Do Stronger IPR Incentivize Female Participation in Innovation? Evidence from Chinese AI Patents*

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Abstract

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

Keywords: Women in Innovation, Intellectual Property Regimes, China

JEL Codes: J16, O34

*This paper has benefited from comments and suggestions from Minyuan Zhao and Ina Ganguli. We thank participants of the EU-SPRI Annual Conference at University of Sussex and XVIII International Conference on Public Policy & Management at IIM Bangalore for useful discussions. Funding from Hoover Institution Visiting Fellowship and University of Sussex Business School is acknowledged. Higgins acknowledges support from the Sorenson Center for Discovery and Innovation Studies, David Eccles School of Business, University of Utah

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1. Introduction

Is there a relationship between a stronger intellectual property regime (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). On the contrary, policymakers in lesser developed countries debate innovation expansion policies of 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 groups. The differences between gender groups arise not due to their identity as male or female per se but due to disparity in access to a suitable innovation environment, tangible investments (finance) and intangible assets (knowledge, training, network ties) (Biscione, Boccanfuso, Caruso, & de Felice, 2021; Frietsch, Haller, Funken-Vrohlings, & Grupp, 2009).

Multiple studies have laid out evidence that when endowed with innovation-supportive culture and optimal resources, women are just as likely to have a positive or even stronger contribution to the field as men (Marvel, Lee, & Wolfe, 2015; Mendonça & Reis, 2020; Wu, Dbouk, Hasan, Kobeissi, & Zheng, 2021). In innovation, while both genders benefit from collaborations, the returns are weaker for female inventors due to poor network positioning (Marvel et al., 2015), status asymmetry between teams (Whittington, 2018) and their lesser share as lead inventors (Wang, Yang, & Wang, 2019). This is potentially where structural changes through a

[1] Trade-Related Aspects of Intellectual Property Rights

stronger IPR can support women's participation in innovation races.

Using novel data from artificial intelligence patents in China, we show how stronger IPR incentivizes the participation of female inventors. China joined WTO on 11th December 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[2] (see Panel (a) of Figure 1). This observation is in line with the findings of Fisch, Block, and Sandner (2016) who found that patent applications by China's inventive labour 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 incentivized the participation of women inventors.

As visible through Figure 1 (see Panel (b)), we find a sharp increase in the share of female inventors in China for artificial intelligence patents compared to the rest of the world. An increase in female inventors with an overall spur in innovation is non-obvious as 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 (See Figure 2). 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 world trade organization by China should have a positive impact on the participation of women 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 occupation status of women (Black & Brainerd, 2004; Black & Strahan, 2001; Ederington, Minier, & Troske, 2009). Liberalization also brings new technology which complements female labor by reducing the need for physical skills (Juhn, Ujhelyi, & Villegas-Sanchez, 2014; Rendall, 2017; Weinberg, 2000).

[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%.

To empirically evaluate the impact of the IPR changes in China, we obtain the information on patents across eight technology classes[4] from the Artificial Intelligence Patents Database (AIPD)[5] by the United States Patent and Trademark Office (USPTO) that were recently made available to researchers for public use. 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 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 Chinese IPR policy shock post-2002 on its female inventive labor compared to the rest of the world. Our regression evidence suggests that in China, the number of AI patents with female inventors increased by 116.1% post-2002, and the participation of female inventors in these patents increased by 186.3% compared to the rest of the world. These results remain robust controlling for unobserved heterogeneity at the country, technology, and time level. We also conduct multiple robustness checks like coarsened exact matching (Iacus, King, & Porro, 2012) and synthetic control method (Abadie, Diamond, & Hainmueller, 2010) and our benchmark findings remain consistent. The results also hold when we use two alternative sets of control groups first, emerging countries and second developed nations.

We find three important mechanisms of why there is a surge in female innovation in China. First, we find that there is a systematic effort from the government of China to promote females in higher education. This is evident from a sharp increase in percentage of female enrollment in Ph.D. programs in scientific research institutes as shown in Figure 6. Second, in line with the becker's model of discrimination, we find evidence for increase in share of domestic female inventors in patent teams in China. Third, we find that post-2002, there was a surge in patents with female inventors filed by private firms compared to state-owned entities. Thus, its a combination of government-led initiatives and opening of market that has led to an increase in the involvement of females in innovation in China.

[4] ML, NLP, Evolution, Knowledge Reasoning, Hardware, Planning, Speech, and Vision

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

Interestingly, female-driven innovation is also contributing to the improvement in quality of patents. We use Derwent Innovation database[6] 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 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 women participating in national innovation ecosystems (Pellegrino & Savona, 2017). There has been a considerable amount of interest and evidence on the integral role that women can play in contributing to innovation at 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 inventors' 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[7] (Koning, Samila, & Ferguson, 2021). The perspective of women innovators can ensure that new technologies cater to the needs of entire population without suffering from male biases.[8]

We also contribute to the literature on the quality of innovation generated by female inventors in China. 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 herein around understanding the heterogeneities from a gender perspective. Past work (Griffin et al., 2021; Kou et al., 2020; Le Loarne-Lemaire, Bertrand, Razgallah, Maalaoui, & Kallmuenzer, 2021; Ritter-Hayashi et al., 2019) have found that more women within the technological innovation value chain and in the boardrooms promise adoption of efficient innovation processes, greater productivity, and better results.

[6]For more than 50 years, Derwent™ has been a leader in life sciences – connecting research applications, exclusive patent data, and expert IP services to support the commercial success of pharma and biotechnology companies around the world.

[7]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

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

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.

2. Impact of China Joining 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 WTO required China to make significant changes to its laws and regulations to gain access to the world market. It was expected to strongly increase transparency standards, limit the domestic trade-distorting subsidies along with protecting the 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 A3). The Chinese government made amendments to its patent law[9] in 2000 to align it with the requirements of the TRIPS. TRIPS[10] is an integral component of WTO trade rules which requires the 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). 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 likely leading 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 about new ideas, the accession to WTO in December 2001 and a series of new laws in 2002 ensured the 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

[9]The changes were made in three strata a) Judicial and administrative procedure b) Patent application procedure c) Streamlined enforcement mechanism

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

to computer software protection came into force on 1st January 2002. Rules related to creative innovation combining publications, motion pictures, sound and video recordings came into effect 1st February 2002. The implementation of regulations for copyright law and trademark law started on 15th September 2002. Finally, the trademark examination guidelines were revised in October 2002 (Thomas, 2017).

Before its membership, 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. As per the patent right index (Park, 2008), China climbed from ranking 69th in 1995 to 34th in 2005 among 123 countries, making remarkable progress in patent protection. With the change in focus on type of ownership, liberal regulations, stronger domestic knowledge base and pro-patent-holder legal environment, innovation witnessed an upsurge in China as documented in prior work (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 innovation environment in China led its economy to evolve into a global technological leader, particularly in terms of 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%)".[11] 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 subsidy, attracting FDI and

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

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 fraction of the growth in patenting. Eberhardt et al. (2016); Guan and Yam (2015); Hu and Jefferson (2009) attribute the explosion to state incentives such as the second amendment of the 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 subsidy across regions as a positive policy shock-inducing firms and individuals to innovate more. Tiwari, Anjum, Chand, and Phuyal (2017) and Lundvall and Rikap (2022) meanwhile show that heavy investments in human capital, education and research universities may explain innovation evolution 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 here towards 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 spillover 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 strong IPR incentivize female participation in innovation remains under investigated. Relatedly, whether stronger IPR also relates to an increase in the quality of patents with women's participation in innovation needs an investigation. Our study provides some of the first evidence on these two important questions.

3. Data

We obtained the data on inventors participating in patenting activity between 1997 to 2011 using PatentsView, a publicly available repository of United States Patent Trademark Office (USPTO).[12] The raw data files in USPTO are widely used for conducting studies related to patenting activity and innovation due to multiple advantages. The PatentsView data aggregation process incorporates an in-built algorithm that predicts an inventor's gender. It builds on prior gender classification methods using country-specific names associated with males and females (Caviggioli & Forthmann, 2022). 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 112 major countries such as China, Japan, USA, South Korea, UK and India.[13]

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.[14] This crossover data gives us an understanding of the participation of inventors in patents granted between 1997 to 2011 that had a component of artificial intelligence. 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 one if the score $>= 0.50$ and zero otherwise. This allows us to categorize each patent as per their dominant technology component.

Using patent and gender information, we generate a panel at country, technology, and year

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

[13] 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)

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

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 the participation of women in innovation activity. First is patents with female inventors which is constructed as the total number of patents in a country in a given year in each technology class with at least one female inventor in the patenting team.[15] The second dependent variable is the total number of female inventors participating in innovation activity at country-technology-year level. To compute this variable, we count the number of inventors in a country for a particular technology class if the gender of inventor is female.[16] For both of our main regressand, we also create share variables by dividing the patents with females variable with total patents and number of female inventors variable with total inventors.

Further, we use the information on citations and strategic importance from Derwent Innovation Database to understand the quality of innovation activity.[17] From our crossover dataset, we identify the patents for each year in a country across the technology class that had non-zero female inventors. We take this information and collapse mean values at the country-technology-year level to calculate the patent quality. The number of citations or forward citation 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 to obtain its effectiveness. Table 2 presents the summary statistics for the main variables in our study.

Table 3 provides descriptive estimates in a simple difference-in-differences framework concerning the impact of China joining 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

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

[16] Since we cannot capture the level of contribution of a female inventor in each technology component of a patent distinctively, we consider a woman as an inventor across multiple technology classes if a patent falls under this ambit. For example: If a patent xyz invented by a Chinese female CF in 2001 had three AI components (ML=0.3, NLP=0.7, Vision=0.6), this female inventor i.e. CF will be included as an AI inventor of ML, NLP and Vision equally.

[17] 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 been used in existing literature.

China and rest of the world. 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 post the accession to WTO.

Table 3 also highlights the difference-in-differences estimate (first minus second difference) of raw means. The estimated value suggests that after accession to the WTO, the average number of patents with female inventors in the team increased by approx. 5 ($e^{1.291}$ - 1). Also, on average, there were approx. 6 ($e^{2.009}$ - 1) more female inventors in China than in the rest of the world. We 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.

4. Empirical Specification

We evaluate the average treatment effect of China's membership of 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 takes value 1 when country i is China and zero for rest of the world (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. These allow us to control

for simultaneous events such as the SkyNet[18] and Smart Cities[19] projects launched in China during the period of patent explosion which may confound our results otherwise. Standard errors are clustered at country level.

The main coefficient of interest in our study is β_1. This estimate captures the effect of China's membership in WTO on the participation of females in innovation activity at technology level as compared to rest of the world exogenous to the regulation. In other words, it measures the change in female inventors and their patenting activity due to accession to WTO, net of change post-2002, and net of possible permanent difference across rest of the world[20].

Our control group comprises 122 countries which are termed as rest of the world in this study. The first bet for a valid 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 rest of the world 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 a bunch of validation checks.

Further, to deal with any other apprehensions, we run our regression specifications with an alternative control group that has only developed countries and only 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 matter of chance. Finally, we use a data-driven procedure to identify a comparison group based on synthetic controls by Abadie and Gardeazabal (2003).

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

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

[20] 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 summarised in **??**. The positive and significant coefficient in column (3) suggests that post the strengthening of IPR in 2002, the total number of patents in China increased by 82% compared to ROW. This specification is inclusive of country-technology and year-fixed effects.

5. Findings

5.1. Increasing Female Led Innovation in China Post-WTO Accession

5.1.1. Baseline Findings

Table 4 presents our main results by estimating Equation 1. The dependent variable in Panel A is the log of number of patents with at least one female inventor and in Panel B is log of 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 interaction dummy for country-technology and technology-year along with the existing fixed effects. Standard errors in all estimations are clustered at country level.[21]

The interaction coefficients in Table 4 indicate the impact of China becoming WTO member on its female inventors and their involvement in AI patenting activity (compared to the rest of the world). We would use column (3) for interpretation since they are most conservative with all fixed effects. In column (3) of Panel A, where we look for patents with at least one female, we find a positive and significant interaction coefficient ($\beta = 1.161$). This indicates that China's WTO accession caused an increase in number of patents with females by 116% as compared to rest of the world. Similarly, findings in column (3) of Panel B, where we look for number of female inventors, indicate a positive and significant interaction coefficient ($\beta = 1.836$). This indicates that the number of female inventors in China increased by 183.6% compared to rest of the world post-2002.

There could be a concern that these results are obtained because of an overall increase in patenting activity and 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 share of patents with females and share of female inventors using Equation 1. We find that across model specification the interaction coefficient is positive and significant. This indicates that with China joining WTO share of females involved in AI-based innovation increased as compared

[21] Estimations with standard errors clustered at country-technology level also follow same sign and significance as baseline. Results are shown in Table A1.

to rest of world.

5.1.2. Alternate Control Group

We perform robustness checks by altering our control group, i.e., the rest of the world. The purpose of these checks is to ensure that our results are not confounded and that the treatment effect holds for our outcome variables in China post-policy shock. Following the IMF's classification of countries, we divide our sample of the control group, i.e. rest of the world into developed economies and emerging economies and perform the analysis using them as two separate control groups. We compute this estimation to ensure that our results are not driven by a control group comprising a pooled set of diverse countries. We present our findings in columns (4) and (5) of Table 4 estimated using Equation 1.

The coefficient of interest remains significant and positive for both outcomes of interest in column (4) of Panel A and B, where the control group comprises only emerging economies. These results indicate that as China joined 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 but contribute to the literature that studies the factors and policies that led to differences in the evolution of innovation between the 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 sample to the developed countries. The findings in column (5) of Panel A and B in Table 4 reveal the percentage of patents with at least one female inventor and percentage of female inventors in China increased by 110% and 168.7% respectively. This is suggestive of an increase in innovation by women in China after 2002 compared to the developed countries. Overall, the effect in China is stronger when compared with developing countries than the developed counterparts.

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, few unmatched units receive zero and get dropped out 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). It can reduce estimation error, bias, model dependence and imbalances between the treatment and the control group. 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 coarsened exact matching technique. Our coefficient of interest remains significant and positive for both outcome variables. We observe that there is a minute drop in the number of observations as compared to our initial sample of 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 females and a 184.3% increase in participation by females in innovation in China post-2002.

5.1.4. Alternate Sample - Extended Period

Our baseline analysis period is 1997 to 2011 i.e. five years before the policy shock of China. There was two reasons for the selection of this time frame. First, to have enough years in the pre-intervention period for observing the pre-trends. Second, this period was marked by the onset of changes in the IPR regime of 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 mentioned in Column (7) of Panel A and B in Table 4. The coefficient for number of patents with female inventors (in log) and

the number of female inventors (in log) remains positive and significant. We find that patents with at least one female inventor and number of female inventors increased by 101% and 178% respectively, post the strengthening of IPR regime in China. These estimates further strengthen our baseline findings.

5.1.5. Non Existent Pre-Trends

To validate the assumption of parallel trends, we estimate the coefficient by plotting the 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 rest of the world should follow parallel trajectories over time. The estimation is made based on the specification shown below:

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

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

To check for the validity of our identification strategy, we plot the estimated coefficients from Equation 2 in Figure 4. We look for insignificant coefficients in the pre-treatment period from 1998 to 2002. In Panel (a) of Figure 4, where the dependent variable is Log Patents with Female, 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 parallel trend. The figure shows significant and positive coefficients for the year following the policy shock i.e. 2002. This indicates the increase in innovation involving females following the strengthening of IP regime in China.

In Panel (b) of Figure 4, we show event study analysis with the dependent variable Log of Number of Female Inventors. We find that except for 2001, all interaction coefficients in pre-

period are insignificant at 95% confidence interval. The figure also shows a significant jump from 2003 onward, indicating an increase in female inventors in China post-WTO accession. We corroborate these findings of pre-period empirically in Table 6.

5.1.6. Synthetic Control

The ideal counterfactual in the case of 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 of 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 characteristic of the treated group in the pre-treatment period. We follow Abadie and Gardeazabal (2003), which used this method for developing a valid counterfactual in the context of Basque countries. 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, 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 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 rest of the world to create an artificially matched sample of China.[22] Figure 5 shows the plots for both of our outcomes of interest between 1997 and 2011. The graph shows that our benchmark findings hold when the control group is substituted with synthetic China. As per the non-parametric analysis, the number of female inventors and the number of patents with at least one female inventor (in log) follow similar trends in the pre-intervention period.

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

This shows that synthetic China provides a sensible approximation for females' participation in inventive labor and their patenting activity. Immediately after the policy shock of 2002 the two lines diverge noticeably. Thus, China joining the WTO changes the trajectory of the outcome variables for the treated group in a positive and significant direction, confirming our baseline results.

5.1.7. Randomized Inference

Randomized Inference (RI) test helps us 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). RI test can also be considered a falsification exercise. We use 'ritest' command developed by Heß (2017) in STATA to conduct the randomization inference 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, and finally, we repeat this exercise 10000 times. The idea is to compare the coefficients we obtain from this random reorganization to the coefficient from our baseline specification. The p-values obtained from randomized inference, clustered at the country level, are shown in Table 7. The p-values suggest that the effects of China joining WTO on increase in female-supported innovation is unlikely to be observed simply by chance.

5.2. Mechanisms

We believe two mechanisms led to the increasing participation of females in the inventive labor market in China. First, increased share of domestic female inventors in patent-inventor teams in China as compared with the sample of 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, increase in female inventors and patents with females filed by private firms post WTO accession. We study how increased competition amongst private firms post-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 women in the Chinese innovation environment, we obtained information on the assignee (the organization to which a patent was granted) of patents between 1997 to 2011 from the PatentsView repository of USPTO. This data file allows us to identify the assignee organization and the assignee country of the patents.[23] After using the patent id as the unique identifier, we match the patents to their inventors and their respective location. We obtain the number of female inventors in each patent-inventor team. Using inventor location, we identify the number of domestic and international female inventors. Finally, the share of domestic female inventors in patent team is calculated as the number of female domestic inventors divided by the total number of female inventors in each patent-inventor team. We estimate the impact of accession to WTO on the share of domestic female inventors for China as compared to the rest of the world, using the following equation:

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

where y_{iy} is the share of domestic female inventors (in the log) measured at the country-year level. The rest of the parameters remain same as the baseline equation.

The results from our regression estimates are presented in Table 8. From column (1), we observe a 65.7% increase in the share of domestic female inventors in patent teams in China post the strengthening of IPR as compared to the rest of the world. Column(2) to (4) gives the coefficients obtained for $Post2002_y$ from a before and after estimation, following Equation 3. It does not include the fixed effects for time and country. In column (2), we estimate the change in the outcome of interest post the policy shock for China. The coefficient for Post 2002 is

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

positive and significant, indicating a 63.2% increase in share of domestic female inventors in China. The coefficient in columns (3) and (4) includes the estimates for developed economies and the rest of the world. The share of domestic female inventors in patent teams decreases by 3.3% for developed economies and 3.4% for rest of the world.

Our findings complement the evidence given by Tang and Zhang (2021) on reducing gender discrimination in domestic firms of China due to cultural transfers generated by multinational firms. While their findings apply to manufacturing firms, our study provides suggestive evidence for the innovation market of China. With the accession to World Trade Organization, the strengthening of intellectual property regime enabled non-state entities to access the innovation market of China. In response to the competition (in line with Becker's model of discrimination) and cultural spillovers, the share of female inventors in domestic firms increased.

5.2.2. Firm Characteristics

In China, accession to the World Trade Organization led to liberalization and openness. The regime change required China to recognize the property rights of the owner of an invention. This allowed the entry of private and foreign firms into the innovation industry, which was previously concentrated by state-owned enterprises. Figure 3 indicates the gradual increase in the number of patents owned by firms other than the state from 1997 to 2011 in China. The graph suggests an increase in competition in the innovation environment of China.

Based on the Becker model we postulate that increased competition increases the cost of discrimination against women. When competition increases, new firms entering the market without a taste for discrimination hire the profit-maximizing number of women innovators. Whereas firms with a strong taste for discrimination end up paying more by not hiring women inventors, thus losing on profits. Subsequently, competition drives out the discriminatory firms earning less than normal profits from the innovation market. Hence, increasing the participation of women inventors in the long run.

Accession to WTO opened up the innovation environment for private firms in China as discussed in Figure 3. With the increased competition, private firms were bound to balance their gendered allocation. As shown in Figure 7, we see a clear jump in both the number

of patents with females and the number of female inventors amongst those who are a part of a multi-national corporation or an individual owner of the patent. Interestingly, the same variables for government firms show negligible change.

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 MNC or an individual. Similarly, if the patent is filed by a public firm we code it as a government-filed patent. The analysis findings are shown in Table 9 with both of our dependent variables. 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 100% increase in the number of patents with at least one female filed in China by private firms or individuals post 2002. Similarly, as shown in column (4), compared to government firms, the number of female inventors in private firms increased by 116.4 % post-2002 in China. These findings justify our theoretical motivation that increased competition post-2002 in China led to reduced discrimination against women, and private firms led this.

5.3. Impact on Quality of Innovation

Our results have provided evidence of female-led innovation in China. However, there can be concerns regarding the quality of innovation women bring to China's environment. Patent quality is important to be examined as it leads to profitable returns for innovation firms (Boeing, Mueller, & Sandner, 2016). The increasing propensity of inventive labor to patent more brought the quality of these patents into question. There has been mixed evidence in the literature on what happens to the value of patents with an explosion in filings. Studies by Chen and Zhang (2019); Dang and Motohashi (2015); Fisch et al. (2017) suggest that the quality of patents in China did not converge with the imploding numbers. 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 the filing of 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

quality of patents using strategic importance and number of citations of patents. 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 used as the number of citations and strategic importance in two separate estimates (in the log). $China_i$ corresponds to when country i is China (1 for our treatment group) or rest of the world (0 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 country level.

Table 10 shows the results from the regression specification mentioned in Equation 4. We use two measures to assess the quality of patents (taken as dependent variable) - a log of the number of citations (columns (1) to (3)) and log of strategic importance of the patent (columns (3) to (6)). Columns (1) and (4) show 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. In columns (3) and (6), we introduce year fixed effects and interaction dummy for country-technology and technology-year along with the existing fixed effects.

The interaction coefficient in Table 10 indicate impact of China's WTO accession on the quality of patents with female. We find that across columns (1) to (6) the interaction term $China \times Post2002$ is positive and significant. We would use columns (3) and (6) for interpretation since they are most conservative with all fixed effects. In Column (3), we find that quality of patents measured by forward citation of AI patents that involved Chinese female inventors increased by 135.8% as compared to the control group post-2002. In Column (6) we find that strategic importance of the patents involving females increased by 33.7%, suggesting a rising contribution of inventive female labor. Our findings support the literature which emphasizes the improvement in quality of innovation involving women (Ain, Yuan, & Javaid, 2021; Xie & Zhang, 2015) and contributes to it by including additional measures to assess the value of

patents.

6. Discussion

There has been a longstanding question on whether countries should strengthen their intellectual property regimes (IPR). While for developed countries, there are clear benefits in strengthening the IPR, for developing countries the debate is still on, as researchers have presented arguments on both sides. In the context of China, as the country joined WTO in December 2001, strengthening of IPR caused a noticeable surge in patenting activity. Hu and Jefferson (2009); Liegsalz and Wagner (2013) find that application examination process for a patent in China became faster by six to eight months on an average[24] from 1990 to 2010. This made the process faster and smoother for the inventive labor, which made them more excited about innovation in China. By the end of 2007, China had surpassed South Korea in number of resident domestic patent filings and now ranks third in the world, only trailing Japan and the United States (Li, 2012). While literature finds evidence that stronger patent regimes can foster innovation, it is yet to be established whether it affects the division of labor across gender in innovation.

This paper aims to examine how strengthening IP regimes due to China joining WTO affects female participation in innovation. Our findings reveal that compared to rest of the world there is a significant increase in the number of patents with females in China and the number of female inventors in China. Our findings undergo battery of robustness checks including alternate control group, coarsened exact matching, randomized inference test and synthetic control method. Not only do we find increase in patent activity by females, we also observe that quality of patents (measured using number of forward citations and strategic importance of patents) comprising of females in patent team also improves.

To our knowledge, this is the first research focusing on gender divisions in inventive labor with explicit attention to identifying heterogeneity at technology class and country levels worldwide. With this study we wish to contribute to the larger debate around strong IP regimes and whether it benefits the research community by fostering innovation across gender. This

[24] In other words the examination period reduced from 56 months to almost 25 months

study remains relevant as the evolution of China from an imitation-based economy to a leader in innovation can present an example for developing countries. The catching up of China with US, Japan and South Korea is more of a temporal phenomenon and its innovation evolution is turning it into the new AI technological leader (Lundvall & Rikap, 2022).

However, our study has limitations that can open potential avenues for future researchers. Our study was not able to examine the patent family relationships. This knowledge could be used by researchers in future work to examine the effect of cross-country collaborations for women across technology classes. It could also be expanded further to study the impact of women inventors across different types of patents (such as design, invention, trademarks and copyrights). Additionally, for future work, 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. the granted patents. From this inspection, innovators can be informed on whether gender differences can lead to a lag in translation of creative efforts and new ideas.

Our results can potentially inform policymakers, especially in low and middle-income countries, to push for stronger IPR; as we find it helpful in the better gender division of labor and thus benefiting society and innovation at large. Although our research is specific to females involved in technology and innovation in AI patents, the learning from the research can easily be adopted in other industries where females work in similar contexts.

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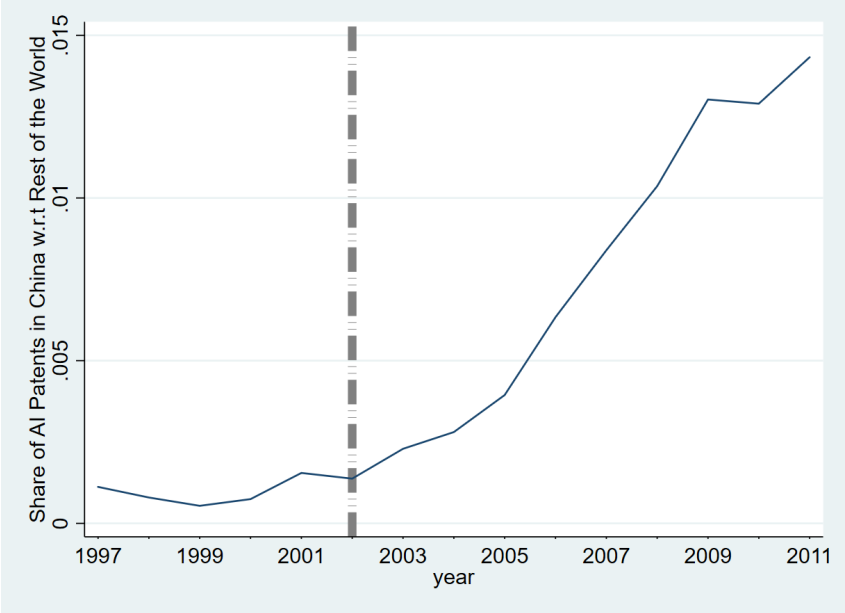
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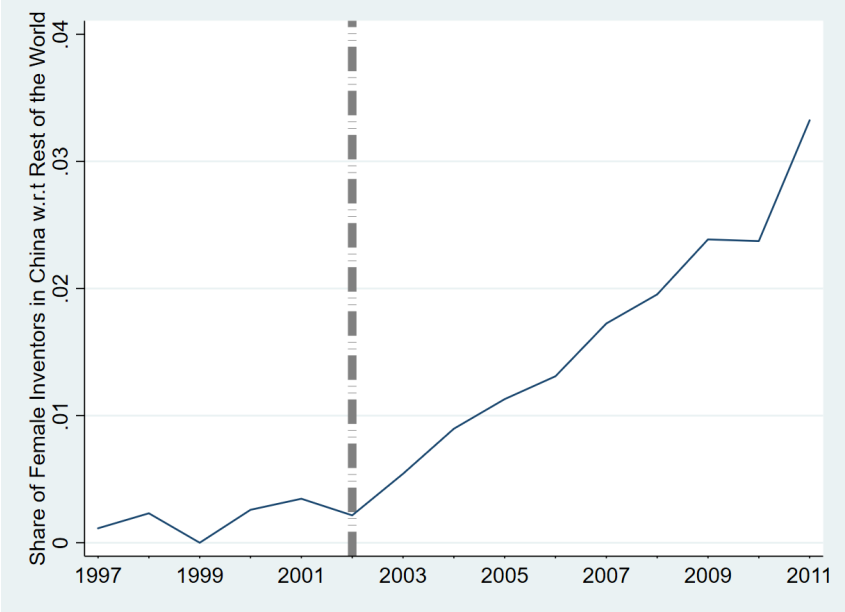
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Figure 1: Innovation in China - Descriptive Plots. In Panel (a), we present share of AI patents in China which is calculated as total number of AI patents across eight technology classes in China divided by the total number of AI patents in the rest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

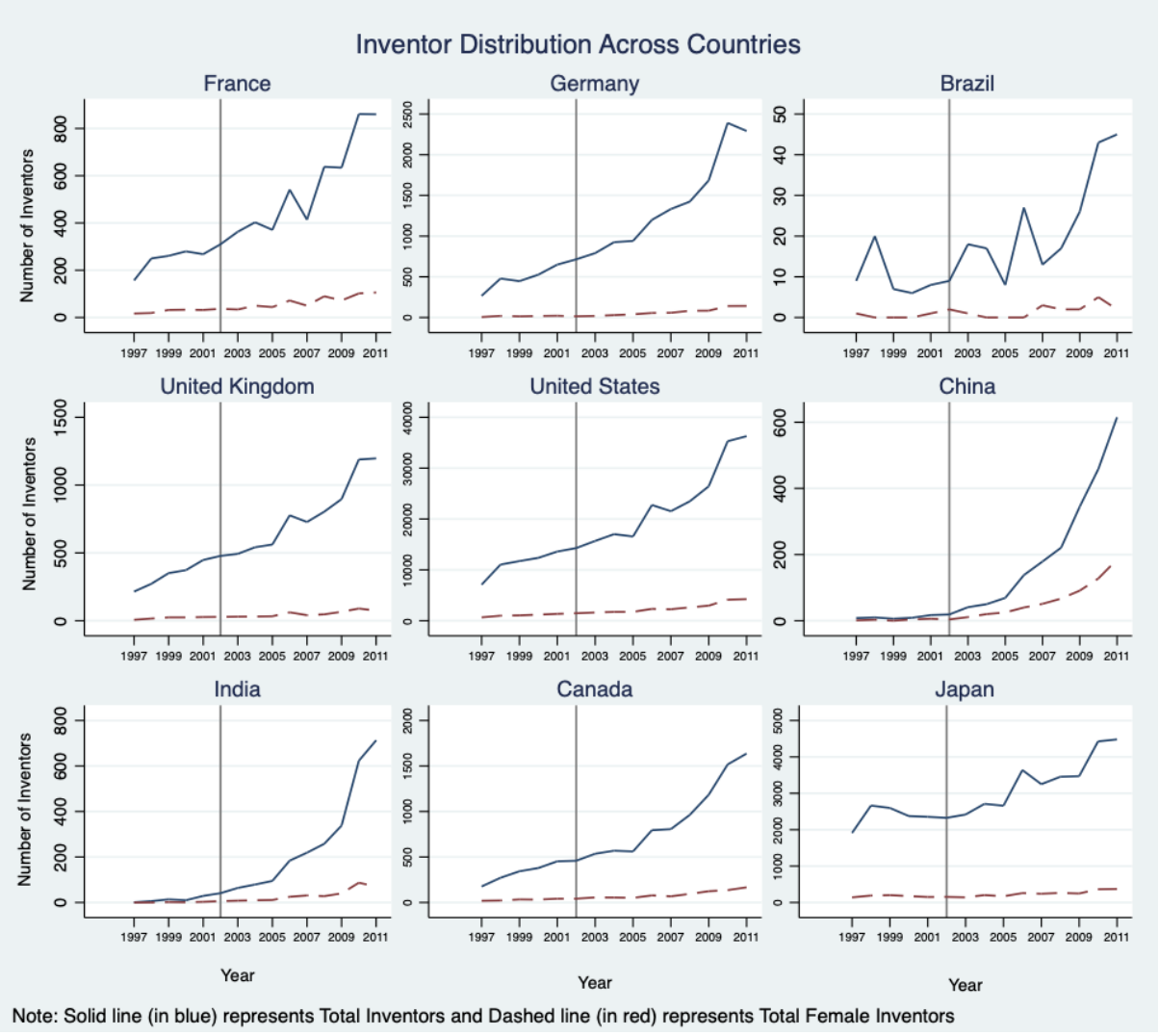


(a) Share of AI Patents in China.



(b) Share of Female Inventors in China.

Figure 2: Inventors Across Countries. The figure includes the graph 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 policy shock, i.e., 2002. We can see that for all countries there is an increase in total number of inventors but female inventors rise only for China.



Note: Solid line (in blue) represents Total Inventors and Dashed line (in red) represents Total Female Inventors

Figure 3: Innovation Environment in China. The graph includes the total number of patents assigned to non-state entities between 1997 to 2011 in China. We observe a gradual increase in the innovation activity of non-state firms post the accession to WTO. This indicates the influx of competition in the innovation environment of China.

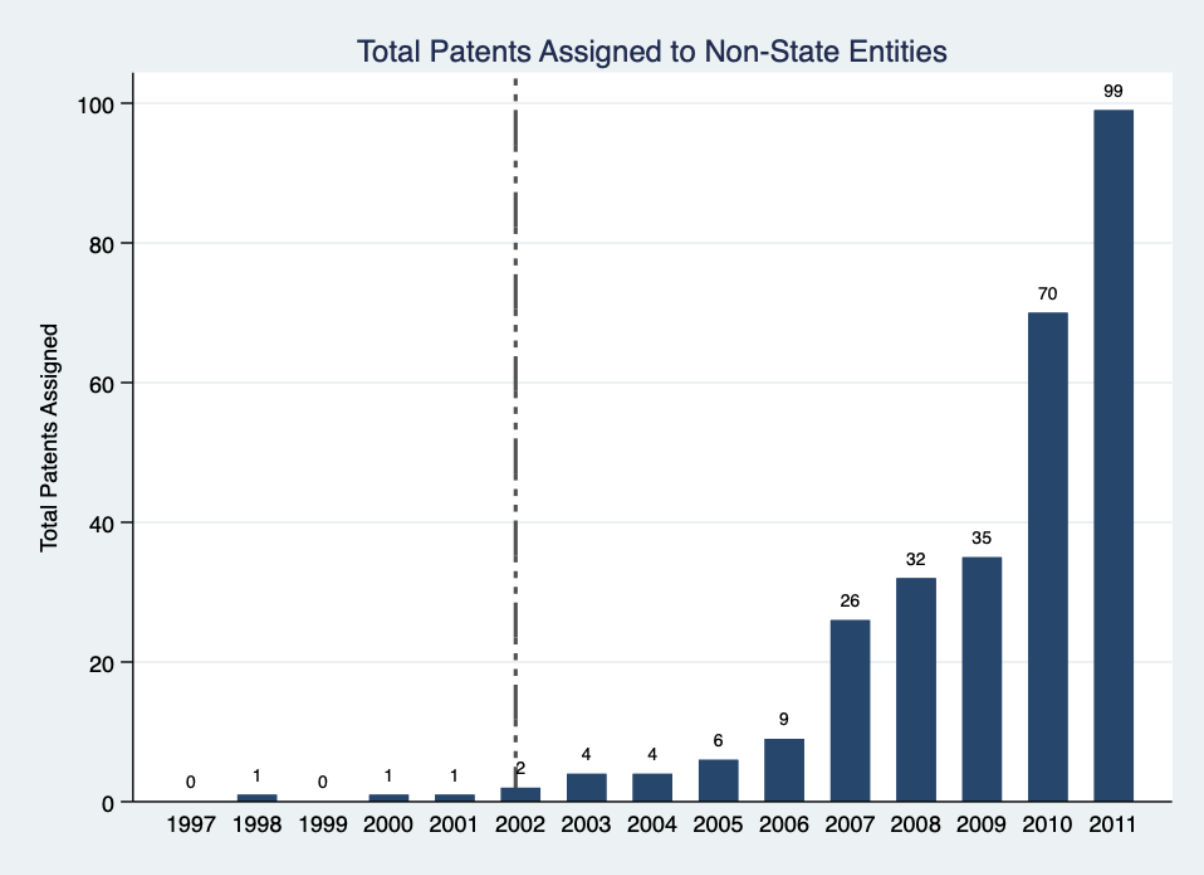
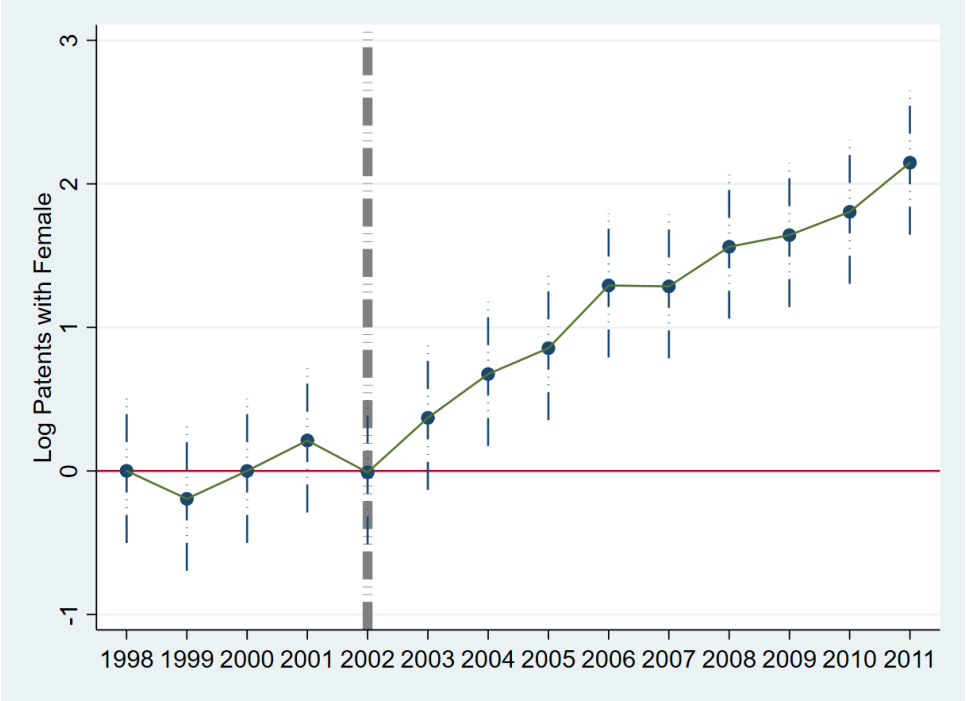
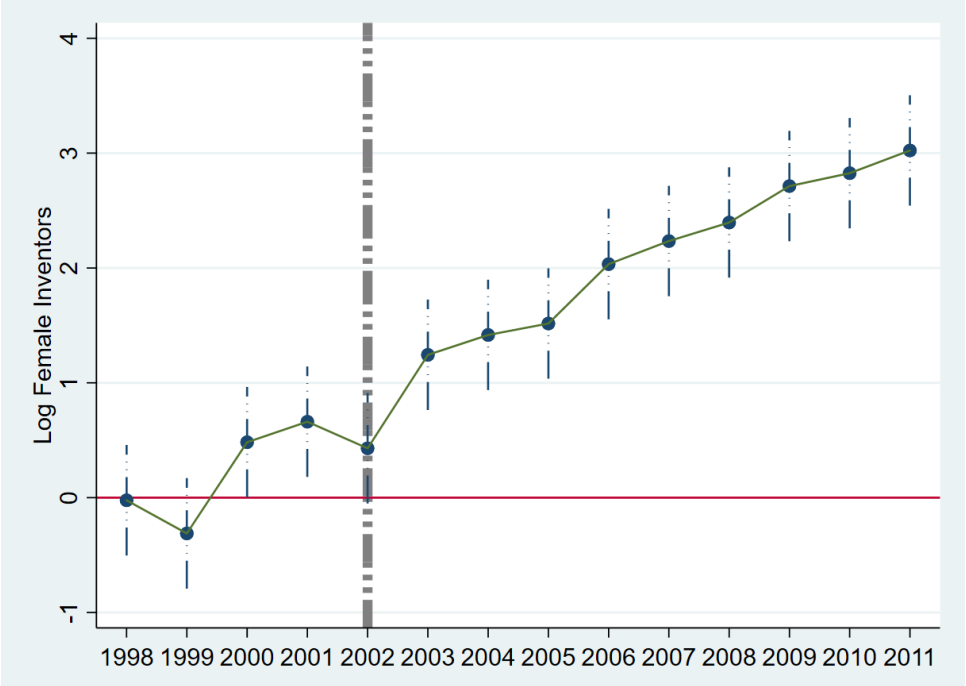


Figure 4: Event Study Design. The point estimates are coefficients for the country-technology class dummy for every year from 1998 to 2011 (1997 is taken as the base year) for our main outcome variables - Log Patents with Female in Panel (a) and Log Female Inventors in Panel (b). The dashed vertical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

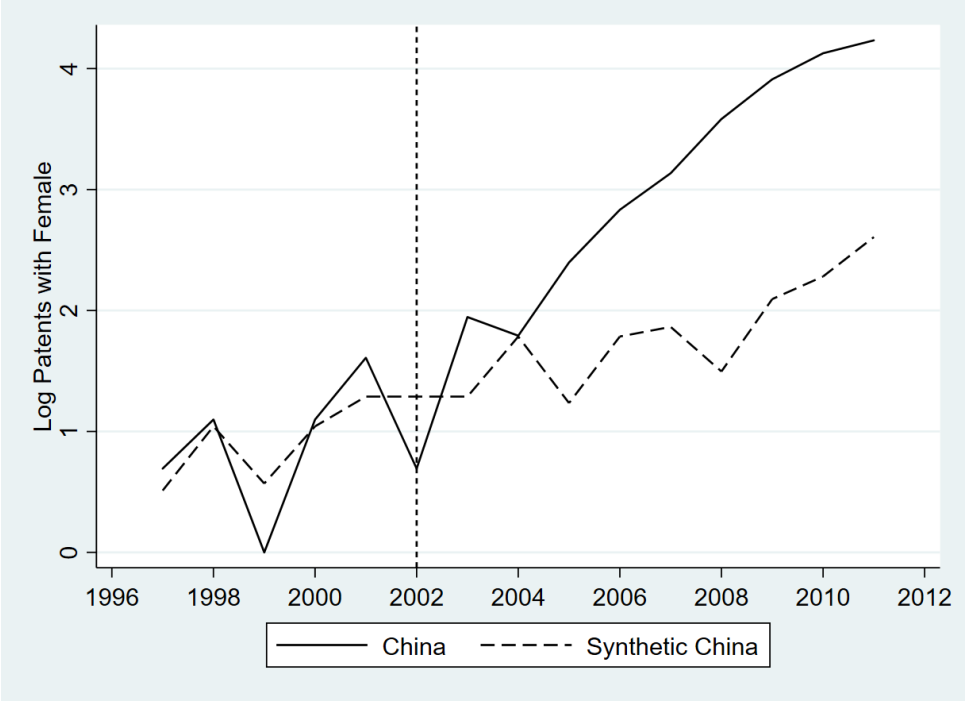


(a) Number of Patents with At Least One Female Inventor

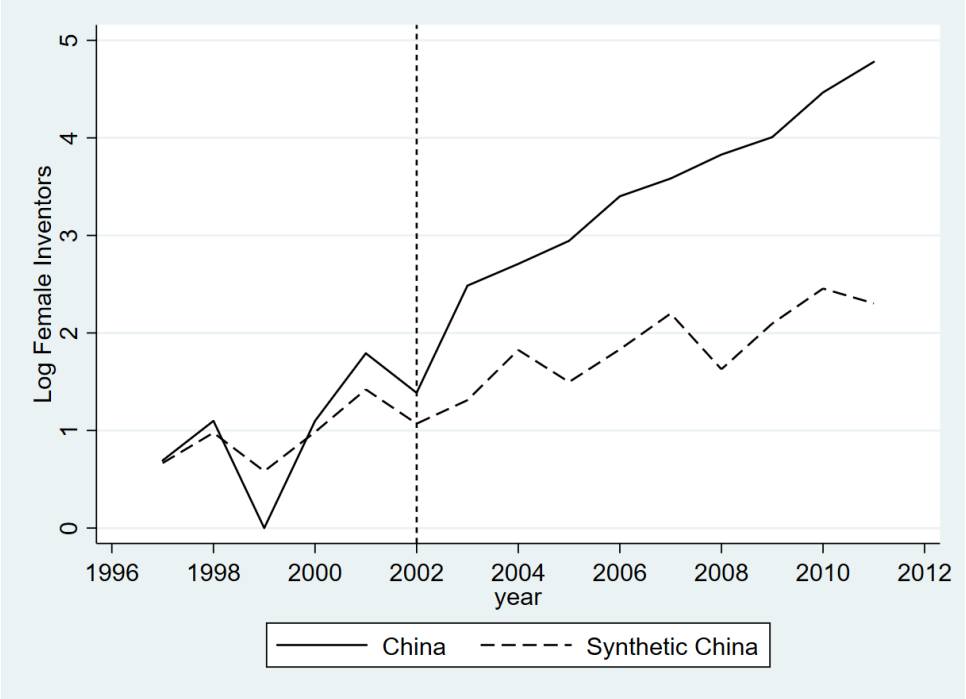


(b) Number of Female Inventors

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 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 outcome variable for China.



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



(b) Number of Female Inventors

Figure 6: 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. We observe a sudden increase in female enrollment from 2004. This indicates the increasing interest of females in higher technical education. Source: Ministry of Education of People's Republic of China - http://www.moe.gov.cn/jyb_sjzl/moe_560.

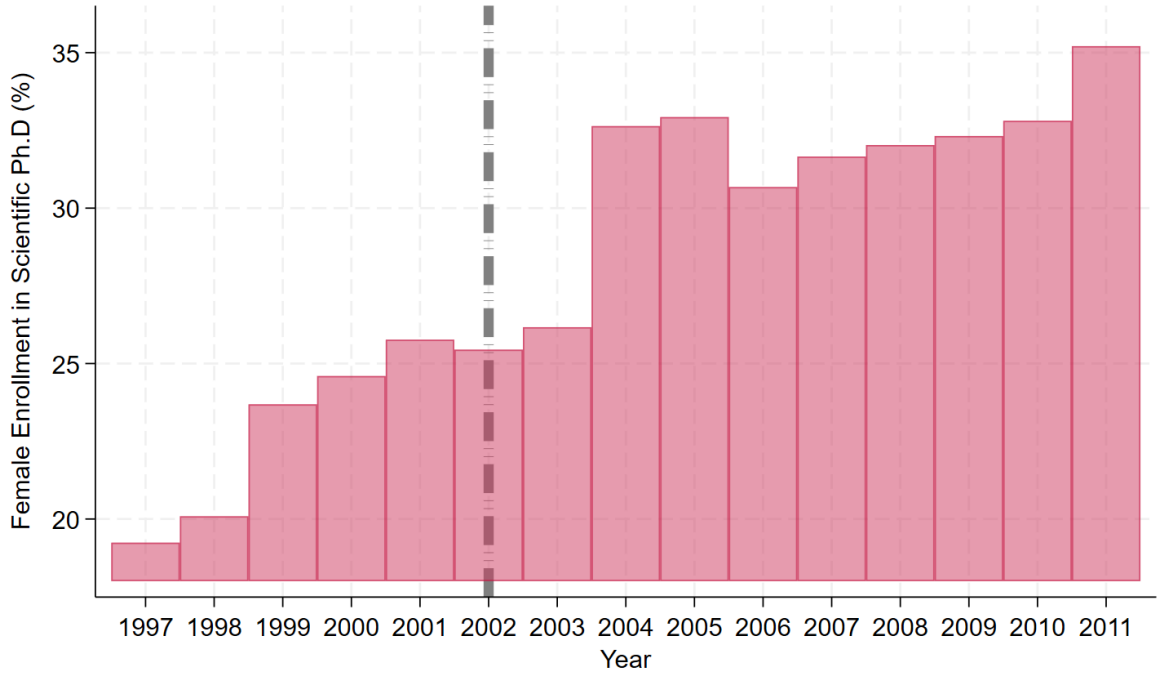
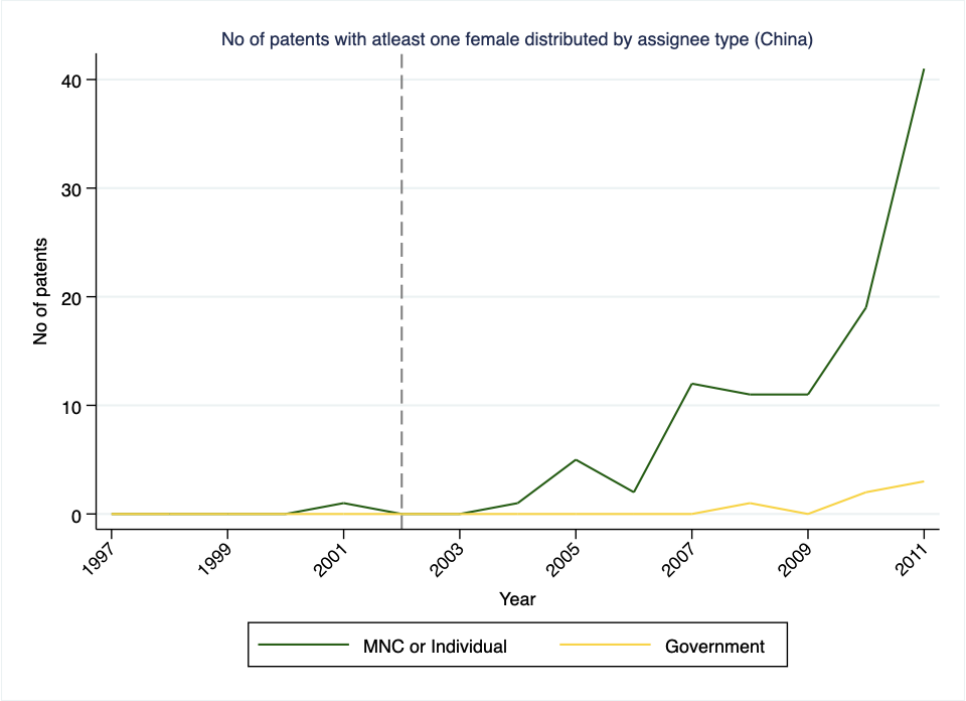
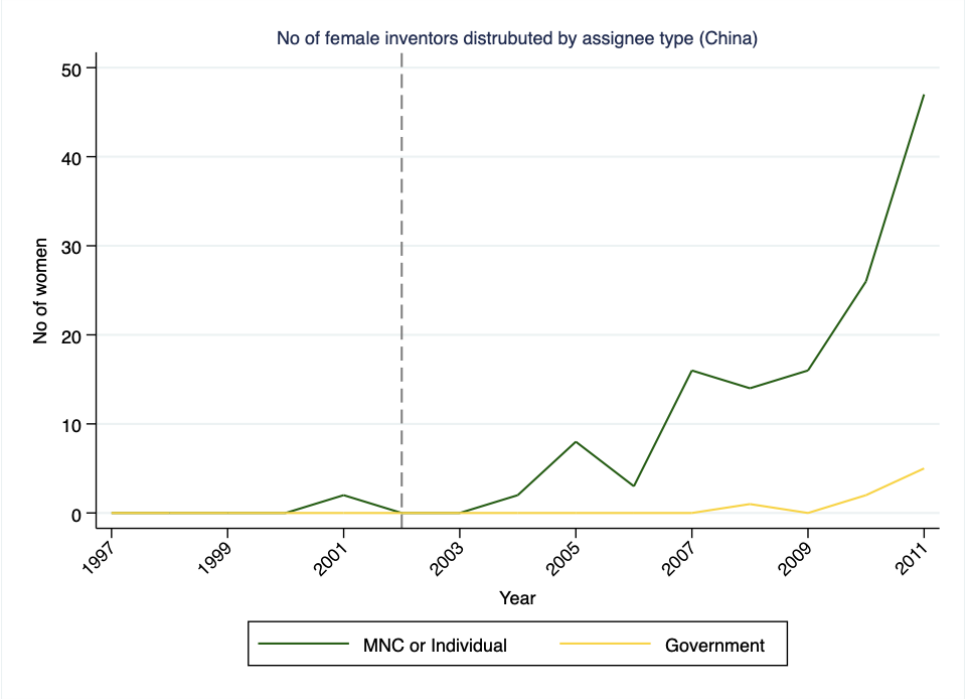


Figure 7: Firm Effect. Panel (a) plots the log of the number of patents with at least one female inventor and Panel (b) plots the log of number of female inventors between the period 1997 and 2011.



(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 atleast 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 1 if country is China, 0 for other countries
Post 2002	Coded as 1 if country-year pair is after 2002, 0 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

Notes: The table shows the number of observations, mean, standard deviation, minimum value and maximum value of variable.

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

	China		Rest of World		China Pre-Post		ROW Pre-Post		Difference-in-Differences		
Variable	Pre	Post	Pre	Post	Diff.	t-stat	Diff.	t-stat	Diff.	t-stat	p-value
Log Patents with Female	0.181	1.563	0.382	0.473	1.382	7.204	0.091	3.252	1.291	6.580	0.000***
Log Female Inventors	0.453	2.611	0.493	0.642	2.158	11.322	0.149	4.494	2.009	8.610	0.000***
Log Share of Patents with Female	0.060	0.162	0.043	0.048	0.102	2.804	0.005	0.902	0.097	3.060	0.002***
Log Share of Female Inventors	0.131	0.26	0.036	0.044	0.129	5.745	0.008	3.229	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 first and second difference value along with respective t-stat and p-value. The post period indicates years from 2003 to 2011 and the pre-period includes years from 1997 to 2002. 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

DV: Log Patent with Female	Baseline Results			Alternate Control Group		CEM	Extended Time Period
				Emerging	Developed		
	(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 A

DV: Log Female Inventors	Baseline Results			Alternate Control Group		CEM	Extended Time Period
				Emerging	Developed		
	(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

Panel B

Notes: The dependent variable in columns (1) to (3) is log of number of patents with at least one female inventor and in columns (4) to (6) is log of 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 post accession to WTO in 2002. The time horizon is from 1997 to 2011. Robust standard errors, clustered at 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 log of share of number of patents with at least one female inventor and in columns (4) to (6) is log of share 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 post accession to WTO in 2002. The time horizon is from 1997 to 2011. Robust standard errors, clustered at country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 6: 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) and (2) is log of number of citations of patents with females and in columns (2) and (3) is log of strategic importance of patent with females. Across model specifications, we see that the interaction term is positive and statistically significant. Thus, there is a significant improvement in quality of patents in China post accession to WTO in 2002. The time horizon is from 1997 to 2011. Robust standard errors, clustered at country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table 7: 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 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 WTO has no effect on women in China and use 10,000 re-randomizations. The p-value of the test statistic (as shown in column 4) indicates that we reject this null-hypothesis. Thus indicating that our baseline results are robust and have not been obtained by chance. We conducted RI tests using the "ritest" command in Stata developed by (Heß, 2017).

Table 8: Increase in Share of Domestic Female Inventors in Patent Team

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 share of domestic female inventors in patent team. The estimates for regression in column (1) takes China as treatment and rest of the world as control to show increase in share of domestic female inventors in China. Columns (2) - (4) are sub-sample analysis where we see change in share of domestic female inventors post 2002 in China, Developed countries and Rest of the word (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 log of number of patents with at least one female inventor and in columns (3) and (4) is log of 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 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 log of number of citations of patents with females and in columns (2) and (3) is log of strategic importance of patent with females. Across model specifications, we see that the interaction term is positive and statistically significant. Thus, there is a significant improvement in quality of patents in China post accession to WTO in 2002. The time horizon is from 1997 to 2011. Robust standard errors, clustered at country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

7. Appendix

Table A1: 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) and (2) is log of number of citations of patents with females and in columns (2) and (3) is log of strategic importance of patent with females. Across model specifications, we see that the interaction term is positive and statistically significant. Thus, there is a significant improvement in quality of patents in China post accession to WTO in 2002. The time horizon is from 1997 to 2011. Robust standard errors, clustered at country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

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 log of total number of patents. Across model specifications, we see that the interaction term is positive and statistically significant. Thus, there is a significant increase in the number of patents in China post-accession to WTO in 2002. The time horizon is from 1997 to 2011. Robust standard errors, clustered at country level are presented in the parenthesis.'***','**','*' indicate significance at the 1%, 5% and 10% respectively.

Table A3: IP Regime Change

S. No.	Mechanisms of Change	Description
1	Article 11 of China's Patent Law	This article 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	This article was amended to include 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 infringer.
3	Article 57 of China's Patent Law	This article 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 ground.
4	Article 52 and 53 of China's Patent Law	In accordance with the TRIPS standards, the duration and scope of compulsory licenses was modified, with increased access to legal and judicial body, guaranteeing the protection of IP rights for original patent owners.
5	State Intellectual Property Office's 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 administration, the Ministry of public security held regular forums from 2002 to table, discuss and address any IP right issues.
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