives to achieve this goal. Moreover, it balances the social costs arising from ownership by limiting grants to novelty, inventiveness, and practical applicability. There has been a longstanding question on whether countries should strengthen their intellectual property regimes. For developed countries, there are clear benefits in strengthening IPR, however, for developing countries the debate is still unresolved; researchers have presented arguments on both sides. Our results suggest that as an emerging economy, China benefited from the strengthening of IPR, especially female inventors.

Our findings reveal that compared to the ROW there is a significant increase in the number of patents with female inventors and the number of female inventors in China. Our findings undergo a battery of robustness checks including alternate control groups, coarsened exact matching, randomized inference testing and synthetic controls. Critically, not only do we find increases in patent activity by female inventors, we also observe that quality of patents with female inventors improved.

To our knowledge, this is the first study focusing on gender divisions in inventive labor with explicit attention to identifying heterogeneity at the technology class and country level. With this study we contribute to the larger debate around strengthening IPR and whether it benefits the research community by fostering innovation across gender. This study remains relevant as the evolution of China from an imitation-based economy to a leader in innovation can present an example for other emerging economies. Moreover, the catching up of China with US, Japan and South Korea is more than a temporal phenomenon and its innovation evolution is turning it into a leader in AI (Lundvall & Rikap, 2022).

As with all studies, ours also suffers from a number of limitations. First, our study was not able to examine patent family relationships. This knowledge could be used by researchers in future work to examine the effect of cross-country collaborations for female inventors across technology classes. It could also be expanded further to study the impact of female inventors across different types of patents. Second, future researchers could examine the innovation stage for patent holders across gender. This could be analyzed by using the data on pre-grant patent holders (i.e., the ones at the application stage) and the ones we are using (i.e. granted patents). From this analysis, future researchers can understand whether gender differences may lead to a lag in translation of creative efforts and new ideas.

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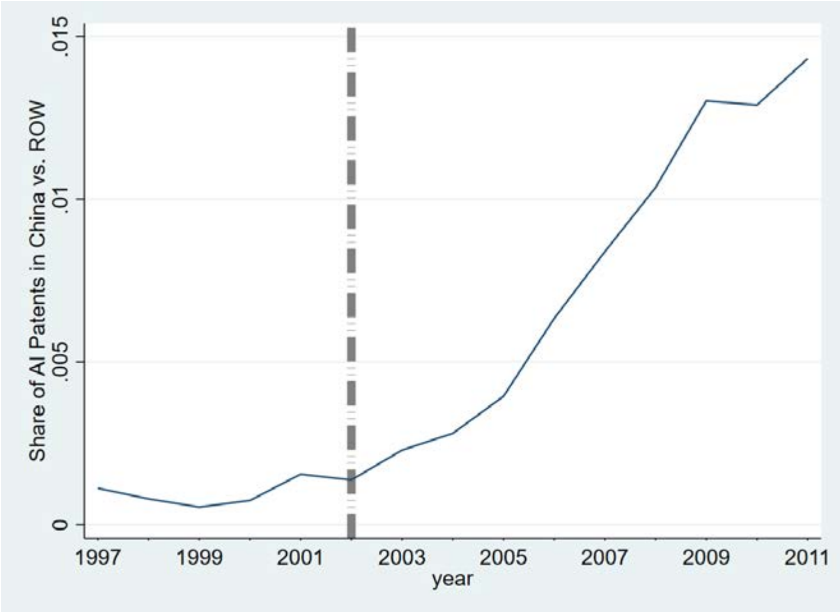
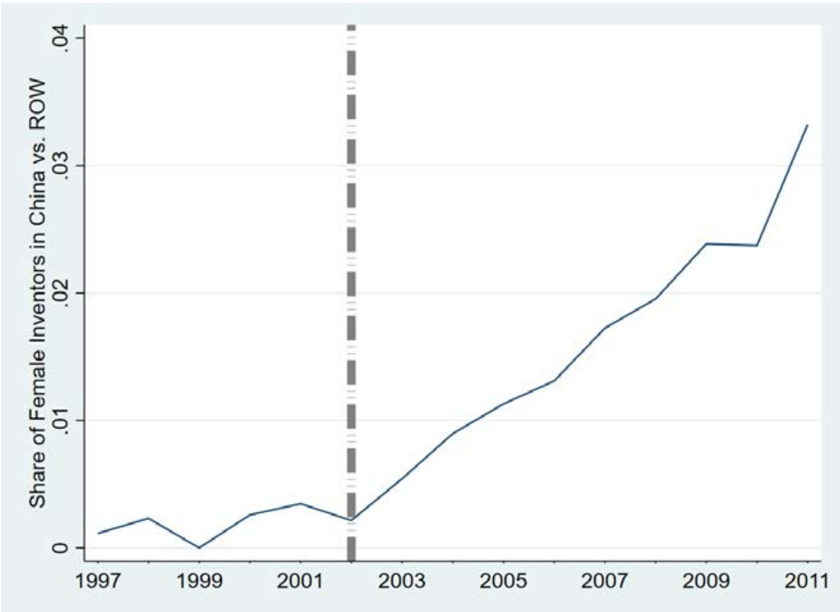
Figure 1: Descriptive Plots: Innovation in China. In Panel (a), we present the share of AI patents in China which are calculated as the total number of Chinese AI patents across eight technology classes divided by the total number of AI patents in the ROW. In Panel (b) we present the share of female inventors in China which is calculated as the total number of Chinese female inventors across eight technology classes divided by the total number of female inventors in the ROW.



(a) Share of AI Patents in China.



(b) Share of Female Inventors in China.

Figure 2: Inventors Across Countries. This figure includes graphs for nine countries indicating the trend lines for the total number of inventors (solid line in blue) and the total number of female inventors (dashed line in red) between 1997 to 2011. The reference line indicates the year of the policy shock (i.e., 2002). We can see that for all countries there is an increase in total number of inventors but female inventors increase only for China.

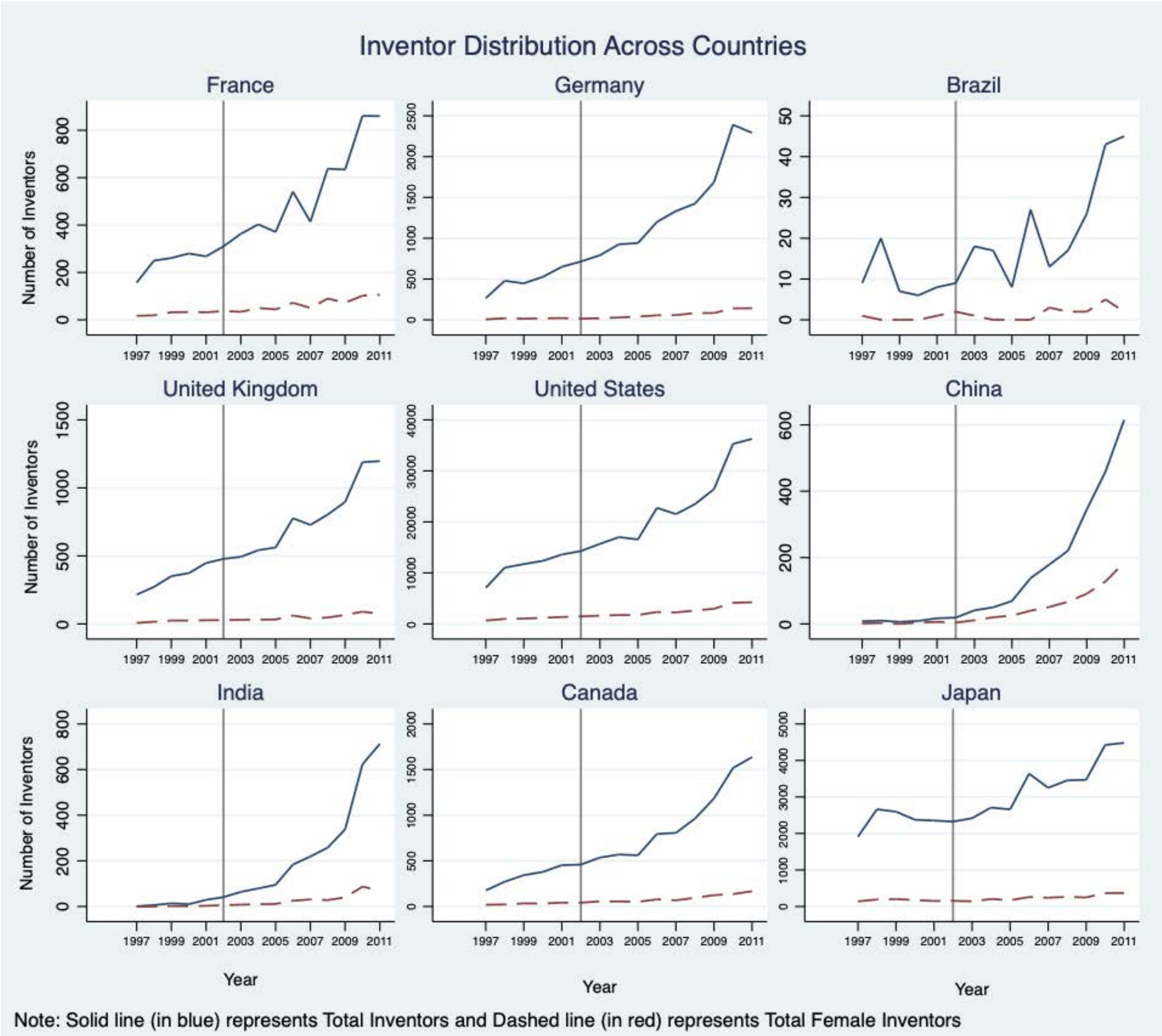


Figure 3: Females in Higher Education. The plot shows the percentage of female Ph.D. enrollment in scientific research institutions from 1997 to 2011. Data for years 2002 and 2003 was not available and has been interpolated. We observe a sudden increase in female enrollment from 2004. These trends imply an increasing interest by females in higher technical education. Source: Ministry of Education of People's Republic of China - http://www.moe.gov.cn/jyb_sjzl/moe_560.

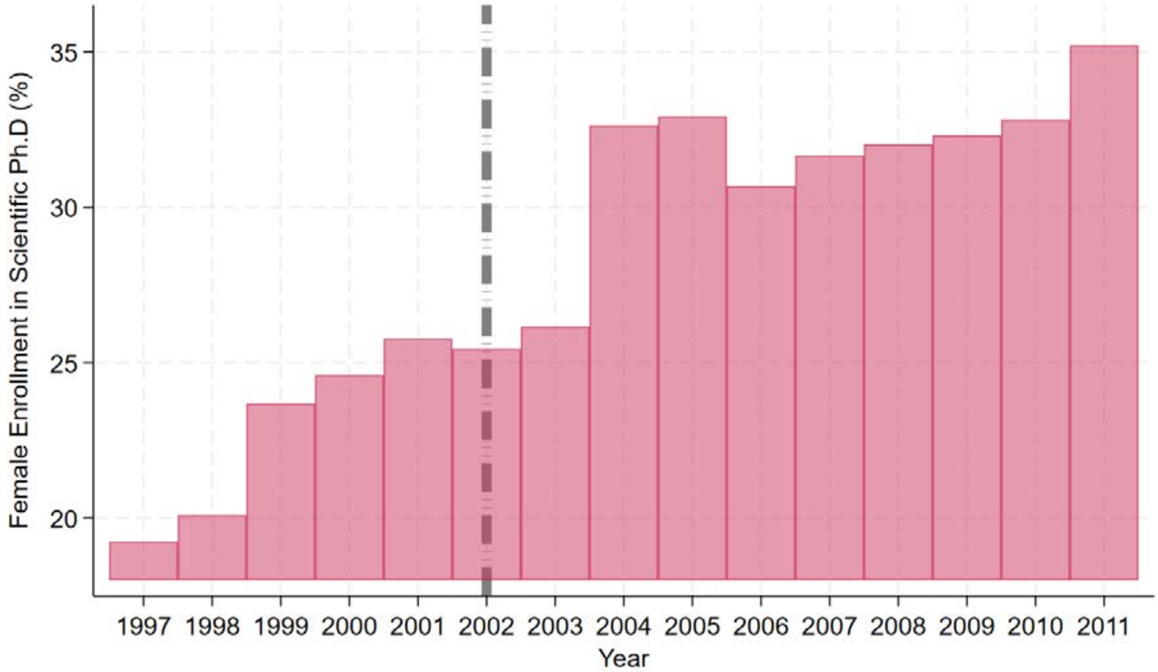
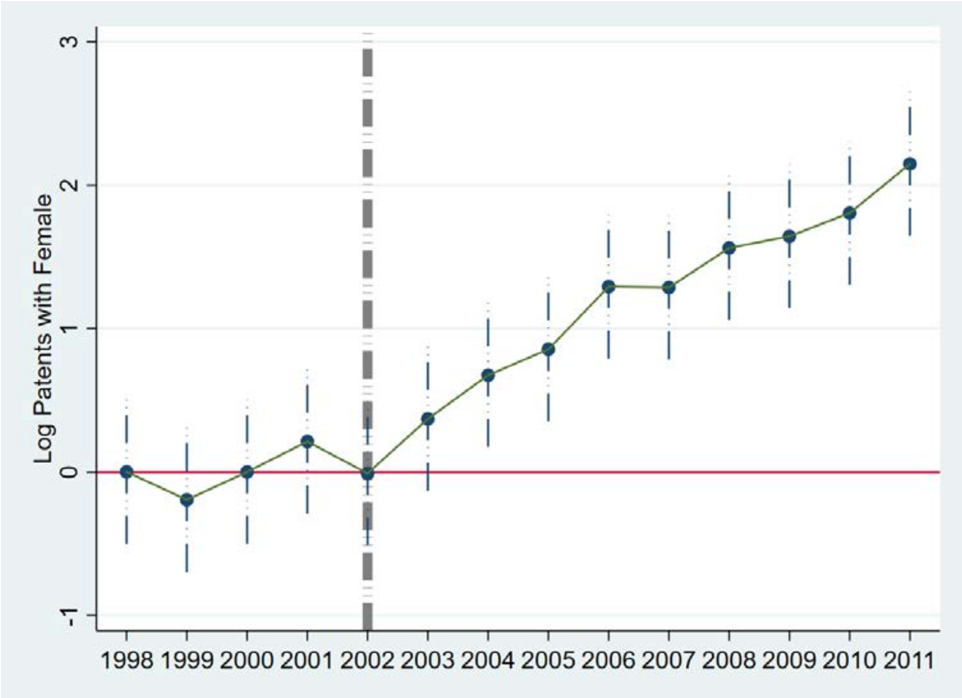
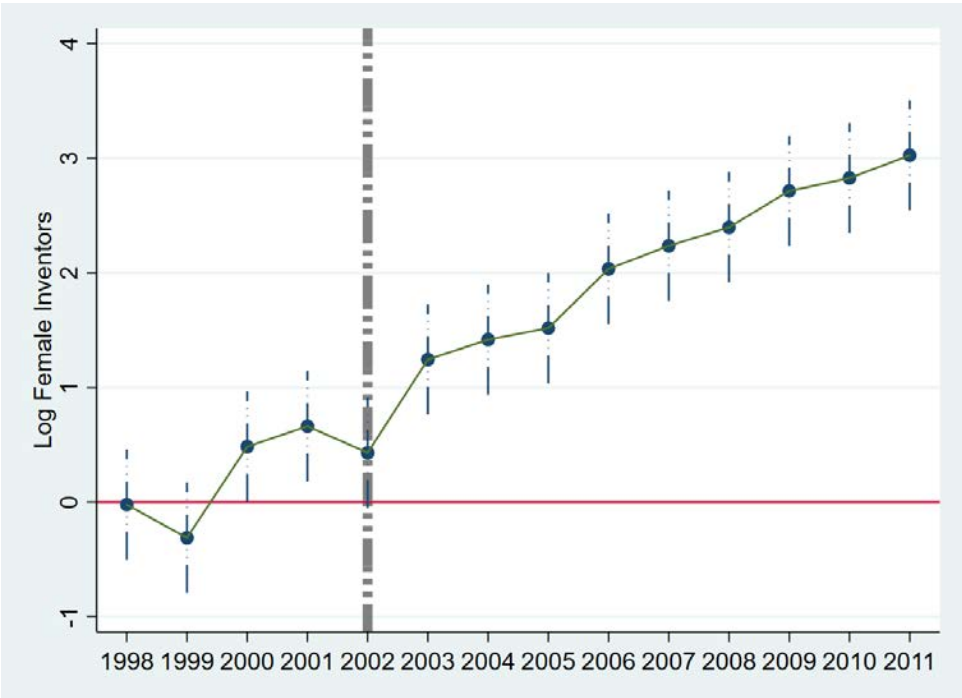


Figure 4: Event Study Design. The point estimates are coefficients for the country-technology class dummy for every year from 1998 to 2011 (1997 is taken as the base year) for our main outcome variables - Log Patents with Female in Panel (a) and Log Female Inventors in Panel (b). The dashed vertical line for each point estimate indicates the 95% confidence interval. The dashed-dotted reference line indicates the year of the policy shock (i.e. 2002). The horizontal red line at 0 indicates no significant difference between treated and control groups.

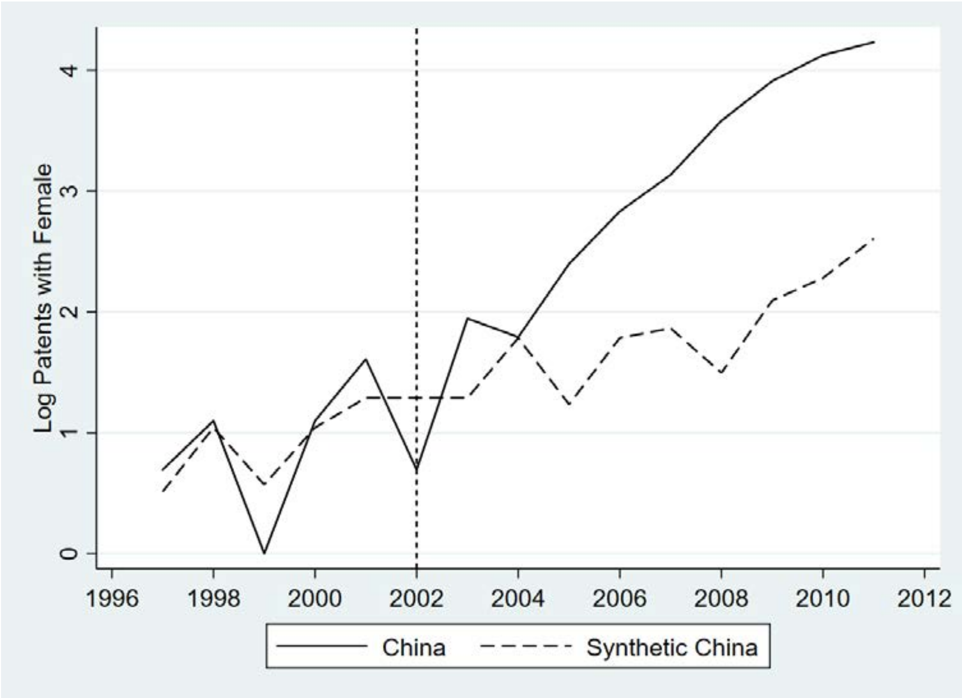


(a) Number of Patents with At Least One Female Inventor

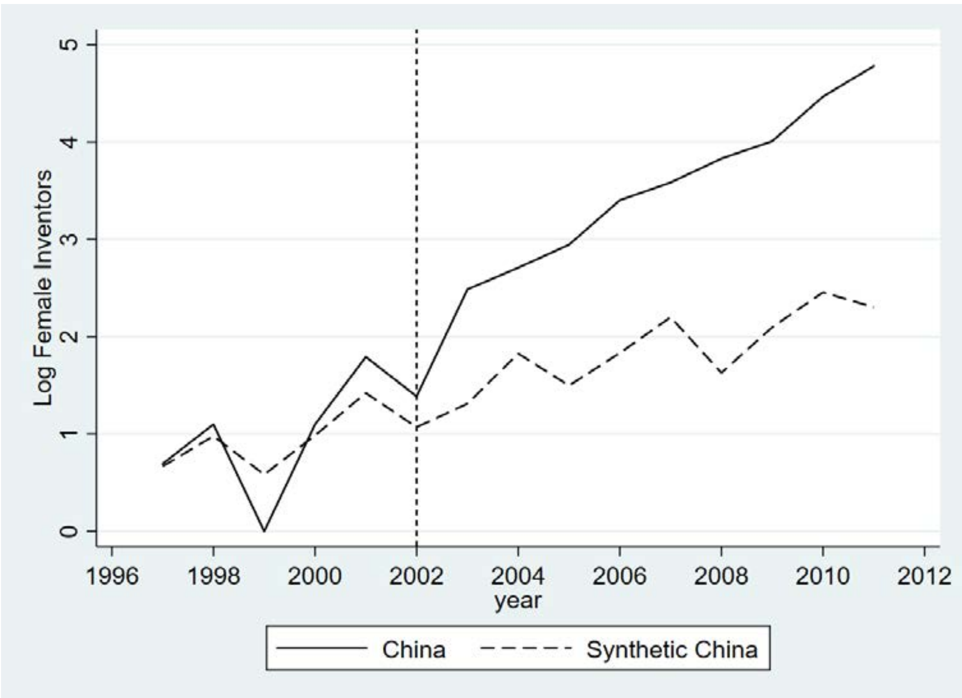


(b) Number of Female Inventors

Figure 5: Synthetic Control. Panel (a) plots the log of the number of patents with at least one female inventor and Panel (b) plots the log of the number of female inventors between the period 1997 and 2011. The dotted line is the trend for synthetic China and the solid line follows the trajectory of our outcome variables for China.



(a) Number of Patents with At Least One Female Inventor



(b) Number of Female Inventors

Figure 6: Innovation Environment in China. The figure includes the total number of patents assigned to non-state entities between 1997 to 2011 in China. We observe a gradual increase in the innovative activity of non-state firms after the accession to the WTO. This suggests an increase in competition in innovative industries in China.

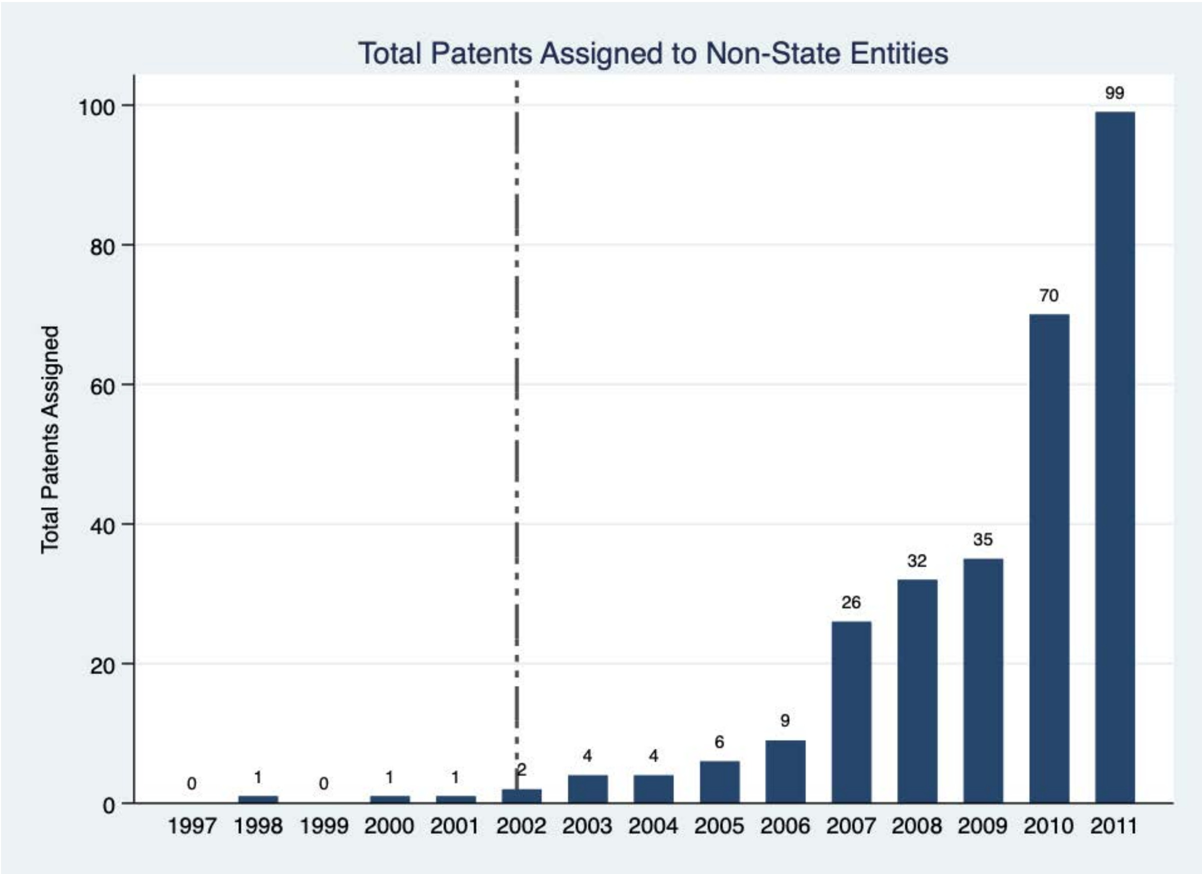
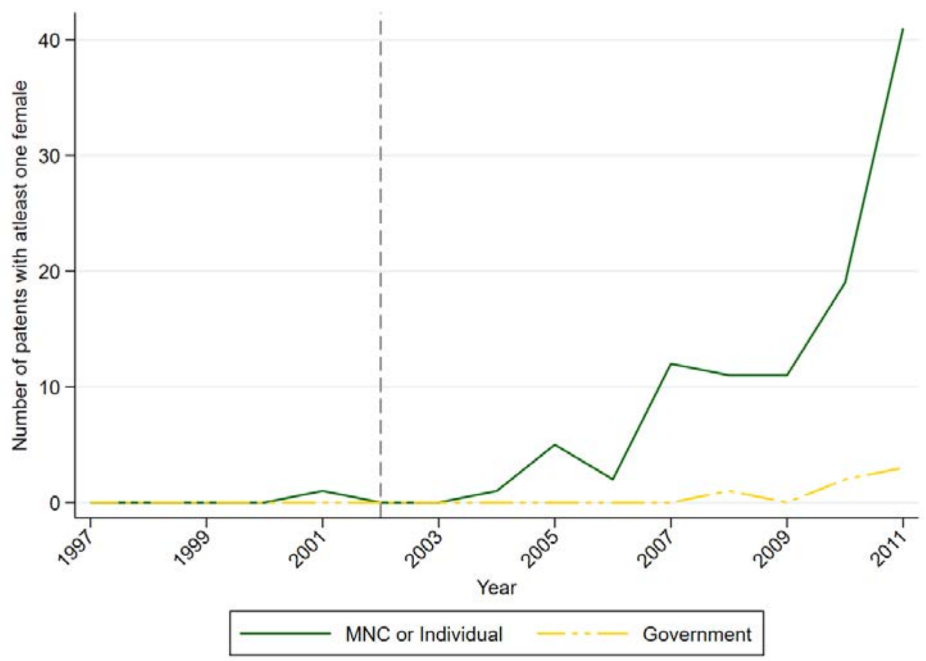
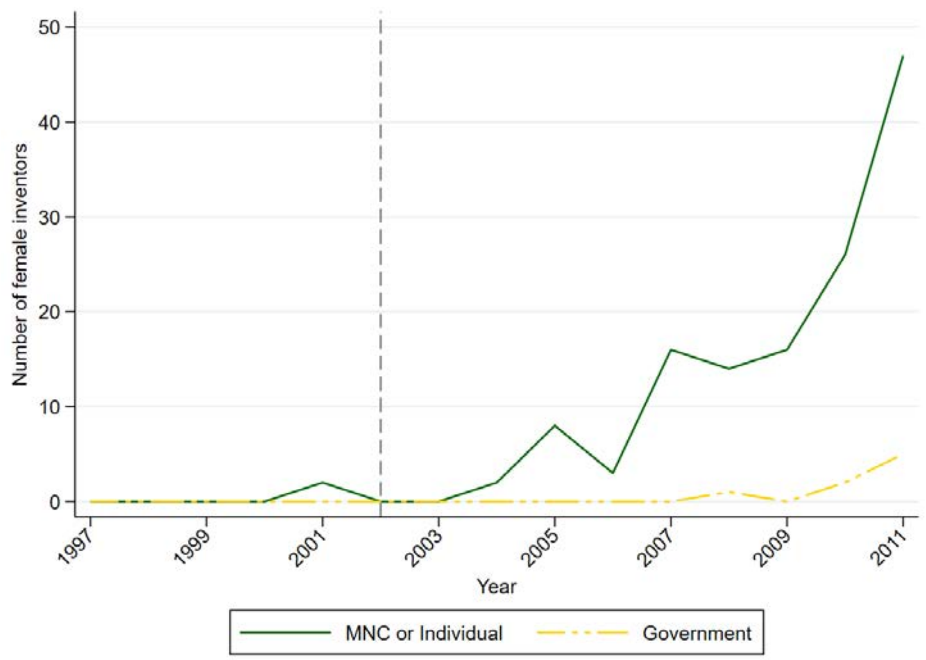


Figure 7: Firm Effect. Panel (a) plots the log of the number of patents with at least one female inventor and Panel (b) plots the log of the number of female inventors between the period 1997 and 2011. Two trends are shown (1) individual patent owners or multinational companies and (2) government or state owned enterprises.



(a) Number of Patents with At Least One Female Inventor



(b) Number of Female Inventors

Table 1: Variable Description

Dependent Variables	Definition and Construction
Log Patents with Female	Logarithm of (1 + number of patents that have at least one female inventor)
Log Female Inventors	Logarithm of (1 + number of female inventors in a country in a year)
Log Number of Citations	Logarithm of number of citings of the patent obtained from Derwent database
Log Strategic Importance	Logarithm of strategic importance score of the patent. Strategic importance score is obtained from Derwent as a combination of other Clarivate scores based on machine learning.
Log Share of Patents with Female	Logarithm of (1 + share of patents with atleast one female out of total patents)
Log Share of Female Inventors	Logarithm of (1 + number of female inventors out of total inventors in a country in a year)
Independent Variables	**Definition and Construction**
China	Coded as one if country is China, zero for other countries
Post 2002	Coded as one if country-year pair is from 2002, zero otherwise

Table 2: Summary Statistics

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
Log Patents with Female	6624	0.46	1.012	0	7.53
Log Female Inventors	6624	0.625	1.214	0	8.071
Log Citations	1645	1.509	1.034	0	5.811
Log Strategic Importance	1645	0.746	0.695	0	4.485
Log Share of Patents with Female	6624	0.048	0.163	0	4.5
Log Share of Female Inventors	6624	0.046	0.099	0	0.693
Log Total Patents	6624	0.713	1.367	0	8.834
Log Total Inventors	6624	1.804	1.975	0	10.17

Table 3: Descriptive Estimates in Difference-in-Differences Framework

	China		Rest of World		Difference-in-Differences		
Variable	Pre	Post	Pre	Post	Diff.	t-stat	p-value
Log Patents with Female	0.181	1.563	0.382	0.473	1.291	6.580	0.000***
Log Female Inventors	0.453	2.611	0.493	0.642	2.009	8.610	0.000***
Log Share of Patents with Female	0.060	0.162	0.043	0.048	0.097	3.060	0.002***
Log Share of Female Inventors	0.131	0.26	0.036	0.044	0.121	6.430	0.002***

Notes: The table represents the initial summary statistics in the difference-in-differences framework. We show mean values of our dependent variables pre and post 2002 and calculate difference-in-differences values along with respective t-stat and p-values. The post-period includes years from 2002 to 2011 and the pre-period includes years from 1997 to 2001. For all four variables, we find a difference-in-difference (first difference - second difference) value to be positive and significant.

Table 4: Change in Number of Patents with Females and Number of Female Inventors

Panel A

DV: Log Patent with Female	Baseline Results			Alternate Control Group Emerging	Developed	CEM	Extended Time Period
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
China x Post 2002	1.291***	1.161***	1.161***	1.299***	1.100***	1.170***	1.011***
	[0.039]	[0.038]	[0.038]	[0.053]	[0.048]	[0.039]	[0.064]
Post 2002	0.091**	0.486***					
	[0.039]	[0.079]					
China	-0.201*						
	[0.114]						
Country Dummies	No	Yes	Yes	Yes	Yes	Yes	Yes
Technology Dummies	No	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	No	No	Yes	Yes	Yes	Yes	Yes
Country - Technology Dummies	No	No	Yes	Yes	Yes	Yes	Yes
Technology - Year Dummies	No	No	Yes	Yes	Yes	Yes	Yes
R-squared	0.017	0.742	0.898	0.652	0.913	0.849	0.852
Observations	6,624	6,624	6,624	2,776	3,432	6,535	8,376

Panel B

DV: Log Female Inventors	Baseline Results			Alternate Control Group Emerging	Developed	CEM	Extended Time Period
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
China x Post 2002	2.009***	1.836***	1.836***	1.996***	1.687***	1.843***	1.780***
	[0.056]	[0.056]	[0.056]	[0.097]	[0.071]	[0.057]	[0.085]
Post 2002	0.149***	0.671***					
	[0.056]	[0.109]					
China	-0.040						
	[0.147]						
Country Dummies	No	Yes	Yes	Yes	Yes	Yes	Yes
Technology Dummies	No	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	No	No	Yes	Yes	Yes	Yes	Yes
Country - Technology Dummies	No	No	Yes	Yes	Yes	Yes	Yes
Technology - Year Dummies	No	No	Yes	Yes	Yes	Yes	Yes
R-squared	0.036	0.841	0.906	0.736	0.921	0.867	0.869
Observations	6,624	6,624	6,624	2,776	3,432	6,535	8,376

Notes: The dependent variable in columns (1) to (3) is the log of the number of patents with at least one female inventor and in columns (4) to (6) is the log of the number of female inventors. Across model specifications, we see that the interaction term is positive and statistically significant. Thus, there is a significant increase in female innovation in China after accession to the WTO. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 5: Change in Share of Patents with Females and Share of Female Inventors

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Share of Patents with Female			Log Share of Female Inventors		
China x Post 2002	0.097***	0.086***	0.086***	0.121***	0.114***	0.114***
	[0.004]	[0.003]	[0.003]	[0.004]	[0.004]	[0.004]
Post 2002	0.004	0.031***		0.009*	0.031***	
	[0.004]	[0.010]		[0.004]	[0.010]	
China	0.017**			0.095***		
	[0.008]			[0.006]		
Country Dummies	No	Yes	Yes	No	Yes	Yes
Technology Dummies	No	Yes	Yes	No	Yes	Yes
Year Dummies	No	No	Yes	No	No	Yes
Country - Technology Dummies	No	No	Yes	No	No	Yes
Technology - Year Dummies	No	No	Yes	No	No	Yes
R-squared	0.006	0.185	0.348	0.064	0.237	0.337
Observations	6,624	6,624	6,624	6,624	6,624	6,624

Notes: The dependent variable in columns (1) to (3) is the log of the share of the number of patents with at least one female inventor and in columns (4) to (6) is the log of the share of the number of female inventors. Across model specifications, we see that the interaction term is positive and statistically significant. Thus, there is a significant increase in female innovation in China after accession to the WTO. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 6: Falsification Check: Randomized Inference

Log Patents with Female (T obs)	c	N	p = c/N	SE(p)	95% confidence interval
1.291	124	10000	**0.0124**	0.0011	0.0103 - 0.0147

Log Female Inventors (T obs)	c	N	p = c/N	SE(p)	95% confidence interval
2.009	382	10000	**0.0382**	0.0019	0.0345 - 0.0421

Notes: This table presents results from randomization inference (RI) tests of the DID model shown in Equation 1. Coefficient of the interaction term T(obs) is our test statistic as obtained in column (1) and (4) of Table 4. We obtain the distribution of the test statistic under the null hypothesis that accession of China to the WTO has no effect on female inventors in China and uses 10,000 re-randomizations. The p-value of the test statistic (as shown in column 4) suggests that we reject the null-hypothesis. These results suggest that our baseline results are robust and have not been obtained by chance. We conducted the RI tests using the "ritest" command in Stata developed by (Heß, 2017).

Table 7: Heterogeneity Across AI Technology Sub-class

Panel A

DV: Log Patent with Female	(1) Computer Vision	(2) Knowledge Processing	(3) Planning	(4) NLP	(5) Speech	(6) Hardware	(7) ML	(8) Evolutionary Computation
China x Post 2002	1.885***	1.860***	1.324***	1.138***	1.120***	0.996***	0.829***	0.136***
	[0.066]	[0.068]	[0.074]	[0.027]	[0.028]	[0.051]	[0.039]	[0.017]
Observations	828	828	828	828	828	828	828	828
Country Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country - Technology Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Technology - Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B

DV: Log Female Inventors	(1) Computer Vision	(2) Knowledge Processing	(3) Hardware	(4) NLP	(5) Speech	(6) Planning	(7) ML	(8) Evolutionary Computation
China x Post 2002	2.270***	2.248***	2.023***	1.929***	1.802***	1.748***	1.635***	1.036***
	[0.065]	[0.076]	[0.071]	[0.059]	[0.039]	[0.078]	[0.062]	[0.050]
Observations	828	828	828	828	828	828	828	828
Country Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country - Technology Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Technology - Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

In panel (a) the dependent variable in all columns is log of the number of patents with female inventors and in panel (b) the dependent variable is log of the number of female inventors. The table represents a split sample analysis across 8 different sub-technologies of AI. Across specifications, we see that although the interaction term is positive and statistically significant there is heterogeneity across different sub-technologies. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 8: Increase in Share of Domestic Female Inventors on Patent Teams

DV: Share of Domestic Female Inventors	(1) All Countries	(2) China	(3) Developed	(4) ROW
China x Post 2002	0.661***			
	[0.019]			
Post 2002		0.632***	-0.033***	-0.034***
		[0.019]	[0.003]	[0.003]
Year Dummies	Yes	No	No	No
Country Dummies	Yes	No	No	No
R-squared	0.132	0.083	0.003	0.003
Observations	41,125	114	40,799	41,023

Notes: The dependent variable in all columns is the share of domestic female inventors on patent teams. The estimates in column (1) take the ROW as the control group. Columns (2) - (4) are a sub-sample analysis where we see a change in the share of domestic female inventors after 2002 in China, Developed countries and the ROW, respectively. The time horizon is from 1997 to 2011. Robust standard errors, '***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 9: Effect of Firm Characteristics: Identification by Assignee Type

	(1)	(2)	(3)	(4)
	Log Patents with Female		Log Female Inventors	
China x Private x Post 2002	1.380***	1.005***	1.590***	1.164***
	[0.088]	[0.106]	[0.093]	[0.110]
Observations	2,640	2,640	2,640	2,640
R-squared	0.006	0.645	0.007	0.646
Year Fixed Effects	No	Yes	No	Yes
Country Fixed Effects	No	Yes	No	Yes
Firm Fixed Effects	No	Yes	No	Yes

Notes: The dependent variable in columns (1) and (2) is the log of the number of patents with at least one female inventor and in columns (3) and (4) is the log of the number of female inventors. Across model specifications, we see that the interaction term is positive and statistically significant. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 10: Improvement in Quality of Innovation

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Number of Citations			Log Strategic Importance		
China x Post 2002	1.107***	1.082***	1.358***	0.326***	0.378***	0.337***
	[0.079]	[0.062]	[0.078]	[0.036]	[0.048]	[0.056]
Post 2002	0.208**	0.549***		0.491***	0.859***	
	[0.079]	[0.128]		[0.036]	[0.096]	
China	-1.010***	-0.956***		-0.260***	-0.304***	
	[0.135]	[0.108]		[0.065]	[0.068]	
Country Dummies	No	Yes	Yes	Yes	Yes	Yes
Technology Dummies	No	Yes	Yes	Yes	Yes	Yes
Year Dummies	No	No	Yes	Yes	No	Yes
Country x Technology Dummies	No	No	Yes	No	No	Yes
Technology x Year Dummies	No	No	Yes	No	No	Yes
R-squared	0.014	0.159	0.540	0.098	0.204	0.490
Observations	1,645	1,645	1,645	1,645	1,645	1,645

Notes: The dependent variable in columns (1) and (2) is the log of the number of citations of patents with female inventors and in columns (2) and (3) is the log of the strategic importance of patents with female inventors. Across all specifications, we see that the interaction term is positive and statistically significant suggesting that there is an improvement in the quality of patents in China after their accession to the WTO. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

7. Appendix

Table A1: IP Regime Change

S. No.	Mechanisms of Change	Description
1	Article 11 of China's Patent Law	Article 11 gave exclusive rights to patent holders to advertise and sell their products while prohibiting any third party from moving the market before seeking permission from the owner.
2	Article 60 of China's Patent Law	Article 60 was amended to include a specific amount of compensation that a patent holder will receive in case of illegal infringement by a third party, depending on the loss of the owner or the profits of the infringer.
3	Article 57 of China's Patent Law	Article 57 establishes a more transparent mechanism to deal with patent infringement. It requires the third party to provide solid evidence to the patent holder and to the judicial body instead of merely stating ignorance as a defense.
4	Article 52 and 53 of China's Patent Law	In accordance with TRIPS, the duration and scope of compulsory licenses was modified, with increased access to legal and judicial bodies, guaranteeing the protection of IPR for original patent owners.
5	State Intellectual Property Office's (SIPO) Initiative of 2004	To protect from illegal infringement SIPO launched the "Work Program on Strengthening Enforcement of the Laws on Intellectual Property Rights and Launching a Special Law Enforcement Campaign"
6	Protection of Intellectual Property Rights against Crimes forum	To improve three-way communication and coordination between IPR proprietors, foreign companies and government, the Ministry of Public Security held regular forums from 2002 to table, discuss and address any IPR
7	Import and Export of Technology	Regulations and amendments were made on administration, registration and prohibition of imports or exports of technologies along with amendments to computer software protection.
8	Copyright and Trademark Laws	Amendments to the existing laws on copyrights and trademark rules were made in 2002.

Notes: The table includes policies, laws and amendments that China launched between 2000-2002 to strengthen it's intellectual property regime.

Table A2: First Stage: Change in Total Number of Patents

DV: Log Total Patents	(1)	(2)	(3)
China x Post 2002	0.706***	0.824***	0.824***
	[0.103]	[0.030]	[0.030]
Observations	6,736	6,736	6,624
R-squared	0.003	0.630	0.946
Year Fixed Effects	No	Yes	Yes
Country Fixed Effects	No	Yes	Yes
Technology Fixed Effects	No	Yes	Yes
Country x Technology Fixed Effects	No	No	Yes
Technology x Year Fixed Effects	No	No	Yes

Notes: The dependent variable in columns (1) to (3) is the log of the total number of patents. Across all specifications, we see that the interaction term is positive and statistically significant. This suggests that there is a significant increase in the number of patents in China after their accession to the WTO. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table A3: Baseline Results with Standard Errors Clustered at Country-Technology Level

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Patent with Female			Log Female Inventors		
China x Post 2002	1.291***	1.161***	1.161***	2.009***	1.836***	1.836***
	[0.234]	[0.236]	[0.186]	[0.160]	[0.162]	[0.132]
Post 2002	0.091***	0.486***		0.149***	0.671***	
	[0.017]	[0.041]		[0.022]	[0.046]	
China	-0.201***			-0.040		
	[0.067]			[0.096]		
Country Dummies	No	Yes	Yes	No	Yes	Yes
Technology Dummies	No	Yes	Yes	No	Yes	Yes
Year Dummies	No	No	Yes	No	No	Yes
Country - Technology Dummies	No	No	Yes	No	No	Yes
Technology - Year Dummies	No	No	Yes	No	No	Yes
R-squared	0.017	0.742	0.898	0.036	0.841	0.906
Observations	6,624	6,624	6,624	6,624	6,624	6,624

Notes: The dependent variable in columns (1) - (3) is the log of the number of patents with female inventors. In columns (4) - (6) is the log of the number of female inventors. Across all specifications, we see that the interaction term is positive and statistically significant suggesting that our results hold even when we cluster at the country-technology level. The time horizon is from 1997 to 2011. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table A4: Non-Existent Pre-Trends

	(1) Log Patents with Female	(2) Log Female Inventors
China x Year 1998	-0.012	-0.026
	[0.293]	[0.272]
China x Year 1999	-0.196	-0.309
	[0.293]	[0.272]
China x Year 2000	0.002	0.486*
	[0.292]	[0.272]
China x Year 2001	0.203	0.669**
	[0.292]	[0.272]
China x Year 2002	-0.011	0.438
	[0.292]	[0.272]
Observations	6,624	6,624
R-squared	0.679	0.807

Notes: The dependent variable in columns (1) is the log of the number of patents with female inventors. In column (2) is the log of the number of female inventors. We see that the interaction term is mostly insignificant suggesting that there was no significant difference between treatment and control group in the pre-treatment period. Robust standard errors, clustered at the country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.