Is Free Trade Good or Bad for Innovation?

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Abstract

In this paper, we investigate whether trade liberalization affects firm innovation. Using China's WTO accession as a quasi-natural experiment, we compare firms in industries experiencing more liberalization with those in industries experiencing less liberalization. We find that trade liberalization reduced firms' overall innovation. However, the effects of trade liberalization differed for different types of innovation. Specifically, trade liberalization reduced firms' invention innovation and utility model invention (with a larger effect on the former), but increased firms' design innovation. We rationalize these results with a model in which trade generates a negative Schumpeterian effect and a positive spillover effect.

Keywords: Trade liberalization; Firm innovation; WTO; Difference-in-differences; Schumpeterian effect; Spillover effect

JEL Codes: F12, F13, F14, F15, L11, L13, O31.

1 Introduction

The world has witnessed an unprecedented degree of globalization in the past decades, e.g., the world's total merchandise trade reached US$17,816 billion in 2011 (World Trade Organization, 2012). However, the recent progress of multilateral free trade negotiations seems to have lost its momentum, and the criticisms of free trade have resurfaced and are gaining some support. The free trade debate centers on questions like whether free trade is good or bad for a nation's economy? Whether a nation can remain competitive in the integrated world market?

This paper contributes to the above debate by investigating whether trade affects innovation, an important factor determining a country's economic growth and long-term competitiveness [1]. Specifically, we examine two research questions: whether import competition (induced by trade liberalization) increases (or decreases) the degree of innovation; and whether import competition has differential effects on different types of innovation (e.g., on invention, utility model, and design innovation).

The innovation-based growth literature yields mixed answers to the first question. For instance, Rivera-Batiz and Romer (1991) suggest that economic integration provides incentives for industrial research, a result of the economies of scale. However the conclusion might be different when countries are asymmetric. Grossman and Helpman (1993) show that a country with a small endowment of human capital will stay away from the R&D activities that are skill intensive in response to trade liberalization. Indeed, according to these authors, these countries (mostly developing countries) are at the wrong side of the comparative advantage in R&D and will invest less in innovation. Moreover, trade policies on different sectors can have opposite impact on innovation: protecting the labor-intensive sectors or the ones where the effect of learning by doing is strong will boost innovation (Grossman and Helpman,1990b, 1991b). And as far as we know, we are the first one to answer the second question [2].

Our research setting exploits China's WTO accession by the end of 2001. After 15 years of applying, China successfully joined the WTO in November 2001 and started to fulfill its tariff reduction responsibilities in 2002 (e.g., the unweighted average tariff dropped from 15.3% in 2001 to 12.3% in 2004). However, China's tariff reduction upon WTO accession exhibited great heterogeneity across industries. Specifically, those industries with higher initial tariffs in 2001 experienced more tariff reduction after the WTO accession (for more details, see Section 3.1). Such a disparity in the degree of trade liberalization across industries provides us with an opportunity to conduct a difference-

[1] Grossman and Helpman (1994) provide convincing arguments to support the idea that innovation and technological progress, rather than capital accumulation, is the real engine of long run economic growth.

[2] In Dhingra (2013) a similar but different question has been addressed: how trade liberalization affects the various nature of innovation, namely product variety expansion and cost reduction

in-differences (DID) identification, that is, to compare the innovation degree in industries experiencing more trade liberalization before and after the WTO accession with those in industries with less trade liberalization during the same period.

Manually matching three datasets (i.e., tariff data, patent filings data, and firm-level data), we find that trade liberalization reduces firms' overall innovation: the overall patent filings fell in industries experiencing more liberalization upon WTO accession relative to those having less liberalization. The findings are robust to a battery of validity checks on our DID estimation (including controlling for the non-random selection of pre-WTO tariffs, the check on the expectation effect, and controlling for other on-going policy reforms), as well as other econometric concerns (such as the aggregation issue, the multi-industry issue, the cross-product within-industry tariff variations issue, etc.).

Meanwhile, with detailed information about the innovation type of each firm (i.e., invention, utility model, and design innovation according to China's patent classification), we are able to uncover differential effects of trade liberalization on innovation. Specifically, we find that the WTO accession significantly reduced firms' invention innovation and utility model invention (with the former experiencing the larger effect), but significantly increased firms' design innovation.

To rationalize these findings, we extend the standard trade model to allow an endogenous selection of product quality (see also Dhingra, 2013)[3]. Our model allows us to demonstrate two effects from trade on firm innovation. First, the increase in competition reduces firms' future profits from innovation and hence dampens firms' incentives to innovate. This is the standard Schumpeterian competition effect identified in the industrial organization literature (see, e.g., Aghion, Bloom, Blundell, Griffith, and Howitt, 2005). The second effect from trade is the spillover effect, that is, firms can share the knowledge stock possessed by foreign firms, through the learning from observing and competition. Hence, the overall effect of trade liberalization on firm innovation depends on the relative importance of these two effects. Meanwhile, given the specifics and requirements of innovation types, it is expected that there will be a larger spillover effect on design innovation than on invention innovation whereas the first effect does not vary across different types of innovation. Combined, this explains the average and differential innovation effects of trade liberalization that we have identified from the data. We provide further support for this argument by conducting a regression analysis following the work by Coe and Helpman (1995) and Coe, Helpman and Hoffmaister (2009).

Our work is related to a growing and important literature that investigates how international trade affects innovation. This growing literature is helped by new insights and

[3]The comparative advantage story could spring to mind as an explanation to our empirical findings. However before trade liberalization took place, the most protected sectors applied relatively more design patents than the least protected ones, while there was no difference regarding invention and utility patents. If the comparative advantage story is at work here, we should observe the least protected sectors with more design patents but less invention ones.

new micro data that is only available recently. In an important work Bustos (2011) suggests that innovation is subject to the economies of scale. Only firms with large sales can afford to pay for innovative activities. Therefore when trade liberalization occurs, firms with an expanding sales (exporters) innovate more while others (non exporters) have to lower their investment. A similar idea is found in Burstein and Melitz (2013): trade liberalization implies more innovation activities among future exporters as they expect more export opportunities. Besides expecting larger revenues from the export markets, firms can spend more on innovation to escape from the competition brought by their domestic rivals (Aghion et al., 2005). Trade liberalization can also release some trapped factors, reducing the costs of innovation, an idea proposed by Bloom, Romer, Terry, and Van Reenen (2013).

Different from the papers above, we show in this paper that trade liberalization (that induces more import penetration) leads to different outcomes of innovation. In this regard, our paper is closely related to Aghion et al. (2007) and Dhingra (2013). In the first paper, Aghion et al. (2007) suggest that the impact of competition depends on the technological distance: competition induced by trade liberalization has a positive impact on innovation in sectors that are close to the world's technological frontier but a negative one on innovation in sectors that are distant from the world's technological frontier. The model used in Aghion et al. (2007) is of oligopolistic competition. This set up is widely used in the early literature on innovation-based growth because it is very well suited to investigate the competition effect which determines the rents and therefore the incentives of carrying research activities. This setup, however, does not allow more than one firm to operate in the market. In this aspect, our monopolistic setup is perhaps more appropriate to exploit the richness of our firm data. In the second paper, Dhingra (2013) combines the economies of scale effect that is used in Bustos (2011) and the cannibalization effect. With these two forces, she is able to generate different reactions on two types of R&D activities: product and process innovation. She shows that as trade liberalization brings more competition from foreign firms, domestic firms react by reducing investment in product innovation, which then helps firms to lower the level of cannibalization. At the same time, firms can expand their operation in the foreign market, consequently inducing them to invest more in process innovation in order to exploit the economies of scale. Our model can work well with both product and process innovation. Our message is that even within these two types of innovation, we still can generate the differential effects of trade liberalization. This is because we introduce here the spillover effect, which is absent in her work. This effect differentiates our paper: while Dhingra (2013) (and other works such as Bustos, 2011) focuses on the demand side of innovation (the profitability of R&D determines the impact of international trade), our focus here is on the cost side: trade liberalization will bring down the costs of carrying R&D activities via the spillover effect.

The role of spillover in the discussion of technological transfer can not be ignored.

Indeed, the knowledge stock in the world has been mostly created in only a few rich, advanced countries. For example, in 1995 the seven largest industrialized countries accounted for more than 80% of the world's R&D spending (Keller, 2009). Moreover, it is reported that most of manufacturing R&D was conducted by multinationals (NSF, 2005). And a large part of international technology diffusion occurs via externalities, or spillovers (see McNeil and Fraumeni, 2005).

The spillover effect can occur via two main channels: foreign direct investment (FDI) or imports. The first channel has been investigated intensively in the literature. For instance, labor turnover is a form of spillover. Workers after being employed by the multinationals learn from the formal training or their on-the-job activity. They can then quit the job and work for or create a domestic firm with the expertise they acquired from the multinationals. Evidence of this channel is that workers with experience in a multinational usually earn higher wages (Poole, 2013). Domestic firms can also copy the business models employed by the multinationals. For example, Iacovone et al. (2013) report that the cold chain operations, a practice in which Walmex (an affiliate of Walmart in Mexico) source the perishables goods locally rather than via their distribution centers, were soon copied by the competing retailers. Besides the horizontal FDI spillover that we just mentioned, spillovers could occur via vertical FDI: Domestic firms can benefit from the better quality, sometimes unavailable inputs supplied by their foreign partners (Javorcik and Spatareanu, 2008).

In this paper, we explore the second channel of spillovers: imported goods. At the country and industry level, Grossman and Helpman (1991c, 1993) show that spillovers can have significant impact on the rate of innovation. We push the literature forward by investigating the question at a more micro level: the firms. Amiti and Konings (2007) document that the liberalization of input tariffs in Indonesia gave a boost to the productivity of the firms in Indonesia. Their findings prompt the question of finding the mechanism behind these observed gains in productivity. Our paper shows here with our supporting evidence that spillovers can be a driver for this result. Together with the usual Schumpeterian effect which is negative on innovation, the effect of trade liberalization on innovation could be positive or negative depending on whether the spillover effect is strong enough to dominate the Schumpeterian effect.

The paper is organized as follows. In the next section, we lay out the theoretical framework that discusses the impact of trade liberalization on the firm's innovation. In Section III, we present our estimation strategy. Our data and variables are introduced in Section IV. We discuss our empirical findings and check the underlying mechanism in Section V while Section VI concludes.

2 Theoretical Analysis

In this section, we use a simple model to illustrate how trade liberalization affects firms' innovation behavior and how it has different effects on different types of innovation. Specifically, we extend the Melitz (2003) model to allow an endogenous selection of product quality (see also Dhingra, 2013). Meanwhile, for the sake of simplicity, we focus on a two-identical-country model (i.e., Home and Foreign; except for their tariff reduction degrees, to be explained later), as a result of which we can only examine the state of one country (i.e., Home).

2.1 Model Setup

Demand. There is a continuum of horizontally differentiated varieties. Let us denote Θ the set of all available varieties in the market. Assuming that the varieties are imperfectly substitutable with a constant elasticity of substitution σ, we then have the preferences of a representative agent in the form of Constant Elasticity of Substitution (CES) as in Dixit and Stiglitz (1977):

$$U = \left[\int_{i \in \Theta} \theta_i^{\frac{1}{\sigma}} \left(q_i\right)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \sigma > 1 \tag{1}$$

In this utility function, we allow the product to be different in terms of quality. In particular, a variety i will be produced with a quality θ_i chosen by the producer. Given a budget limit E (which represents the size of the market), the demand for each product is given by

$$q_i = \theta_i \left(\frac{p_i}{P}\right)^{-\sigma} \frac{E}{P}, \tag{2}$$

where P is the true price index, $P = \left[\int_{i \in \Theta} \theta_i p_i^{1-\sigma} di \right]^{\frac{1}{1-\sigma}}$.

Production. The market is free to enter, but requires a fixed cost of entry f_e (in units of labor). Upon paying this entry cost, the firm draws its productivity level φ from a Pareto distribution $G(\varphi)$. The variable cost is then $c = \frac{1}{\varphi}$ units of labor, independent of the quality of the product [4]. If it decides to be active, it has to incur a fixed cost f in units of labor. Additionally, it has to bear a quality investment $I(\theta)$, which enables it to supply the good with a quality level θ.

Innovation. We follow Romer (1990) and Grossman and Helpman (1990a) to model

[4] It is natural to assume that the marginal costs of producing quality goods are higher. However, this assumption does not change our model as we can always factor the production costs in the demand function (2)

innovation. A firm, when investing in R&D, creates two types of products: one is appropriable (the blue print), which is patentable, and the other is non-appropriable (knowledge). This investment serves to improve the firm's product quality. In particular, to have a quality level θ, a firm has to make a fixed investment $I(\theta)$, where

$$I(\theta) = \frac{\theta^{\gamma}}{K^{\alpha}}, \gamma > 1, \alpha > 0, \theta \geq 1.^{5}. \tag{3}$$

This investment is increasing in the desired quality θ but decreasing in the stock of knowledge K.[6] The parameter γ indicates the ineffectiveness of quality investment: higher γ corresponds to less effective investment.[7] The parameter α captures the effect of the knowledge stock (or the spillover effect) on innovation: a higher α means less investment for the same quality degree θ; in other words, a stronger spillover effect.

2.2 Equilibrium Analysis

Pricing strategy. We can divide the problem faced by a firm into two steps: it first chooses its desired quality level and then it decides on its sales. Since upgrading the quality only requires a fixed investment, the price chosen by the firm is the marginal cost plus the mark-up:

$$p = \frac{\sigma - 1}{\sigma} c. \tag{4}$$

The stock of knowledge. The by-product of an R&D investment is to generate more public knowledge which depends on the amount of innovation taken. Investment in R&D, although it might not lead to a fruitful result, still contributes to the knowledge stock of the economy. This investment benefits not only the investor but also the other firms via the spillover effect.

We assume that the spillover effect is of an international nature. For example, in Grossman and Helpman (1991c), international spillover takes place in the form of the volume of trade: the more the two countries trade, the more pronounced is the spillover effect. We formalize their idea by assuming, as we mentioned above, that the knowledge generated from the innovation invesment of the foreign firms contributes to the total national stock of knowledge. The presence of the foreign exporters, together with their experience and expertise, help the domestic firms in improving their quality. In other

[5] With this innovation costs, our model has the process innovation flavor as in Dhingra(2013). Our model can be generalized to incorporate the product innovation. Indeed one can change the innovation costs to $I(n) = \frac{n^{\gamma}}{K^{\alpha}}$ where n is the number of supplied varieties. In this case all of our arguments still go through.

[6] We can think of this as upgrading on the intensive margin. Grossman and Helpman (1991a) model the cost of upgrading on the extensive margin, which rises with the number of new products and decreases in the stock of knowledge available in the economy. Besides the difference on the margin, we also allow a variation of the degree of the spillover effect (captured by α).

[7] Indeed, when γ converges to infinity, all firms optimally choose $\theta = 1$. In this case, $I = K^{-\alpha}$ and we have the usual Melitz (2003) framework.

words, we have

$$K = \int_{\varphi_0^x}^{+\infty} \frac{(\theta^x)^\gamma}{K^\alpha} dG(\varphi). \tag{5}$$

Note that φ_0^x is the foreign exporter cut-off. As in Bustos (2011), we assume the two countries are symmetric for simplicity. Hence, the foreign exporter cut-off is also the exporter cut-off in the Home country.

Endogenous quality selection. With the pricing strategy (4), the profit of a domestic firm is given by

$$\begin{aligned} \pi_d(\varphi_i) &= p_i q_i - c_i q_i - f - I(\theta_i) \\ &= B\theta_i \varphi_i^{\sigma-1} - f - I(\theta_i), \end{aligned} \tag{6}$$

where $B = \frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma} P^{\sigma-1} E$ indicates the effective size of the market.

The first-order condition (FOC) of choosing the optimal qualtiy is then

$$B\varphi_i^{\sigma-1} = \gamma \frac{\theta_i^{\gamma-1}}{K^\alpha}, \tag{7}$$

which implies the desired quality of the domestic firm i:

$$\theta_i = \left(\frac{BK^\alpha}{\gamma}\right)^{\frac{1}{\gamma-1}} \varphi_i^{\frac{\sigma-1}{\gamma-1}} = \theta(\varphi_i, B, K). \tag{8}$$

Exporters, in addition to serving the domestic market, can also serve the foreign market, subject to the fixed export cost f^x and Foreign country's ad valorem tariff τ_F. Note that we make an explicit distinction between the Home country's ad valorem tariff (τ) and the Foreign country's (τ_F) because our empirical setting is more about a unilateral tariff reduction, i.e., τ falls but τ_F remains unchanged [8].

We then can write the profit of the exporter of the Home country as

$$\pi_e(\varphi) = B\theta\varphi^{\sigma-1} - f + B\theta \left(\frac{\varphi}{\tau_F}\right)^{\sigma-1} - f^x - I(\theta). \tag{9}$$

As a result, the quality chosen by an exporter is given by

$$\theta_i^x(\varphi_i, B, K, \tau_F) = \left(\frac{B\left(1+\tau_F^{1-\sigma}\right)K^\alpha}{\gamma}\right)^{\frac{1}{\gamma-1}} \varphi_i^{\frac{\sigma-1}{\gamma-1}}. \tag{10}$$

As in Dhingra (2013), Equations 8 and 10 demonstrate the effect of the economies of scale here: when the firm makes more sales, it will decide to upgrade its quality level. This economies of scale effect takes place via the market size B and productivity φ. These

[8] Indeed our setup is to look at the impact of import tariff reductions on innovation. Readers who are interested in the impact of export tariff reduction are encouraged to read Bustos (2011).

equations also illustrate the asymmetric impact of trade liberalization: A reduction in export tariff τ_F encourages exporters to invest more on quality but reduces the incentives for non-exporters (Bustos, 2011). The new element which we introduce is the spillover effect K, which we will discuss later.

Production cut-off and export cut-off. As in Melitz (2003), only a subset of firms (those whose productivity is higher than a certain threshold) can afford to pay the production fixed cost. Denote the cut-off productivity of production is φ_0, then the zero-profit condition $\pi(\varphi_0) = 0$ implies

$$B\theta(\varphi_0, B, K)\varphi_0^{\sigma-1} = \frac{\theta^\gamma(\varphi_0, B, K)}{K^\alpha} + f. \tag{11}$$

Since $B\varphi_i^{\sigma-1} = \gamma\frac{\theta_i^{\gamma-1}}{K^\alpha}$ (Equation 7), we then have

$$B = \gamma\left(\frac{f}{\gamma-1}\right)^{\frac{\gamma-1}{\gamma}} K^{\frac{-\alpha}{\gamma}}\varphi_0^{1-\sigma}. \tag{12}$$

The firm only exports if being an exporter brings more profit, i.e., when $\pi_e(\varphi) > \pi_d(\varphi_i)$. And hence the exporter cut-off will be determined by

$$\frac{\gamma-1}{\gamma}\frac{r(\varphi_0^x)}{\sigma}\left[\left[1+\tau_F^{1-\sigma}\right]^{\frac{\gamma}{\gamma-1}} - 1\right] = f_x. \tag{13}$$

where $r(\varphi_i) = \theta_i\left(\frac{p_i}{P}\right)^{1-\sigma} E$ is the revenues of the firm with productivity φ_i. From (11) and (13), we have

$$\varphi_0^x = \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}\left[\left[1+\tau_F^{1-\sigma}\right]^{\frac{\gamma}{\gamma-1}} - 1\right]^{\frac{-1}{\sigma-1}}\varphi_0. \tag{14}$$

Equilibrium. An equilibrium is characterized by $(B, P, K, \varphi_0, \varphi_0^x)$ which can be solved from Equations 5, 11, 13 and the free entry condition:

$$f_E = \int_{\varphi_0}^{\varphi_0^x}\pi(\varphi)\,dG(\varphi) + \int_{\varphi_0^x}\left[\pi(\varphi) + \pi^x(\varphi)\right]dG(\varphi). \tag{15}$$

2.3 The Effect of Trade Liberalization

We now consider how trade liberalization (i.e., the reduction of Home's ad valorem tariff τ) affects the equilibrium, and in particular, a firm's innovation investment decision.

On the stock of knowledge. We can show (in Appendix A) that trade liberalization raises the stock of knowledge available to Home firms. Note that the spillover effect comes from the foreign exporters. As trade liberalization allows more of them to enter the Home market, there are more technologies and new products available to Home firms. Moreover, as in Verhoogen (2008), trade liberalization brings more overseas sale opportunities for foreign exporters, therefore enabling them to invest more in upgrading quality. These two effects result in a rise in the stock of knowledge in the Home country.

On innovation. The effect of a tariff reduction in the Home country on a Home firm's innovation investment decision is

$$\begin{aligned}\frac{\partial\theta}{\partial\tau} &= \frac{1}{\gamma-1}\frac{\theta}{B}\frac{\partial B}{\partial\tau}+\frac{\alpha}{\gamma-1}\frac{\theta}{K}\frac{\partial K}{\partial\tau} \\ &= \underbrace{-\frac{\sigma-1}{\gamma-1}\frac{\theta}{\varphi_0}\frac{\partial\varphi_0}{\partial\tau}}_{the\ Schumpeterian\ effect} + \underbrace{\frac{\alpha}{\gamma}\frac{\theta}{K}\frac{\partial K}{\partial\tau}}_{the\ spillover\ effect}. \end{aligned} \tag{16}$$

The first term of Equation (16) refers to the Schumpeterian effect. When trade liberalization occurs, the increase in imports drives down the price index P in the Home country, which in turn reduces the effective market demand B in the Home country. As a result, Home firms will then invest less in innovation as their profits from innovation fall due to the smaller effective market demand.

The second term of Equation (16) refers to the spillover effect. As we showed above that trade liberalization raises the amount of knowledge for Home firms, Home firms tend to invest more in quality.

Since we have both negative and positive effects from tariff reduction on innovation by Home firms, we then have the following result.

Proposition 1 *Trade liberalization reduces firm innovation if the Schumpeterian effect dominates, but raises firm innovation when the spillover effect dominates.*

In particular, according to Equation (16), the magnitude of the spillover effect increases with the parameter α. Note that this parameter denotes how strongly the firm benefits from the existing stock of knowledge in terms of the innovation costs (see Equation 3). It is clear to see that while the Schumpeterian effect only depends on the industry specific variables such as the elasticity of substitution σ, the survival cut-off φ_0, the spillover effect depends on the parameter α, which according to our conjecture, is specific to the type of innovation. In order words, different types of innovation are subject to the same import competition effect, but the extent to which the spillover effect exerts pressure on these types of innovation varies. As a result, they respond differently to trade liberalization, which is the task we will perform in the next section.

3 Estimation Strategy

3.1 China's WTO Accession

In July 1986, China notified the GATT (the predecessor of the WTO) that she would like to resume her status as a GATT contracting party, the process eventually lasting 15 years.

Between 1987 and 1992, as China was debating the direction of her economic reforms, the return to GATT was suspended. The momentum resumed after Deng Xiaoping's southern tour speech in 1992, and in July 1995, China officially filed her application to join the WTO.

The pivotal part of China's WTO accession process involved bilateral negotiations between China and WTO members. The first country signing a bilateral agreement (in August 1997) with China regarding China's WTO accession was New Zealand. However, the negotiations between China and the U.S. took 25 rounds and four years for an agreement to be reached in November 1999. After that, China reached agreements with 19 countries within half a year, including Canada in November 1999 and the European Union in May 2000. In September 2001, China reached an agreement with Mexico, which indicated that negotiations with all WTO member countries had been completed. Finally, WTO's Ministerial Conference approved by consensus the text of the agreement for China's entry into the WTO on November 10, 2001.

As a commitment for joining the WTO, China carried out large scale tariff reductions between 1992 and 1997. Specifically, in 1992, China's (un-weighted) average tariff was as high as 42.9%. Shortly after the GATT Uruguay round negotiations, China substantially reduced her tariffs: the average tariff dropped from 35% in 1994 to around 17% in 1997. Tariffs remained stable after 1997 until China joined the WTO at the end of 2001. Starting with the beginning of 2002, China started to fulfil her tariff reduction responsibilities as a WTO member country. According to the WTO accession agreement, China would complete the tariff reduction by 2004 (with a few exceptions to be completed by 2010), and the average tariffs of agriculture and manufacturing goods would be reduced to 15% and 8.9%, respectively.

Figure 1 plots China's (un-weighted) average tariffs during the period 1996–2007. It can be seen that tariff rates dropped substantially in 1996, remained relatively stable in 1997–2001, and gradually reduced in 2002 until reaching a steady state in 2005. The un-weighted average tariff dropped from 15.3% in 2001 to 12.3% in 2004, whereas the weighted average tariffs changed from 9.1% to 6.4%.

Interestingly, tariff reduction on accession to the WTO exhibited great heterogeneity across products. As shown in Figure 1, the ratio of tariffs at the 25th percentile over those at the 75th percentile also had a sharp drop in 2002 and then stabilized after 2005. In Figure 2, we further plot the relation between tariffs in 2001 (the year just before the WTO accession) and the changes in tariffs between 2001 and 2005 across 3-digit industries (the unit used in the main regression analysis).[9] Clearly, there is a strong, positive correlation, implying that industries with higher tariffs before the WTO accession experienced more tariff reductions after the WTO accession. Presumably, China had to reduce her tariffs to the WTO-determined levels that are quite uniform across products, whereas China's

[9] A similar pattern was uncovered at the HS-6 product level (results available upon request).

pre-WTO tariffs differed a lot across products.

3.2 Estimation Specification

To identify the impact of trade liberalization on innovation, we explore the fact that after China joined the WTO, some previously more protected industries (i.e., industries with higher tariffs in 2001) experienced more tariff reductions, due to the WTO agreement, and hence higher degrees of liberalization, whereas other previously more open industries (i.e., industries with lower tariffs in 2001) had smaller changes in tariffs and hence less liberalization. The timing of the tariff reductions (2002) and the disparity in liberalization degrees provide us with an opportunity to conduct a DID estimation, that is, to compare the change of innovative activities in those previously more protected industries (the treatment group) before and after 2001 with the corresponding change in those previously more open industries (the control group) during the same period (see, for example, Guadalupe and Wulf, 2010 for a similar practice).

The specification of our DID estimation is

$$y_{fit} = \alpha_f + \beta Tariff_{i2001} \cdot Post02_t + \mathbf{X}'_{fit}\gamma + \lambda_t + \varepsilon_{fit}, \tag{17}$$

where f, i and t represent firm, 3-digit industry and year, respectively; y_{fit} measures the innovation made by firm f in industry i in year t; $Tariff_{i2001}$ is the tariff rate of industry i in 2001; $Post02_t$ is an indicator of post-WTO period, taking a value of 1 if it is 2002 and onwards, and 0 otherwise; α_f is the firm fixed effect, controlling for all time-invariant differences across firms (as well as industries and regions); λ_t is the year fixed effect, controlling for all yearly shocks common to industries such as business cycles; and ε_{fit} is the error term. To deal with the potential heteroskedasticity and serial autocorrelation, we cluster the standard errors at the firm level (see Bertrand, Duflo, and Mullainathan, 2004).

To isolate the effect of trade liberalization, we control for several time-varying firm characteristics ($\mathbf{X}_{fit}$) that may affect its innovation, such as firm age, firm size, capital–labor ratio, exporting status, and share owned by foreign investors.

In the main specification, we define an industry at the 3-digit Chinese Industrial Classification (CIC) level, presumably there are relatively more observations within such defined industries and hence smaller measurement errors of our outcome variable. However, to address the concern of any potential aggregation bias, we conducted a robustness check at the 4-digt CIC level, the finest definition in our data.

Note that we use the interaction of tariffs in 2001 ($Tariff_{i2001}$)[10] and the post-WTO indicator ($Post02_t$) as our regressor of interest, instead of yearly tariffs ($Tariff_{it}$). One

[10] Using the average tariffs over 1997–2001 or tariffs in 1997 generates similar results (available upon request), presumably tariffs did not change much between 1997 and 2001.

motivation is that the schedule of tariff reduction upon WTO accession in China was released in 2002, and hence the phase-out process was expected and could be exploited by firms. Meanwhile, as elaborated in Liu and Trefler (2011), the use of the interaction between $Tariff_{i2001}$ and $Post02_t$ can capture both the real and the expected effects of trade liberalization. Nonetheless, using yearly tariffs ($Tariff_{it}$) produces similar results (available upon request).

3.3 Identifying Assumption and Checks

The identifying assumption associated with our DID estimation specification (17) is that conditional on a whole list of controls ($\alpha_f, \mathbf{X}_{fit}, \lambda_t$), our regressor of interest, $Tariff_{i2001} \cdot Post02_t$, is uncorrelated with the error term, ε_{fit}, i.e.,[11]

$$E\left[\varepsilon_{fit}|Tariff_{i2001} \cdot Post02_t, \alpha_f, \mathbf{X}_{fit}, \lambda_t\right] = E\left[\varepsilon_{fit}|\alpha_f, \mathbf{X}_{fit}, \lambda_t\right]. \tag{18}$$

In other words, innovation in the treatment group would have followed the same trend as that in the control group if there had been no trade liberalization in 2002.

However, there may exist a few challenges to our identifying assumption, specifically, the non-random selection of tariffs in 2001, the timing of the WTO accession, and some other simultaneous policy reforms.

Firstly, tariffs in 2001 were not set randomly, creating concerns that our treatment and control groups could be systematically different *ex ante*. To alleviate the concern that some pre-existing differences between the treatment and the control groups may also differentially affect the innovation degrees of these two groups even after the WTO accession (and hence contaminate our DID estimates), we first carefully characterize what were the significant tariff determinants in the pre-WTO period (for details see Appendix B), and then control flexibly for post-WTO differences in the time path of our outcome variable generated by these pre-existing differences (see Gentzkow, 2006 for a similar approach). Specifically, we add into our DID regression the interactions between those significant tariff determinants ($\mathbf{Z}_{i2001}$) with a fourth order polynomial function of time, i.e., $\mathbf{Z}_{i2001} \cdot f(t)$. Moreover, we further included industry-specific linear time trend (i.e., $\alpha_i \cdot t$) to control for the underlying differences between our treatment and control groups in a restricted way, that is, assuming these potential confounding factors affect our outcome variable in the specification of linear trend.

Secondly, one may be concerned that China's WTO accession by the end of 2001

[11] Note that the identification does not require our control variables to be exogeneous, e.g.,

$$E\left[\varepsilon_{it}|\alpha_i, \mathbf{X}_{it}, \lambda_t\right] = 0.$$

In other words, for these control variables, their estimated coefficients may not have causal interpretation. See Stock and Watson (2012, p274) for more discussion of this point.

was expected and firms could then have adjusted their behavior even before the tariff reduction happened after 2002. However, China's WTO accession process has been very lengthy, taking about 15 years to complete, and the approval required a consensus by all WTO member countries. Despite China's having achieved important breakthroughs by signing agreements with the U.S. in 1999 and the EU in 2000, there were still many leftovers unresolved until the mid 2001. Hence, the timing of China's WTO accession was largely uncertain before 2001. Nonetheless, in a robustness check, we include in the DID regression an additional control, $Tariff_{i2001} \times Next\ Year_t$ (where $Next\ Year_t$ indicates that the WTO accession would happen next year), to examine whether firms changed their innovation behavior in anticipation of the WTO accession next year.

Thirdly, if there were other policy reforms targeting differentially our treatment and control groups around the time of the WTO accession (i.e., the end of 2001), our DID estimates may also capture the effects of these other policy reforms, making it hard to pinpoint the effect of trade liberalization. There were two important on-going reforms in the early 2000s, the SOEs reform and the relaxation of FDI regulations (which allowed more wholly-owned FDI rather than equity joint ventures). To control for any confounding effects from these two policy reforms, we include in our DID estimation $SOE\ Share$ (measured by the ratio of the number of SOEs over the number of domestic firms) and FDI (measured by the logarithm of the number of foreign invested firms)[12].

To further check our identifying assumption, we conducted three additional tests: a placebo test using only the pre-WTO period data (as in Topalova, 2010), a placebo test using the sample of processing traders, and a flexible estimation (in which our regressor of interest becomes $Tariff_{i2001} \times \lambda_t$) to check whether treatment and control groups are comparable up to the time of the WTO accession. For details, see Section 5.3.

4 Data and Variables

Our empirical analysis draws on three datasets, and as these three datasets use different identity codes, we matched them manually, which brings us a unique firm-level dataset containing industry-level tariff information, firm-level innovation information, and other firm-level characteristics.

We first used the *Tariff Download Facility* to obtain information about Chinese tariffs. The tariff data provide, for each product defined at the HS-6 digit level, detailed information of the number of tariff lines, the average, minimum and maximum ad valorem tariff duties, etc. The tariff data is available for 1996, 1997 and the period 2001-the latest. As the tariff information on the WTO website is missing for 1998–2000, we supplemented the missing tariff data from the World Integrated Trade Solution website maintained by

[12] As discussed in the introduction, the alternative channel of the spillovers beside imports is the investment from foreign firms.

the World Bank. Meanwhile, as different HS codes are used before and after 2002, we matched the 1996 HS codes (also used for the 1997–2001 tariffs) to the 2002 HS codes (used for the 2001–2006 tariffs) using the standard HS concordance table. There are in all 5,036 HS-6 products from manufacturing industries in our tariff data.

As our outcome variable (i.e., firm innovation degree) can only be linked to the tariff change at the industry level, we need to aggregate tariffs from the HS-product level to the industry level. To this end, we first matched the HS classification to the Chinese Industrial Classification using the concordance table from the National Bureau of Statistics of China.[13] Then, for each industry and each year, we calculated the simple average tariff. However, one may be concerned that such aggregation may conceal substantial variations in tariff reduction across products within an industry, which may underestimate the effect of trade liberalization. To address this concern, we, in a robustness check, added an interaction between our regressor of interest ($Tariff_{i2001} \times Post02_t$) and the number of products within a 3-digit industry, to check whether industries with more HS-6 products (and hence potentially more tariff variations) behave differently from those with less products.

To capture the degree of firm innovation, one can use either the innovation input (i.e. R&D spending) or the innovation output (i.e. patents application). We follow the literature by using patent filings information (see, e.g., Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Hashmi, 2013). By construction, a patent provides the holder a temporary monopoly rent with the corresponding innovation. Relative to R&D spending, using patents has the advantage that it is available for developing countries such as China. However, one must be aware with the issues of using such measure. First, patents could underestimate technology because the innovation must be important enough to be registered as a patent and some part of technology can not be codified in the patents. Second, some patents are more important and therefore more cited than the others.

The patent filings data were downloaded from the State Intellectual Property Office of China, containing detailed information of each patent filing since 1985, such as the date of filing, the name and the address of the applicant, the name of the patent, and also the type of the patent (i.e., whether the patent is an invention patent, a utility model patent, or a design patent). As our firm-level data only have R&D information for two post-WTO years, we use the ratio of new product output as an alternative measure of innovation degree in a robustness check.

Besides the problems with patent as we mentioned above, another drawback of the patent filings dataset is that it does not have much information about firm characteristics (except for the name and address). We then obtained all necessary firm characteristics from our third data source, the *Annual Survey of Industrial Firms* (ASIF) maintained by the National Bureau of Statistics of China for the period 1998 to 2005. This is the most

[13]We thank Yifan Zhang for sharing this concordance table.

comprehensive firm-level dataset in China, as it covers all state-owned enterprises and non-state-owned enterprises with annual sales of above five million Renminbi (around US$600,000). The number of firms varies from over 140,000 in the late 1990s to over 243,000 in 2005, spanning all 31 provinces or province-equivalent municipalities and all manufacturing industries, which ensures an invaluable national representativeness. The dataset provides detailed firm information, including name, industry affiliation, location, and all operation and performance items from the accounting statements such as age, employment, capital, intermediate inputs, and ownership.

As the patent filings data and the ASIF data have different firm identity codes, we manually merged the two data sets by firm name, and double-checked our matching with the firms' location information. According to a report by the National Bureau of Statistics of China, about 8.8% of the manufacturing firms with annual sales above 5 million Renminbi applied for patents during 2004–2006. In our matched data, for the period 2004–2005, there were about 4% of firms that applied for patents. Given that the patent filings increased quickly in the 2000s, we should have obtained a reasonably good match. Meanwhile, we have used consistent rules for the data matching through the whole sample period (from 1998 to 2005) and there are no reasons to expect that there are discontinuities in the degree of mis-match across industries with different degrees of trade liberalization upon the time of the WTO accession, thereby alleviating the estimation biases arising from the matching process. The matched data have an unbalanced panel of 440,877 firms and a total of around 1.3 million observations, with both detailed patent filing information and firm characteristics for the period 1998–2005.

Note that in the ASIF data, each firm only reports one industrial affiliation, presumably its main industry. However, it is possible that firms may produce goods in multiple industries (but we only observe one due to the limitations of the data). This might cause an estimation issue: our estimation may ignore the effect of trade liberalization from other industries in which firms have production but do not report in the data. To check whether our estimates are biased due to such multiple-industry issue, we first conducted a robustness check at the 2-digit industry level, in which the multiple-industry issue is less severe. Moreover, we obtained product level data from the National Bureau of Statistics of China for the period 2000–2006, which contains the information about each product (defined at the 5-digit product level) produced by the firm, firm identity, etc. As the product-level data and the ASIF data use the same firm identity, we can easily match these two datasets, and we conducted a robustness check by focusing on a sub-sample of firms producing all goods within only one 3-digit industry.

Table 1 shows, for each of the 29 2-digit industries, the total number of patent filings, the average number of patent filings per firm, and the proportion of firms that ever filed a patent. It is found that by total numbers, Electric Equipment ($30,793$ filings), Electric Machinery ($26,267$ filings), and Transport Equipment ($10,707$ filings) are the top three industries in this respect; whereas Other Manufacturing (26 filings), Chemical Fibre (315 filings), and Petroleum Processing (494 filings) are the bottom three industries. However, these numbers may be inflated by the total number of firms in each industry. By looking at the average patent filings per firm, we find intuitively that high-tech and capital-intensive industries have larger numbers, e.g., Electric Equipment (0.6887 filings per firm), Electric Machinery (0.3245 filings per firm), and Special Equipment (0.1786 filings per firm); whereas low-tech and labor intensive industries tend to have smaller numbers, e.g., Food Processing (0.0168 filings per firm), Garments (0.0196 filings per firm), and Print and Record Medium Reproduction (0.0199 filings per firm).

Industries have different propensities of filing different patents. Generally, low-tech and labor-intensive industries have a higher propensity of filing design patents, while high-tech and capital-intensive industries are more prone to file invention and utility model patents. For example, Stationery, Educational and Sporting Goods, Food Production, and Beverage are the top three industries in the average design patent filings per firm. Electric Equipment, Medical, and Electric Machinery have the largest average invention patent filings per firm.

Another interesting finding from Table 1 is that only a minority of firms ever filed patents during our sample period (1998–2005). Industries with the largest ratios of patent filings firms are Medical (0.0739), Electronic and Telecom (0.0729), and Electric Equipment (0.0571). Given the zero patent filings at the firm level, we use the following transformed measure as our outcome variable:

$$y_{fit} = \ln\left[Y_{fit} + \left(Y_{fit}^2 + 1\right)^{1/2}\right],$$

where Y_{fit} is the total number of patent filings by firm f in industry i in year t. This transformation allows us to keep all observations of zero patent filings and to interpret our estimate β as a percentage change in patent filings. We prefer this transformation to other log-like transformations (such as $\ln(Y_{fit} + 1)$) as it is more flexible and capable to handle negative values (Pence, 2006) and our results are robust to the use of $\ln(Y_{fit} + 1)$ as the outcome variable (results available upon request).[14]

5 Empirical Findings

5.1 Graphical Presentation

We plot, in Figure 3, the time trends of firm innovation (measured by total number of patent filings in Figure 3a and average number of patent filings per firm in Figure 3b)

[14] Another way of dealing with the zero patent filings is to use the Poisson or zero-inflated negative binomial models. However, we cannot get convergence in estimating these models, presumably because we include a larget set of firm and year dummies.

for high-tariff industries (industries with tariffs above the sample median in 2001; i.e., our treatment group) and low-tariff industries (industries with tariffs below the sample median in 2001; i.e., our control group) for 1998–2005.

By observing this figure, especially in the pre-WTO period, we find two points worth noting here. First while the most protected sectors possess more design patents, they have the same amount of invention and utility patents as the least protected sectors. This feature leads us to believe that what is at work here is not led by the comparative advantage story. Second it is clear that in the pre-WTO period (1998–2001; i.e., the pre-treatment period), the two groups have quite similar trends. Such parallel pre-treatment trends in firm innovation between treatment and control groups alleviates the concerns that our treatment and control groups are *ex ante* incomparable, lending support to our DID identifying assumption.

Meanwhile, there is a visible divergence in the trends of firm innovation after 2002, the point in time when China started to reduce its tariffs upon the WTO accession. The consistency in timing between the divergence in firm innovation and the WTO accession suggests that trade liberalization affects firm innovation. Specifically, trade liberalization has a visible, negative effect on overall innovation and invention innovation; a visible, positive effect on design innovation; and a modest, negative effect on utility model innovation.

In the remaining parts of this section, we use a regression analysis to formally establish these innovation effects of trade liberalization (via the WTO accession).

5.2 Main Results

The regression results of the DID specification (17) are presented in Table 2. We start with a simple DID specification with the inclusion of only firm and year fixed effects in column 1. Our regressor of interest, $Tariff_{i2001} \cdot Post02_t$, is negative and statistically significant, suggesting that firms innovate less after 2002 in industries with higher tariffs in 2001 than those in industries with lower tariffs in 2001. Given that industries with higher tariffs in 2001 experienced more tariff reduction after 2002, these results imply that trade liberalization reduces firm innovation.

In column 2, we further add some time-varying firm characteristics that may correlate with both our outcome variable (i.e., firm innovation) and our regressor of interest (i.e., the degree of trade liberalization). Specifically, we include firm age (single and squared terms), firm size, capital–labor ratio, exporting status, and equity share owned by foreign investors. Evidently, our results are found to be robust to these additional controls.

One prominent concern of our DID estimation is that tariffs in 2001 were non-randomly determined, and hence our treatment and control groups could be systematically different *ex ante*, which may spuriously generate the negative effect of trade liberalization on firm innovation. However, as displayed in Figure 3, firm innovation in high 2001-tariff industries and in low 2001-tariff industries have similar time trends in the pre-WTO period and start to diverge upon the WTO accession, implying that our treatment and control groups are largely comparable. To further alleviate the concern that the nonrandom determination of tariffs in 2001 may bias our estimates, we conducted a robustness check following Gentzkow (2006). Specifically, we added, stepwise in columns 2–3, the interaction terms between a fourth order polynomial function of time and tariff determinants (for details, see Appendix B) to control for flexible time trends in firm innovation generated by these tariff determinants. Clearly, the coefficient of our regressor of interest remains negative and statistically significant.

In column 4, we further address the concern that our estimates may capture the effects of two on-going policy reform in the early 2000s (the SOEs reform and the lifting of some FDI regulations). Specifically, we add two control variables (the number of foreign-invested firms, and the share of SOEs among domestic firms). It is found that our main findings remain robust.

In summary, the results in Table 2 show that trade liberalization (via China's WTO accession) caused firms to innovate less. And this effect is not contaminated by the non-random tariff selection in the pre-WTO period and other on-going police reforms. Referring to our theoretical model in Section 2 (Proposition 1), these findings imply that the negative Schumpeterian competition effect dominates the positive spillover effect of trade, which then dampens firms' incentives to innovate.

5.3 Different Types of Innovation

In the above sub-section, we focus on the total number of patent filings, without differentiating between types of patents. However, our patent filing data contain information about the patent types. Specifically, the patents are classified into three categories at the filing stage, that is, invention, utility model, and design patents. According to the Patent Law of China, invention patents refer to technical innovations on products, methods, or both; utility model patents refer to technical proposals on the shape and/or structure of a product; and design patents refer to changes in the shape and/or color of a product.

Meanwhile, the requirements and the application procedure for the three types of patents are very different. Applications for invention patents are subject to strict examinations of the utility, novelty, and non-obviousness, and, compared with the existent technologies, the innovation must have "prominently substantive characteristics and significant improvement." However, the utility model and the design patents are more or less incremental innovations and are not subject to the examination for novelty and non-obviousness. Generally, both are granted on a registration basis. Compared to the requirement for the design patent which focuses only on the appearance or the shape, the requirement for the utility model patent application is stricter in the sense that the utility model innovation must also be functionally useful and have "substantive characteristics and improvement" compared with existing technologies.

With such detailed patent type information in our data, we are able to test whether trade liberalization has different effects on different types of innovations. Our model in section 2 does predict that the effect is increasing in the spillover parameter α which is specific to patent types, that is, we have

$$\frac{\partial^2 \theta}{\partial \tau \partial \alpha} = \frac{\theta}{\gamma K} \frac{\partial K}{\partial \tau} + \frac{\alpha}{\gamma K} \frac{\partial K}{\partial \tau} \frac{\partial \theta}{\partial \alpha} > 0. \tag{19}$$

As to the three types of patents, given the specifics and requirements of each innovation, we expect that the knowledge spillover parameter α is largest for design innovation, followed by utility model innovation, and then by invention innovation. Therefore we expect that the innovation effect is decreasing in the order of design innovation, utility model innovation, and invention innovation.

The regression results are presented in Table 3. Indeed, we find that the effect of trade liberalization on design innovation is positive and statistically significant, but negative and statistically significant on invention and utility model innovation with the former having a much larger effect.

5.4 Checks on the Identifying Assumption

In this sub-section, we present the results of a battery of robustness checks on the identifying assumption of our aforementioned DID estimation. The regression results are presented in Table 4. To save space, we focus on the total number of patent filings, and report those checks for the three different types of patent filings in Appendix Table 2.1, 2.2 and 2.3.

Industry-specific linear time trend. Despite having controlled for flexible time trends of firm innovation generated by those significant pre-WTO differences between our treatment and control groups, one could still be concerned about some unobserved industry characteristics that might compromise the comparability between the treatment and control groups. To check whether these unobserved industry factors could bias our estimates, we include an industry-specific linear time trend, e.g., $\alpha_i \cdot t$. This enables us to control for all unobserved industry characteristics in a limited format, that is, provided they affect firm innovation in a specification of a linear time trend. The regression results are presented in column 1. Evidently, our regressor of interest remains negative and statistically significant, implying that our estimates are not driven by those unobserved underlying industry characteristics.

Expectation effect. In column 2, we add to the regression an additional control,

$Tariff_{i2001} \times Next\ Year_t$, to check whether firms changed their innovative behavior in anticipation of the coming WTO accession, which might in turn have made our treatment and control groups *ex ante* non-comparable, thus biasing our estimates. The coefficient of $Tariff_{i2001} \times Next\ Year_t$ is found to be statistically insignificant and very small in magnitude, suggesting that there is no such expectation effect. Moreover, the coefficient of our regressor of interest remains negative and statistically significant.

Placebo test I: Pre-WTO period. As the first placebo test, we follow Topalova (2010) in looking at the effect of tariffs on firm innovation in the pre-WTO period (1998–2001). The premise is that as tariffs did not change much during this period, we would not expect any significant effects; the contrary might indicate the existence of some underlying confounding factors. As shown in column 3, we indeed find that tariffs had no significant effect on firm innovation in the pre-WTO period.

Placebo test II: A sample of processing traders. A unique feature of the Chinese trade regime is that some firms are allowed to import materials free of tariffs but required to export all their output, the so-called processing trade regime. The establishment of such a trade regime was to protect much of the fragile domestic economy from foreign competition but to also open its economy when the Chinese government adopted the "reform and opening" policy in 1978. Given that processing traders were relatively immune from the trade liberalization caused by the WTO accession, the estimation using the sample of processing traders should produce an insignificant liberalization effect. The regression results are presented in column 4. As expected, the coefficient of $Tariff_{i2001} \times Post02_t$ is highly insignificant.

Flexible estimation. We use a flexible estimation specification, that is, replacing the post-treatment period indicator ($Post02_t$) with year dummies (λ_t). Such an exercise can allow us to check whether the treatment and the control groups were comparable up to the time of the WTO accession and became different after that event (a similar approach as in Figure 3 but in a more rigorous way). As shown in column 5, in the pre-WTO period, all the estimated coefficients are positive, insignificant, and small in magnitude. However, right after the WTO accession, the estimated coefficients become negative and continuously increase in magnitude. These results further corroborate our previous findings in Figure 3, that is, trade liberalization (through the WTO accession by the end of 2001) triggered a fall in firm innovation.

5.5 Other Robustness Checks

In this subsection, we present another series of robustness checks on other econometric concerns. The regression results are presented in Table 5. To save space, we focus on the total number of patent filings, and report those checks for the three different types of patent filings in Appendix Table 3.

Finer industry definition. Thus far, our analysis is based on the 3-digit CIC industry level. To alleviate the concern about aggregation biases, we conducted a robustness check at the 4-digit CIC industry level (note that a trade-off is that there are fewer observations within each industry-year cell and hence potentially higher measurement errors). The regression results are presented in column 1. Clearly, our results are robust to this finer industry definition, albeit less precisely estimated.

Check on cross-product, within-industry tariff variations. As noted in Section 4, one drawback of our empirical data is that tariff information is at the HS-6 product level, while the firm innovation information can only be linked to tariffs at the CIC 3-digit industry level. Hence, the mapping from the HS-6 product to the CIC 3-digit industry level may conceal variations of tariff reduction across different HS-6 products but within the same 3-digit industry, which may lead to an underestimate of the trade liberalization effect. As a check on this issue, we add an interaction between our regressor of interest ($Tariff_{i2001} \times Post02_t$) with the number of products within a 3-digit industry. As shown in column 2, the triple interaction term is not statistically significant, implying that industries with more HS-6 products (and hence potentially more variations of tariffs within the industry) do not behave differently from those with fewer products.

Checks on the multi-industry issue. One might be concerned that firms could produce multiple products spanning different 3-digit industries, and hence our aforementioned DID estimation may miss the liberalization effect from other related 3-digit industries. To check this concern, we first investigated the effect at the 2-digit industry level, where the multi-product issue is less severe. As shown in column 3, the innovation effect of trade liberalization remains negative and statistically significant. Meanwhile, in column 4, we focus on a sub-sample of firms producing only in one 3-digit industry (through the use of a product-level data set; see Section 4 for details), and continue to find a negative innovation effect of trade liberalization.

Using new product share as a measure of firm innovation. To measure the degree of firm innovation, we follow the literature by using patent filings. To check whether our findings of the negative innovation effect of trade liberalization are sensitive to the choice of the measure of firm innovation, we could use some alternative measures of firm innovation. Ideally, we want to use firm R&D expenditure share; however, our ASIF data only have such information for a few years in the post-WTO period, precluding the use of the DID identification. Instead, we use the share of new product output over total output. The regression results are presented in column 5. Consistent with our previous findings, trade liberalization is found to reduce the share of new product output, albeit imprecisely estimated.

Two-period estimation. One concern with the DID estimation is how to accurately calculate the standard errors and hence the statistical inference. Thus far, we have followed the suggestion by Bertrand, Duflo, and Mullainathan (2004) to cluster the standard errors at the firm level. As a robustness check, we use another approach suggested by Bertrand, Duflo, and Mullainathan (2004), that is, collapsing the panel structure into two periods, one before and the other after the WTO accession, and then using the White-robust standard errors. Meanwhile, such an exercise can also allow us to compare the long-run average effect of trade liberalization on firm innovation. The regression results are presented in column 6. Evidently, we obtain similar (but larger) results.

5.6 Underlying Mechanisms

In this sub-section, we investigate potential underlying mechanisms through which trade liberalization might affect firm innovation. Our perceived channels, as illustrated in the theoretical model in Section 2, are that trade liberalization generates two opposing effects, the negative competition effect and the positive spillover effects from the increase in imports. To check whether such an argument is supported by our data, we firstly investigate whether imports increase after the tariff reduction; secondly, we exclude other channels like foreign market access brought about by the WTO accession; and finally, we examine the existence of positive spillover effects.

Tariff reduction and imports. With import and tariff information both available at the HS-6 product level, we conduct the analysis of import response to trade liberalization at the HS-6 product level. However, there are many HS-6 product categories with zero import value, which creates a potential estimation bias (i.e., the sample selection issue). To correct for such a zero trade value issue, we use the Poisson pseudo-maximum likelihood estimation by Silva and Tenreyro (2006). Specifically, we regress the level of imports on our regressor of interest ($Tariff_{p2001} \times Post02_t$, where $Tariff_{p2001}$ is the tariff of product p in 2001) along with a set of product and year dummies. The regression results are presented in column 1 of Table 6. Evidently, we find that imports increase in those product categories experiencing more tariff reduction, corroborating our import competition argument.

Market access effect. The WTO accession is multi-lateral, that is, China's trading partners may also reduce their tariffs on imports from China. To fix the idea that the change in firm innovation comes from the increase in domestic competition degree generated by tariff reduction, we include total exports (in logarithmic form) to control for the access to foreign markets. The regression results are presented in column 2 of Table 6. Clearly, our main findings remain robust to this additional control, lending support to the argument of import competition.

Spillover effect. The innovative part of our theoretical analysis to explain the differential innovation effects of trade liberalization is the existence of a spillover effect from imports. To provide further support for this argument, we carry out a formal test of the spillover effect following the work by Coe and Helpman (1995) and Coe, Helpman and Hoffmaister (2009). Specifically, we regress firm innovation on the stock of industrial patents. The regression results are presented in columns 3–6 of Table 6. It is found that the stock of industrial patents has a positive and statistically significant effect on firm overall innovation (column 3); and the effect increases from invention innovation, to utility model innovation, to design innovation (e.g., the t-statistic of the difference between invention innovation and design innovation coefficients has a p-value of 0.0595). These findings confirm our argument that there exist spillover effects, and that design innovation benefits more from such spillovers.

6 Conclusion

The impact of trade liberalization on growth has long been a hot issue in the discussion of globalization. In this paper, we investigated whether trade liberalization positively or negatively affects firm innovation which is regarded as one of the key determinants of long-run economic growth. To establish the causality from trade liberalization to innovation, we employed the Difference-in-Differences technique to exploit the quasi-natural experiment brought about by China's accession to the WTO. Specifically, China's accession to the WTO generated industrial heterogeneity in tariff reduction, based on which, we compared firms in industries experiencing more liberalization with those in industries experiencing less liberalization.

We have found that trade liberalization reduces a firm's overall innovation, and this finding is robust to a series of checks. Furthermore, with detailed information about types of innovation, we have found different effects of trade liberalization on the different types of innovation. Specifically, WTO accession reduced firms' invention innovation and utility model invention, but increased firms' design innovation. As far as we know, the present paper is the first to uncover the differential effects of trade liberalization on different innovation types.

We also showed that these findings can be rationalized in an extended trade model with endogenous selection of product quality. On the one hand, increased competition due to trade liberalization dampens firms' incentives to innovate (i.e., the standard Schumpeterian effect, see Aghion, et al., 2005). On the other hand, the increased stock of knowledge accompanying trade liberalization lowers the cost of innovation, which helps boost innovation (i.e., the spillover effect, see Coe and Helpman, 1995 and Coe, Helpman and Hoffmaister, 2009). Given the specific requirements of the specific types of innovation, it is expected, and also confirmed by our data, that the spillover effect is larger for design innovation than for invention innovation. The combination of the two effects then drives the differentiation of the effects on innovation.

Our findings complement the current literature on the growth effect of trade liberalization. In particular, the findings remind us of the potential heterogeneity of the effect on innovation. Trade liberalization may be detrimental for fundamental innovation activities due to the negative Schumpeterian effect, unless firms can obtain substantial positive spillovers from foreign firms.

References

Aghion, P., N. Bloom, R. Blundell, R. Griffith, and P. Howitt (2005): "Competition and Innovation: An Inverted U Relationships," *Quarterly Journal of Economics*, 120(2), 701–28.

Aghion, P., R. Blundell, R. Griffith, P. Howitt, and S. Prantl (2007): "Entry, Innovation, and Growth: Theory and Evidence," *Review of Economics and Statistics*.

Amiti, M., and J. Konings (2007): "Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia," *American Economics Review*, 97(5), 1611–38.

Anderson, T., and H. Rubin (1949): "Estimators of the parameters of a single equation in a complete set of stochastic equations," *Annals of Mathematical Statistics*, 21, 570–82.

Artuc, E., S. Chaudhuri, and J. McLaren (2010): "Trade Shocks and Labor Adjustment: A Structural Empirical Approach," *American Economic Review*, 100, 1008–45.

Attanasio, O., P. K. Goldberg, and N. Pavcnik (2004): "Trade Reforms and Wage Inequality in Colombia," *Journal of Development Economics*, 74, 331–66.

Bertrand, M., E. Duflo, and S. Mullainathan (2004): "How Much Should We Trust Differences-in-Differences Estimates?," *Quarterly Journal of Economics*, 119, 249–75.

Bloom, N., P. Romer, S. J. Terry, and J. V. Reenen (2013): "A Trapped-Factors Model of Innovation," Stanford mimeo.

Brandt, L., J. V. Biesebroeck, L. Wang, , and Y. Zhang (2013): "WTO Accession and Performance of Chinese Manufacturing Firms," working paper.

Burstein, A., and M. Melitz (2013): "Trade Liberalization and Firm Dynamics," Harvard mimeo.

Bustos, P. (2011): "Trade Liberalization, Exports, and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinian Firms," *American Economic Review*, 101(1), 304–40.

Coe, D., and E. Helpman (1995): "International R & D spillovers," *European Economic Review*, 39, 859–87.

Coe, D., E. Helpman, and A. W. Hoffmaister (2009): "International R & D spillovers and institutions," *European Economic Review*, 53(7), 723–41.

Dhingra, S. (2013): "Trading Away Wide Brands for Cheap Brands," *American Economic Review*, 103(6), 2554–84.

Dixit, A. K., and J. E. Stiglitz (1977): "Monopolistic Competition and Optimum Product Diversity," *American Economic Review*, 67(3), 297–308.

Gentzkow, M. (2006): "Television and Voter Turnout," *The Quarterly Journal of Economics*, 121(3), 931–72.

Gorodnichenko, Y., J. Svejnar, and K. Terrell (2010): "Globalization and Innovation in Emerging Markets," *American Economic Journal: Macroeconomics*, 2, 194–226.

Grossman, G., and E. Helpman (1990a): "Comparative Advantage and Long-Run Growth," *American Economic Review*, 80(4), 796–815.

——— (1990b): "Trade, Innovation and Growth," *American Economic Review*, 80(2), 86–91.

——— (1991a): "Endogenous Product Cycle," *Economic Journal*, 101, 1214–29.

——— (1991b): "Growth and Welfare in a small Open Economy," NBER Working Paper No.2970.

——— (1991c): "Trade, knowledge spillovers, and growth," *European Economic Review*, 35, 517–26.

——— (1993): *Innovation and Growth in the Global Economy*. MIT Press.

——— (1994): "Endogenous Innovation in the Theory of Growth," *Journal of Economic Perspectives*, 8(1), 23–44.

Guadalupe, M., and J. Wulf (2010): "The Flattening Firm and Product Market Competition: The Effect of Trade Liberalization on Corporate Hierarchies.," *American Economic Journal: Applied Economics*, 2(4), 105–27.

Han, J., R. Liu, and J. Zhang (2012): "Globalization and Wage Inequality: Evidence from Urban China.," *Journal of International Economics*, 87(2), 288–97.

Hashmi, A. R. (2013): "Competition and Innovation: The Inverted-U Relationship Revisited," *Review of Economics and Statistics*, 95(5), 1653–68.

Iacovone, L., B. Javorcik, W. Keller, and J. Tybout (2013): "Supplier Responses to Walmarts Invasion in Mexico," University of Oxford, mimeo.

Javorcik, B., and M. Spatareanu (2008): "To share or not to share: Does local participation matter for spillovers from foreign direct investment?," *Journal of Development Economics*, 85, 194–217.

Kambourov, G. (2009): "Labour Market Regulations and the Sectoral Reallocation of Workers: The Case of Trade Reforms," *Review of Economic Studies*, 76, 1321–58.

Keller, W. (2005): "International Trade, Foreign Direct Investment, And Technology Spillovers," NBER Working Paper No. 15442.

Liu, R., and D. Trefler (2011): "A Sorted Tale of Globalization: White Collar Jobs and the Rise of Service Offshoring," NBER Working Paper No. 17559.

Lu, Y., and T. Ng. (2012): "Do Imports Spur Incremental Innovation in the South?," *China Economic Review*, 23, 819–832.

McNeil, L., and B. Fraumeni (2005): "International trade and economic growth: A possible methodology for estimating cross-border R&D spillovers," BEA Working Paper 2005-03.

Melitz, M. (2003): "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 71(6), 1695–1725.

NSF (2005): "Research and Development Data Link Project: Final Report," NSF and Census Bureau, Bureau of Economic Analysis report.

Pavcnik, N. (2002): "Trade Liberalization, Exit, and Productivity Improvements: Evidence from Chilean Plants," *The Review of Economic Studies*, 69, 245–76.

Poole, J. P. (2013): "Knowledge Transfers from Multinational to Domestic Firms: Evidence from Worker Mobility," *The Review of Economics and Statistics*, 95(2), 393–406.

Rivera-Batiz, L., and P. Romer (1991): "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, 106(2), 531–55.

Romer, P. (1990): "Endogenous Technological Change," *Journal of Political Economy*, 98(5), 71–102.

Santos Silva, J. M. C., and S. Tenreyro (2006): "The Log of Gravity," *The Review of Economics and Statistics*, 88(4), 641–58.

Stock, J. H., and M. W. Watson (2012): *Introduction to Econometrics*. Essex, England: Pearson Education Limited, 3rd edn.

Topalova, P. (2010): "Factor Immobility and Regional Impacts of Trade Liberalization: Evidence on Poverty from India," *American Economic Journal: Applied Economics*, 2(4), 1–41.

Trefler, D. (2004): "The Long and Short of the Canada-U.S. Free Trade Agreement," *American Economic Review*, 94, 870–95.

Verhoogen, E. (2008): "Trade, Quality Upgrading and Wage Inequality in the Mexican Manufacturing Sector," *Quarterly Journal of Economics*, 123(2), 489–530.

WTO (2012): *International Trade Statistics 2012*.

Appendix A: The Effect of Trade Liberalization on the Stock of Knowledge

We will show here that the stock of knowledge rises when trade liberalization takes place. Assume that the firm distribution is of Pareto with the probability density function $g(\varphi) = \frac{k\underline{\varphi}^k}{\varphi^{k+1}}$. Note that the stock of knowledge is the total investment of the foreign exporters, which are subject to the tariff τ set by the Home government. Therefore we can replace τ_F in Equation (10) and (14) by τ and calculate the stock of knowledge as:

$$\begin{aligned} K &= \int_{\varphi_0^x}^{\infty} \frac{(\theta^x)^\gamma}{K^\alpha} dG(\varphi) \\ &= K^{-\alpha}\left(\frac{BK^\alpha}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} \left(1+\tau^{1-\sigma}\right)^{\frac{\gamma}{\gamma-1}} \int_{\varphi_0^x}^{\infty} \varphi^{\frac{(\sigma-1)\gamma}{\gamma-1}} dG(\varphi) \\ &= K^{-\alpha}\left(\frac{BK^\alpha}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} \frac{k\underline{\varphi}^k}{k-\frac{(\sigma-1)\gamma}{\gamma-1}} \left(\varphi_0^x\right)^{\frac{(\sigma-1)\gamma}{\gamma-1}-k} \left(1+\tau^{1-\sigma}\right)^{\frac{\gamma}{\gamma-1}} \end{aligned}$$

Replacing $B = \gamma\left(\frac{f}{\gamma-1}\right)^{\frac{\gamma-1}{\gamma}} K^{\frac{-\alpha}{\gamma}} \varphi_0^{1-\sigma}$ and $\varphi_0^x = \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}} \left[\left[1+\tau^{1-\sigma}\right]^{\frac{\gamma}{\gamma-1}} - 1\right]^{\frac{-1}{\sigma-1}} \varphi_0$, we then have

$$\begin{aligned} K &= D\left[\left[1+\tau^{1-\sigma}\right]^{\frac{\gamma}{\gamma-1}} - 1\right]^{\frac{-\gamma}{\gamma-1}} \left(1+\tau^{1-\sigma}\right)^{\frac{\gamma}{\gamma-1}} \left(\varphi_0^x\right)^{-k} \\ &= D\left[\frac{1+\tau^{1-\sigma}}{\left[1+\tau^{1-\sigma}\right]^{\frac{\gamma}{\gamma-1}} - 1}\right]^{\frac{\gamma}{\gamma-1}} \left(\varphi_0^x\right)^{-k} \end{aligned}$$

where $D = \frac{k\varphi^k}{k - \frac{(\sigma-1)\gamma}{\gamma-1}} \gamma^{\frac{\gamma}{\gamma-1}} \left(\frac{f}{\gamma-1}\right) \left(\frac{f_x}{f}\right)^{\frac{\gamma}{\gamma-1}}$. The equation above demonstrates very clearly two effects of trade liberalization on the stock of knowledge. First import tariff reduction allows more foreign exporters to enter the Home market (i.e., φ_0^x falls), which raises the stock of knowledge. On top of that, as in Bustos (2011), the opening of the Home market induces the foreign exporters to invest more on their quality (the first term). Mathematically the first term falls with import tariff τ (i.e. it rises when τ falls). We can rewrite the first term as $f(x) = \frac{x}{x^a - 1}$ with $x = 1 + \tau^{1-\sigma}$ and $a = \frac{\gamma}{\gamma-1} > 1$. The function $f(x)$ is clearly decreasing in x. Therefore $\left[\frac{1+\tau^{1-\sigma}}{[1+\tau^{1-\sigma}]^{\frac{\gamma}{\gamma-1}} - 1}\right]^{\frac{\gamma}{\gamma-1}}$ is decreasing in τ.

The two effects mentioned above show that import tariff reduction raises the stock of knowledge K.

Appendix B: Tariff Determinants in 2001

Our identification uses the variations in tariffs across industries in the pre-WTO period and hence the variations in tariff reduction after the WTO accession. However, it must be recognized that China's tariff structure before its WTO accession was not randomly determined. Therefore, an understanding of how the pre-WTO tariffs were determined is important for pinpointing potential biases in our DID estimation (i.e., the comparability between our treatment and control groups) and attributing the change in firm innovation to trade liberalization.

There are many reasons why the government imposes different tariffs on different industries. First, according to the political economy literature (e.g., Grossman and Helpman, 1994), industries with more political power are more capable of lobbying and influencing governments to provide more protection. We use two measures to capture this political economy consideration. One is the labor size of each industry (as in Trefler 2004), and the other is the output share of domestic firms in each industry. Second, the government may set different tariff rates for industries with different levels of technological advancement. We capture this consideration with the ratio of total value-added over total output and the capital–labor ratio of each industry. The third category of potential factors is the development trend of the industry, e.g., declining industries may receive more or less protection from the government. We capture industrial trends with the growth rate of employment and the growth rate of output for each industry.

The regression results are presented in Appendix Table 1, in which industry-level tariffs in 2001 are regressed on those aforementioned potential determinants with level variables being measured in 2001 and growth variables being measured in 1998–2001. Three variables are found to be robustly and statistically significant and negative: the output share of domestic firms and the growth rate of output. These findings are consistent with the ideology of China in those years, that is, to promote growth through reform and opening, and also may show the confidence of the government in those fast-growing industries in competing with foreign firms.

Moreover, columns 4–5 show that the tariff structure is not related with industrial patenting behavior. Both the average number of patents and the growth rate of patents during 1998–2001 are insignificant. This implies that, conditional on those potential tariff determinants, China's industrial tariff is not reversely affected by industrial innovation.

Figure 1: Tariffs (1996-2007)

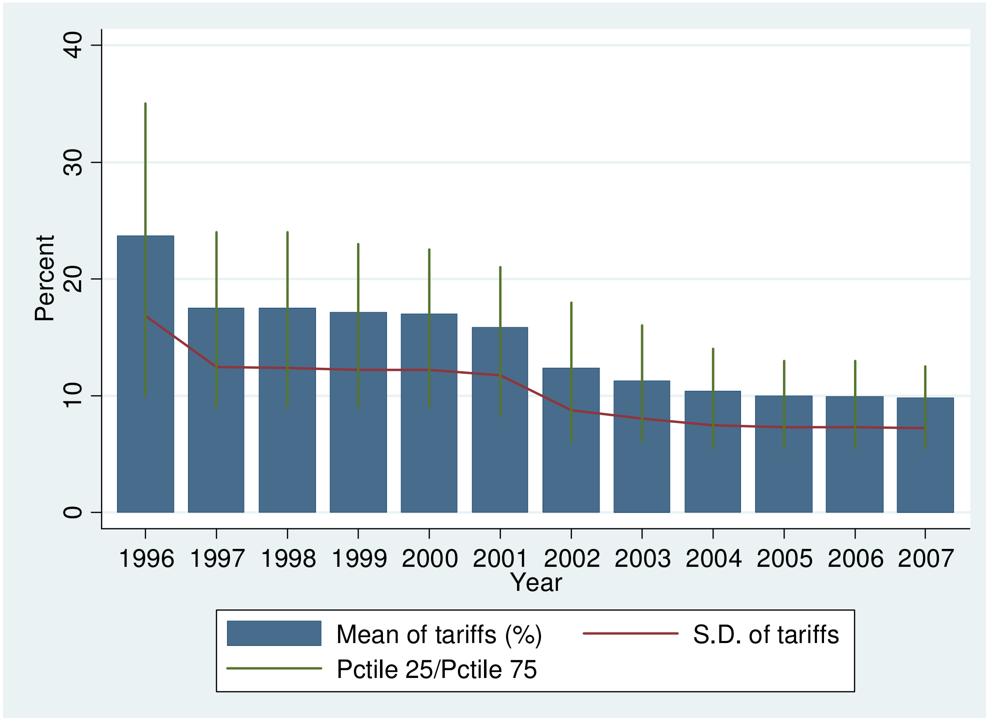

Figure 2: The correlation between tariffs in 2001 and tariff changes during 2001-2005

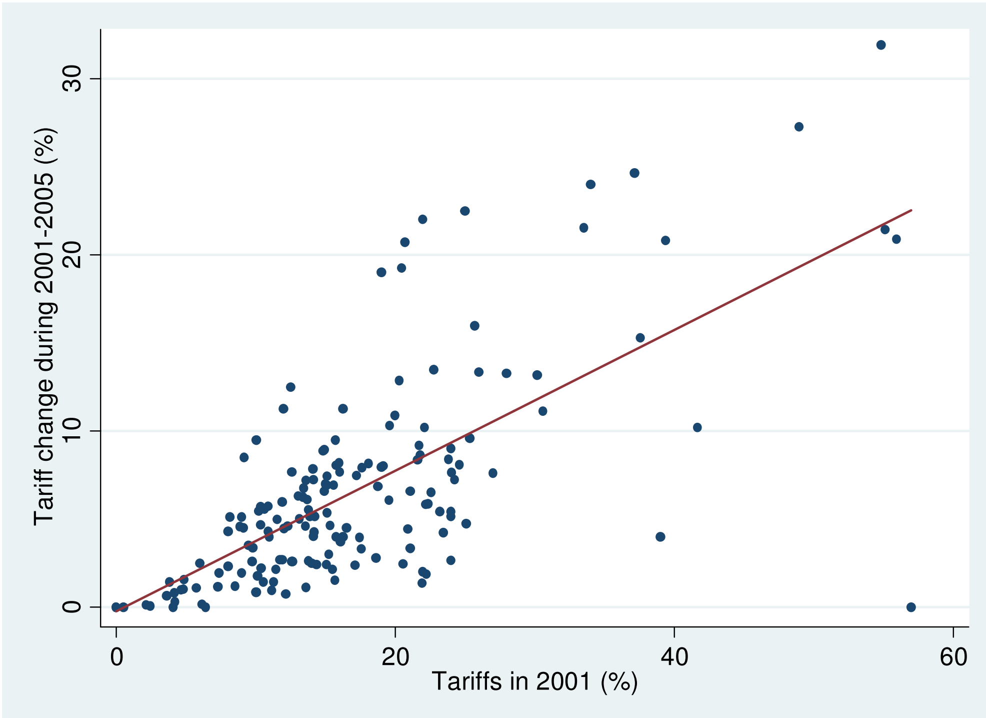

Figure 3, Time Trends of Innovation for High and Low Tariff Industries

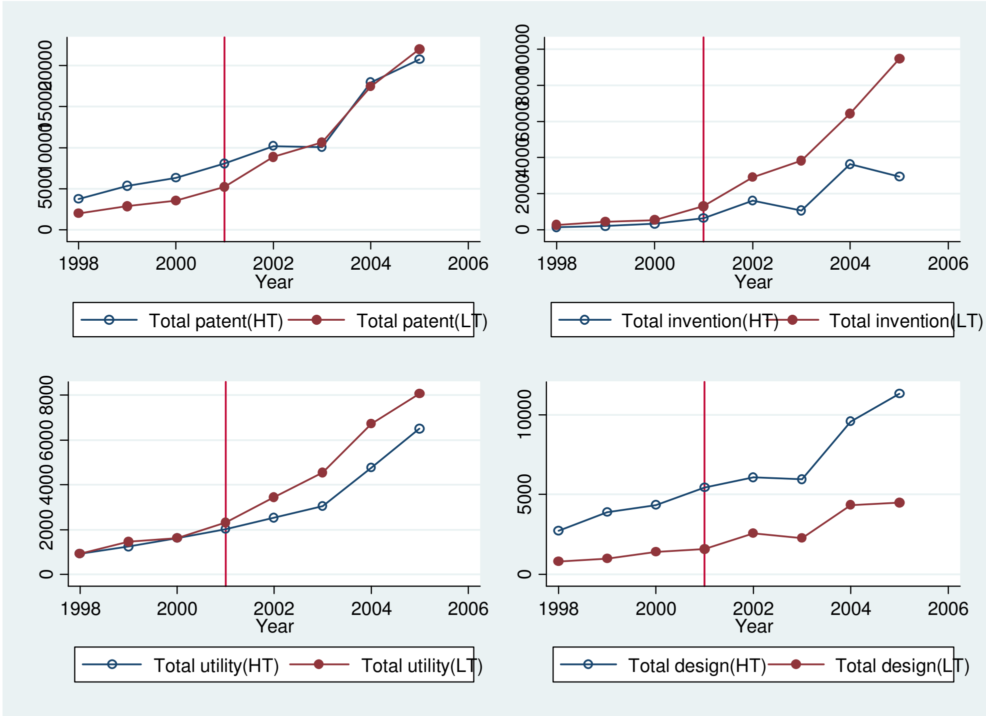

Figure 3a, Total Number

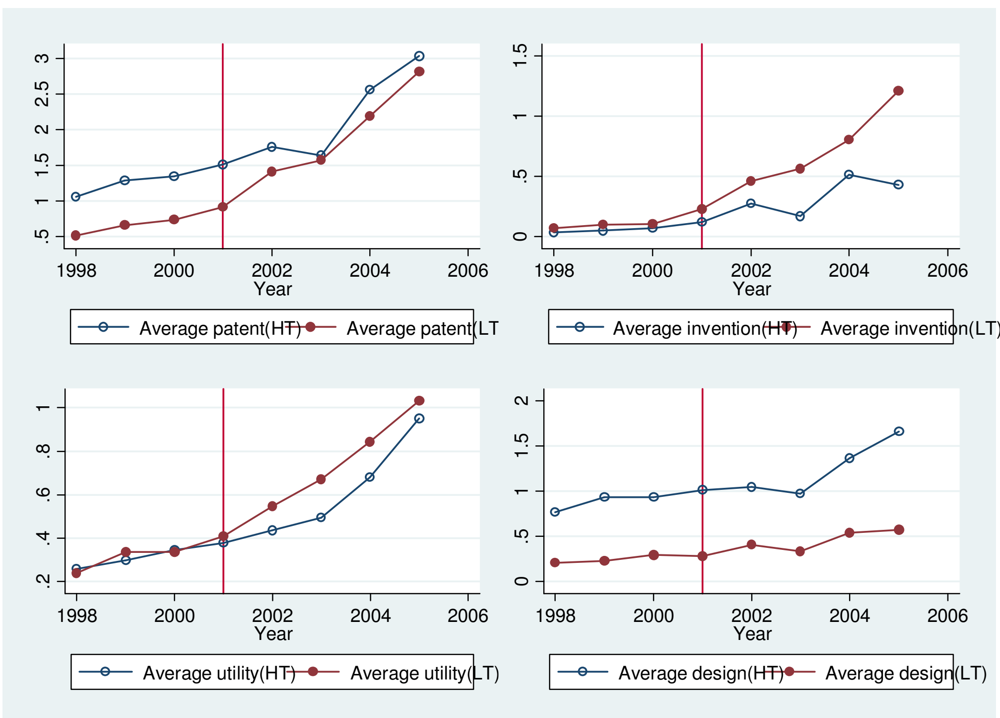

Figure 3b, Number per Firm

Table 1, Summary statistics of patent filings in Chinese 2-digit industries

SIC	Industry	Total				Average				Ratio of Innovative Firms
		Patent	Invention	Utility	Design	Patent	Invention	Utility	Design	
13	Food Processing	1462	298	88	1076	0.0168	0.0034	0.0010	0.0124	0.0068
14	Food Production	6207	316	156	5735	0.1752	0.0089	0.0044	0.1619	0.0341
15	Beverage	3877	166	103	3608	0.1642	0.0070	0.0044	0.1528	0.0352
17	Textile	3517	321	603	2593	0.0298	0.0027	0.0051	0.0219	0.0049
18	Garments	1327	70	130	1127	0.0196	0.0010	0.0019	0.0167	0.0025
19	Leather	867	19	145	703	0.0262	0.0006	0.0044	0.0213	0.0041
20	Timber	682	56	222	404	0.0255	0.0021	0.0083	0.0151	0.0070
21	Furniture	1772	11	274	1487	0.1174	0.0007	0.0182	0.0985	0.0168
22	Papermaking	920	142	295	483	0.0215	0.0033	0.0069	0.0113	0.0074
23	Print and Record Medium Reproduction	580	111	248	221	0.0199	0.0038	0.0085	0.0076	0.0072
24	Stationery, Educational and Sporting Goods	5218	98	1150	3970	0.2875	0.0054	0.0634	0.2188	0.0378
25	Petroleum Processing	494	320	99	75	0.0491	0.0318	0.0098	0.0074	0.0132
26	Raw Chemical	7126	2595	720	3811	0.0811	0.0295	0.0082	0.0434	0.0210
27	Medical	5734	2922	363	2449	0.2431	0.1239	0.0154	0.1038	0.0739
28	Chemical Fibre	315	164	140	11	0.0444	0.0231	0.0197	0.0016	0.0135
29	Rubber	853	124	406	323	0.0518	0.0075	0.0247	0.0196	0.0199
30	Plastic	3791	344	1261	2186	0.0602	0.0055	0.0200	0.0347	0.0176
31	Nonmetal Products	5604	672	1120	3812	0.0454	0.0054	0.0091	0.0309	0.0096
32	Pressing Ferrous	2904	884	1877	143	0.0865	0.0263	0.0559	0.0043	0.0113
33	Pressing of Nonferrous	1671	595	510	566	0.0648	0.0231	0.0198	0.0220	0.0162
34	Metal Products	6398	445	2688	3265	0.0975	0.0068	0.0409	0.0497	0.0243
35	Ordinary Machinery	10487	1213	6779	2495	0.1054	0.0122	0.0681	0.0251	0.0315
36	Special Equipment	10232	1208	7149	1875	0.1786	0.0211	0.1248	0.0327	0.0546
37	Transport Equipment	10707	765	4813	5129	0.1730	0.0124	0.0778	0.0829	0.0352
39	Electric Machinery	26267	5211	10251	10805	0.3245	0.0644	0.1266	0.1335	0.0471
40	Electric Equipment	30793	17088	7515	6190	0.6887	0.3822	0.1681	0.1384	0.0571
41	Electronic and Telecom	4565	476	2207	1882	0.2481	0.0259	0.1199	0.1023	0.0729

42	Instruments	2736	65	410	2261	0.0962	0.0023	0.0144	0.0795	0.0124
43	Other Manufacturing	26	24	2	0	0.0293	0.0271	0.0023	0.0000	0.0079

Table 2, Main Results

	(1)	(2)	(3)	(4)	(5)
Tariff2001*Post2002	-0.0287***	-0.0287***	-0.0202**	-0.0175*	-0.0204**
	(0.0089)	(0.0090)	(0.0093)	(0.0092)	(0.0096)
SOE share					-0.0142
					(0.0129)
FDI (ln)					0.0070***
					(0.0019)
Controls					
Year Dummy	X	X	X	X	X
Firm Dummy	X	X	X	X	X
Firm Characteristics		X	X	X	X
Time Polynomial Interactions with					
Output Share of Domestic Firms in 2001			X	X	X
Output Growth Rate 1998-2001			X	X	X
Value-added/Output in 2001				X	X
Capital-Labor Ratio in 2001				X	X
Total Employment in 2001				X	X
Employment Growth Rate 1998-2001				X	X
Observations	1,339,899	1,323,179	1,317,686	1,317,686	1,317,501
R-squared	0.5395	0.5408	0.5415	0.5416	0.5417

Note: Standard errors, clustered at the firm level, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3, Different Types of Innovation

Specification	(1) Invention	(2) Utility Model	(3) Design
Tariff2001*Post2002	-0.0196***	-0.0132**	0.150**
	(0.0037)	(0.0056)	(0.0075)
Year Dummy	X	X	X
Firm Dummy	X	X	X
Firm Characteristics	X	X	X
SOE share and FDI (ln)	X	X	X
Observations	1,317,501	1,317,501	1,317,501
R-squared	0.5131	0.5156	0.5115

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1

Table 4, Checks on the Identifying Assumption

Specification	(1) Industry linear trend	(2) Next year	(3) Pre-WTO	(4) Processing traders	(5) Flexible
Tariff2001*Post2002	-0.0222**	-0.0200*		-0.0713	
	(0.0107)	(0.0108)		(0.0855)	
Tariff2001*Next Year		0.0010			
		(0.0092)			
Tariff rate			0.0164		
			(0.0181)		
Tariff2001*Year1999					0.0006
					(0.0088)
Tariff2001*Year2000					0.0076
					(0.0100)
Tariff2001*Year2001					0.0040
					(0.0109)
Tariff2001*Year2002					-0.0079
					(0.0121)
Tariff2001*Year2003					-0.0219*
					(0.0132)
Tariff2001*Year2004					-0.0128
					(0.0156)
Tariff2001*Year2005					-0.0379**
					(0.0164)
Year Dummy	X	X	X	X	X
Firm Dummy	X	X	X	X	X
Firm Characteristics	X	X	X	X	X
SOE share and FDI (ln)	X	X	X	X	X
Industry time trend	X				
Observations	1,317,501	1,317,501	520,032	38,620	1,317,501
R-squared	0.5419	0.5417	0.6116	0.6672	0.5418

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1

Table 5, Other Robustness Checks

Specification	(1) 4-digit industry	(2) Number of products	(3) 2-digit industry	(4) Single industry	(5) New product share	(6) Two periods
Tariff2001*Post2002	-0.0136	-0.0227**	-0.0740***	-0.0159	-0.0016	-0.0367***
	(0.0100)	(0.0111)	(0.0150)	(0.0098)	(0.0049)	(0.0115)
Tariff2001*Post2002*ProdNum2001		0.0001				
		(0.0001)				
Post2002*ProdNum2001		-0.0021				
		(0.0019)				
Year Dummy	X	X	X	X	X	X
Firm Dummy	X	X	X	X	X	X
Firm Characteristics	X	X	X	X	X	X
SOE share and FDI (ln)	X	X	X	X	X	X
Observations	1,280,600	1,315,729	1,280,600	1,215,228	1,075,270	630,230
R-squared	0.5442	0.5418	0.5442	0.5372	0.7815	0.7801

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1

Table 6, Underlying Mechanism

Specification	(1) Import	(2) Total	(3) Total	(4) Invention	(5) Utility model	(6) Design
Tariff2001*Post2002	0.0205***	-0.0205**				
	(0.0000)	(0.0095)				
Exports (ln)		0.0008				
		(0.0015)				
Stock of Patents (ln)			0.0010***	0.0002**	0.0003**	0.0006***
			(0.0002)	(0.0001)	(0.0001)	(0.0001)
Year Dummy	X	X	X	X	X	X
Product/Firm Dummy	X	X	X	X	X	X
Firm Characteristics		X	X	X	X	X
SOE share and FDI (ln)		X	X	X	X	X
Observations	35,252	1,317,489	1,328,192	1,328,192	1,328,192	1,328,192
R-squared		0.5417	0.0027	0.0030	0.0022	0.0006

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions except column (1). *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 1, Determinants of Tariff Rates in 2001

	(1)	(2)	(3)	(4)	(5)
D.V.			Tariff2001		
Employment2001 (ln)	0.0056	0.0061	0.0034	0.0021	0.0034
	(0.0059)	(0.0059)	(0.0062)	(0.0062)	(0.0064)
Domestic output share2001	-0.0740*	-0.0868**	-0.1129**	-0.0832	-0.0878*
	(0.0410)	(0.0414)	(0.0476)	(0.0514)	(0.0517)
Value added ratio2001		0.0270	0.0127	-0.0170	-0.0098
		(0.1925)	(0.1881)	(0.1883)	(0.1887)
Capital-labor ratio2001		-0.0333**	-0.0117	-0.0137	-0.0140
		(0.0156)	(0.0179)	(0.0179)	(0.0179)
Growth of employment1998-2001			0.0280	0.0530	0.0554
			(0.1498)	(0.1501)	(0.1502)
Growth of output1998-2001			-0.3841**	-0.4133***	-0.3953**
			(0.1552)	(0.1557)	(0.1572)
Average patents per firm2001				0.0747	0.0810
				(0.0496)	(0.0501)
Growth of patents1998-2001					-0.0069
					(0.0079)
Observations	156	156	153	153	153

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 2.1, Checks on the Identifying Assumption for Invention

	(1)	(2)	(3)	(4)	(5)
VARIABLES			Invention		
Tariff2001*Post2002	-0.0246***	-0.0196***		-0.0020	
	(0.0043)	(0.0041)		(0.0258)	
Tariff2001*Next Year		0.0000			
		(0.0031)			
Tariff rate			-0.0014		
			(0.0043)		
Tariff2001*Year1999					0.0072**
					(0.0030)
Tariff2001*Year2000					0.0057*
					(0.0034)
Tariff2001*Year2001					0.0043
					(0.0037)
Tariff2001*Year2002					-0.0049
					(0.0044)
Tariff2001*Year2003					-0.0185***
					(0.0051)
Tariff2001*Year2004					-0.0205***
					(0.0061)
Tariff2001*Year2005					-0.0316***
					(0.0066)
Year Dummy	X	X	X	X	X
Firm Dummy	X	X	X	X	X
Firm Characteristics	X	X	X	X	X
SOE share and FDI (ln)	X	X	X	X	X
Industry time trend	X				
Observations	1,317,491	1,317,491	520,031	38,620	1,317,501
R-squared	0.5133	0.5131	0.5422	0.6708	0.5131

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 2.2, Checks on the Identifying Assumption for Utility Model

	(1)	(2)	(3)	(4)	(5)
VARIABLES			Utility model		
Tariff2001*Post2002	-0.0124**	-0.0152**		-0.0041	
	(0.0062)	(0.0064)		(0.0507)	
Tariff2001*Next Year		-0.0056			
		(0.0050)			
Tariff rate			0.0109		
			(0.0115)		
Tariff2001*Year1999					-0.0067
					(0.0050)
Tariff2001*Year2000					-0.0027
					(0.0055)
Tariff2001*Year2001					-0.0083
					(0.0063)
Tariff2001*Year2002					-0.0150**
					(0.0070)
Tariff2001*Year2003					-0.0201**
					(0.0080)
Tariff2001*Year2004					-0.0154
					(0.0094)
Tariff2001*Year2005					-0.0227**
					(0.0103)
Year Dummy	X	X	X	X	X
Firm Dummy	X	X	X	X	X
Firm Characteristics	X	X	X	X	X
SOE share and FDI (ln)	X	X	X	X	X
Industry time trend	X				
Observations	1,317,491	1,317,491	520,031	38,620	1,317,501
R-squared	0.5157	0.5156	0.5764	0.6521	0.5156

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 2.3, Checks on the Identifying Assumption for Design

	(1)	(2)	(3)	(4)	(5)
VARIABLES			Design		
Tariff2001*Post2002	0.0186**	0.0163*		-0.0640	
	(0.0084)	(0.0084)		(0.0681)	
Tariff2001*Next Year		0.0037			
		(0.0076)			
Tariff rate			0.0077		
			(0.0144)		
Tariff2001*Year1999					-0.0019
					(0.0072)
Tariff2001*Year2000					0.0027
					(0.0082)
Tariff2001*Year2001					0.0038
					(0.0087)
Tariff2001*Year2002					0.0114
					(0.0097)
Tariff2001*Year2003					0.0170*
					(0.0103)
Tariff2001*Year2004					0.0251**
					(0.0122)
Tariff2001*Year2005					0.0180
					(0.0128)
Year Dummy	X	X	X	X	X
Firm Dummy	X	X	X	X	X
Firm Characteristics	X	X	X	X	X
SOE share and FDI (ln)	X	X	X	X	X
Industry time trend	X				
Observations	1,317,491	1,317,491	520,031	38,620	1,317,501
R-squared	0.5115	0.5113	0.6121	0.6159	0.5115

Note: Standard errors, clustered at the firm level, are in parentheses. All Time Polynomial Interaction terms are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 3, Other Robustness Checks for the Three Patent Types

Specification	4-digit industry	Number of products	2-digit industry	Single industry	Two periods
	(1)	(2)	(3)	(4)	(5)
Patent type			Invention		
tariff01post02	-0.0129***	-0.0213***	-0.0403***	-0.0158***	-0.0235***
	(0.0038)	(0.0045)	(0.0061)	(0.0037)	(0.0045)
t01post02num		0.0000			
		(0.0001)			
post02num		-0.0001			
		(0.0014)			
Observations	1,280,600	1,315,729	1,280,600	1,215,228	630,230
R-squared	0.5156	0.5133	0.5156	0.5112	0.7699
	(6)	(7)	(8)	(9)	(10)
Patent type			Utility Model		
tariff01post02	-0.0057	-0.0165***	-0.0280***	-0.0089	-0.0201***
	(0.0058)	(0.0058)	(0.0066)	(0.0059)	(0.0070)
t01post02num		0.0001			
		(0.0001)			
post02num		-0.0034***			
		(0.0010)			
Observations	1,280,600	1,315,729	1,280,600	1,215,228	630,230
R-squared	0.5176	0.5156	0.5176	0.5098	0.7607
	(11)	(12)	(13)	(14)	(15)
Patent type			Design		
tariff01post02	0.0142*	0.0165*	-0.0174	0.0117	0.0036
	(0.0083)	(0.0091)	(0.0126)	(0.0077)	(0.0088)
t01post02num		-0.0000			
		(0.0001)			
post02num		0.0001			
		(0.0010)			
Observations	1,280,600	1,315,729	1,280,600	1,215,228	630,230
R-squared	0.5144	0.5115	0.5144	0.5071	0.7683

Note: In all regressions we include Year Dummies, Firm Dummies, Firm Characteristics, SOE share and FDI (ln), and all Time Polynomial Interactions terms. Standard errors, clustered at the firm level, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1