Import Competition and Innovation: Evidence from China*

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Abstract

Does foreign competition encourage innovation? This question has received renewed attention recently in two prominent papers by Autor, Dorn, Hanson, Pisano and Shu (2016) and Bloom, Draca and Van Reenen (2016), which come to different conclusions. We contribute to this area of research by exploring the link between innovation and import competition in China, a country that during the period we study (2000-2007) saw both a rapid increase in patenting and a lowering of import barriers due to accession to the WTO. Combining manufacturing firm survey data with customs and patent data, we find that import competition encouraged innovation, but only for the most productive firms. Those top firms saw an increase in patenting probability 3.6 - 4% for every percentage point drop in import tariffs. The result is quantitatively similar whether we use a sector-wide tariff on output or a weighted tariff at the firm level as a measure of import competition. Consistent with the main finding, top firms also feature increased R&D expenditures and an increase in market shares following import liberalization. In addition, we find that in the face of more competition, top firms not only strengthen their core technology, but also enlarge the scope of their patent portfolio. We rationalize the empirical findings with a model of step-by-step innovation à la Aghion et al. (2009) where import competition generally discourages innovation by reducing sector-wide profits, but encourages firms close to the technological frontier to escape competition by increasing investments in R&D.

Keywords: China, Import competition, Innovation, Heterogeneous firms.

JEL Codes: F12, F14, O31.

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1 Introduction

The link between innovation and prosperity is not only at the heart of a large literature on endogenous growth, but also the target of much attention by policymakers. A recent paper by Akcigit et al. (2017) documents a long-run relationship between innovation and growth in the United States. This broad consensus on the value of innovation stands in contrast with the disagreement on what are its main drivers. We focus on a question that has proven particularly difficult to settle, that is the link between competition, in particular import competition, and innovation. In fact, despite recent evidence on the effect of trade on innovation in several developed countries (Aghion et al., 2017; Autor et al., 2016; Bloom et al., 2016), no clear consensus has emerged on whether import competition encourages or discourages innovation. This paper contributes to this discussion by analyzing firm level evidence from China. We ask the following questions: what is the impact of import competition on Chinese firm's capacity to innovate? And what firms are affected the most?

China serves as an interesting case to study the relationship between import competition and innovation because it experienced both a rapid growth in patenting and intensified foreign competition after its accession to the WTO in December 2001. From 2001 to 2007, invention patents filed in the State Intellectual Property Office (SIPO) of China grew at an average annual rate of 25 percent, comparing to 6 percent in the US patent office (USPTO). In 2007, the number of total patents filed in SIPO has reached 53 percent that of the USPTO. During this post-WTO period, China experienced large drop in import tariff barriers and other kinds of local protections mandated by WTO, which significantly increased presence of foreign competition. The effectively applied tariff dropped by 6.2 percentage points, from 0.166 to 0.104. Total import quadrupled from 243.5 billion USD in 2001 to 956.1 billion USD in 2007. We exploit the variation in the import tariff decreases across industry and over time to identify the shock to import competition on firms. It is worth noting that, even though China's first application to the GATT dates to 1986, the schedule of tariff changes was not known until September 2001. The negotiation took 18 meetings between 1996 and 2001 and was characterized by Vice Minister LONG Yongtu, Head of the Chinese Delegation in his Statement on Sep 17, 2001: "The complexity and difficulty of this process are beyond the imagination of almost everybody." It is unlikely that anybody knew the timing and extent of tariff cuts and much less the impact of those tariff custs on imports.

More specifically, we draw on the Chinese Annual Survey of Manufacturing firms and match it to the patent and customs data. The matched firms account for over two thirds of total patents filed by Chinese enterprise assignees during 2001-2007. We estimate the elasticity of firm patent application on two-period lagged industry output tariff through a Poisson count data model, controlling for industry fixed effects and time trends. Output tariff is measured as the average import tariff faced by products that the industry (firm) produces. The idea is that, when the import tariff decreases, there are more competing foreign goods (final or intermediates) in the domestic market. Thus a decrease in the import tariff proxies for an increase in total import of the industry. Moreover, we use the WTO accession tariff that is scheduled at the time of China's WTO entry, instead of using the actually applied tariff for each year. In this way, we try to minimize the concern that concurrent tariff may be affected by industry lobbying that is correlated with productivity or innovation, our outcome variable. We find that for firms above the 75 percentile in terms of productivity, a one percentage point decrease in output tariff could induce 3.6 - 4 percent increase in patenting. This increase is due to both strengthening firms' core technology, and enlarging the technology scope.

There are several challenges in our measurement and identification of the problem at hand. First, we measure innovation with patent applications in SIPO. Of course, patent application is not the only output of innovation. Many innovative activities such as improvement in management or business model is not patentable, and firms may prefer to keep some new formula secrecy[1]. However, survey evidence shows that all outputs of innovation are positively correlated (Hall et al., 2014; Moser, 2013), and comparing to productivity, patenting is a more direct and precise way of measuring technology progress at the firm level (Griliches, 1990; Nagaoka et al., 2010). Therefore, we use patent application count as our benchmark measure of innovation, and maintain the assumption that patent count is a sufficient statistic in measuring firm innovation.

Another concern is that the measured increase in patenting is totally driven by the change in the propensity to patent. For example, studies have shown that stronger IP protection due to entrance into the WTO would boost domestic patent filing, and the patent system may shift firms' innovation effort from unpatentable to patentable products (Qian, 2007; Arora et al., 2015).

[1] Hall et al. (2014) reviewed the literature on choice between formal IP and secrecy. They concluded that although the choice is made strategically and is affected by various industry and market characteristics, empirical evidence shows that secrecy and IP are usually complements. And the choices within formal IP — patent, trademark and copyrights — are used as complements as well.

There definitely exist nation-wide trends in IP protection and propensity to patent in China. The question is whether the propensity to patent due to IP protection has differentially affected sectors that experienced different degrees of import liberalization. Because we show, similarly to Brandt et al. (2017), that tariff cuts are unrelated to observable pre-trends like productivity growth, we do not find the conditions for our regressions to pick up this type of spurious correlation. Furthermore, if patenting propensity differentially changes by aggregate sectors, our sector-time dummies will absorb different trends in industry patenting propensity. Another concern is that some firms may file multiple patents for the same technology to form a strategic portfolio. If firms become more strategic due to competition, our estimate will be upward biased. We check for the specification with patent dummy, instead of patent counts, as our dependent variable, and our results remain.

To reconcile our empirical findings with the theory, there are several existing frameworks that we can take off the shelf. First, there is the “trapped factor” theory used to explain findings in Bloom et al. (2016), who find that European firms increased investment in technology after Chinese imports increased. The basic idea is that the increased low-tech import lowers the opportunity cost of firms to switch technology, and frees up the labor that was initially trapped in low-tech tasks, so that they can now engage in research and development. This story is unlikely to be suitable to our case as China is still a developing country and its labor force in manufacturing is not well educated. The second possible theoretical framework is the monopolistic competition structure that is widely used in the trade literature. In these models, especially model with Constant Elasticity of Substitution (CES) demand system, the negative price effect tends to be very big, therefore, without any market size effect, it is hard to generate pro-innovation incentives after competition intensifies. The third strand of literature is the series of papers by Aghion and co-authors that explore the “escape competition” effect. This family of models emphasizes the distinction between pre- and post- innovation returns. While these models adopt a stylized framework with either duopolies or monopolies,[2] we explore how robust their insights are in a more general model of monopolistic competition.

Therefore, we combine the features of the monopolistic competition as in Melitz and Ottaviano (2008) and the step-by-step innovation as in Aghion et al. (2009) to generate a model with heterogeneous firms and escape competition effect at the top. On the one hand, from the monopo-

[2] See for example Aghion et al. (2009), and also the IO literature surveyed in Gilbert (2006)

listic competition framework, there is a “price index effect” that will discourage innovation for all firms. On the other hand, the opportunity of innovating and retaining the market from the foreign competitors generate incentives for top firms to innovate more.

Our paper is related to several strands of literature. First, it is related to the studies about China’s gains from accessing the WTO. In addition to the usual gains from trade such as selection through exports, or access to more imported varieties, evidence has shown that accessing the WTO helped correct resource misallocation and accelerated the market reforms that is sometimes difficult to implement within political constraints (Khandelwal et al., 2013; Lu and Yu, 2015). In a recent and very related paper, Brandt et al. (2017) studied the effect of lowering import tariffs on industry average productivity and mark-up. They find that when import competition intensifies, there is a decrease in output price level and mark-up, and an increase in aggregate productivity. While confirming their findings, we go one step further to study the innovation channel of productivity increase, among other potential channels such as purchasing new machines.

The second strand of literature looks at channels through which trade could impact firm’s capacity to innovate. On the one hand, getting access to bigger markets due to export liberalization has been found to induce firms to switch to skill intensive technology (Bustos, 2011), increase R&D spending (Aw et al., 2011) and engage in more innovation (Aghion et al., 2017; Trefler and Yu, 2017). On the other hand, import liberalization could enable access to better imported inputs, which helps to enhance knowledge diffusion (MacGarvie, 2006), complement R&D spending (Bøler et al., 2015), and induce quality upgrading (Fieler et al., 2016).[3] We focus on the specific channel of import competition brought by trade liberalization, while controlling for other channels, i.e. accessing the export market and better intermediate inputs.

We also contribute to the theory on trade and innovation in a heterogeneous firm framework. Conclusions usually differ because of different assumptions or targeted data moments. An earlier contribution is Atkeson and Burstein (2010). Under the assumption of zero spillover or diffusion, they find theoretically that there is little dynamic gains from trade by allowing firms to innovate. Perla et al. (2015) could generate dynamic gains from trade, while the prediction on the heterogeneous effect among firms is contrary to ours: only firms at the productivity cutoff would find it optimal to innovate. Three recent work in progress that is closely related to our model are Aghion

[3] See also Teshima (2008)

et al. (2017), Akcigit et al. (2017) and Lim et al. (2017). Aghion et al. (2017) also builds on the framework of Melitz and Ottaviano (2008), but focus on the effect of exporting. Consistent with us, they also find a negative effect of competition on the price index which would discourage innovation among firms away from the technology frontier. In Akcigit et al. (2017), importing happens in sectors the home country is very lagged behind, therefore, only firms at the middle-lower part of the productivity distribution would react to import competition. In contrast, we model foreign entry to be more technological advanced, which is more consistent with the data in China. Lim et al. (2017) build a dynamic model where firms have to move up a quality ladder and endogenously choose to upgrade or not. Their framework could also generate an escape-competition effect in face of trade liberalization.

Our paper is also related to the literature that explores the reason behind the rapid increase in patenting in China after 2000. The most studied causes are increased investment in R&D (Wei et al., 2017; Hu et al., 2005; Hu and Jefferson, 2009), improvement in Intellectual Property Right (IPR) protection (Ang et al., 2014), ownership reforms, government's pro-patenting policies, and FDI. Fang et al. (2017) found that privatization of state-owned firms motivate more patenting, especially in prefectures with higher IPR protection. Shifts in demographic structure also affects patenting behavior in China. Xie and Zhang (2015) find that rising wages have propelled labor-intensive sectors to become more innovative, and firms in female-intensive industries have exhibited more innovations than those in male-intensive industries. While we focus on the effect of import competition and market structure, we take into consideration these other forces through controlling for region and ownership characteristics.

The remainder of the paper is organized as follows: Section 2 shows our theoretical framework and the escape-competition mechanism. Section 3 describes the data and summary statistics. Section 4 shows our empirical framework, and section 5 discusses the empirical results. Section 6 concludes.

2 Theoretical framework

We build a model of monopolistic competition where domestic producers compete in the home market (China) with other domestic firms. Let us consider a model with a home country (China) and a foreign country (the rest of the world).

2.1 Market structure

There is a finite number, N, of varieties in a sector indexed by i, and a homogeneous good which we also use as numeraire. To simplify notation we also assume that $L = 1$ since population size will not play any role in our analysis. The consumer utility function follows the linear demand literature as in Ottaviano et al. (2002) and Melitz and Ottaviano (2008),

$$U = q_0 + \alpha \sum_{i=1}^{N} q_i di - \frac{1}{2}\gamma \sum_{i=1}^{N} (q_i)^2 \, di - \frac{1}{2}\eta \left(\sum_{i}^{N} q_i \right)^2 \tag{1}$$

where q_0 and q_i denote the individual consumption of, respectively, the numeraire good and differentiated good i. The parameters α and η index the relative importance of the differentiated good over the numeraire. The parameter γ governs the degree of substitutability between the differentiated varieties. Following Melitz and Ottaviano (2008), the quantity demanded for each variety can be expressed as a function of the average price and the price of the variety p_i:

$$q_i = \frac{\alpha}{\eta + \gamma} - \frac{1}{\gamma} p_i + \frac{\eta}{\eta + \gamma} \frac{1}{\gamma} \bar{p}$$

Differently from Melitz and Ottaviano (2008) we fix the number of varieties and do not allow for free entry. We assume that for each variety there is one domestic firm and one foreign firm and that they compete in a Bertrand fashion. This is a similar setup to Bernard et al. (2003). The domestic firm has unit cost c_i while the foreign firm has cost c_i^* , which includes an iceberg transport cost $d > 1$ so that d units have to be shipped for one unit to arrive. The firm cost parameter c_i follows a distribution $F(c)$ in the home country, while c_i^* is distributed according to $F^*(c)$ in the foreign country.

The presence of foreign firms intensifies competition in three ways. First, if a foreign firm is more productive than the domestic firm, the domestic firm will be priced out of the market. Second, even if a foreign firm is not as productive as the domestic firm, it could force the domestic firm to engage in limit pricing instead of charging the unconstrained monopolistic markup. Third, there is a general effect of foreign entry on the average price in the market.

When not ambiguous, we drop the subscript i. The unconstrained profit-maximizing price p_i and markup m_i (defined here as price minus marginal cost) are given by the following linear functions of the average price $\bar{p}$, and the firm cost c_i:

$$\begin{aligned} p = & \quad \rho + \mu\bar{p} + \frac{c}{2} \\ \overline{m} = & \quad \rho + \mu\bar{p} - \frac{c}{2} \end{aligned} \tag{2}$$

where we defined $\rho = \frac{\alpha\gamma}{2(\eta+\gamma)}$, and $\mu = \frac{\eta}{2(\eta+\gamma)}$. When unconstrained by its direct competitor, profits for firm i take the following quadratic form:

$$\pi(c, \bar{p}) = \frac{1}{4\gamma}(2\rho + 2\mu\bar{p} - c)^2 \tag{3}$$

Under the threat of foreign entry, the domestic firm cannot charge a price higher than the cost of the foreign firm, therefore the markup is either the unconstrained one, $\bar{m}_i$ or the difference between the foreign firm's cost and the firm's own cost:

$$m = \min\{\bar{m}, c^* - c\}.$$

Although there is a potential number of N firms, some may decide not to operate if their cost is too high. We denote like Melitz and Ottaviano (2008) by c_D the highest cost compatible with non-negative profits. Given the average price $\bar{p}$, the cutoff cost c_D, price, quantity and profit can be rewritten as:

$$\begin{aligned} c_D &= 2\rho + 2\mu\bar{p} \\ \bar{m} &= \frac{c_D - c}{2} \\ p &= c + m \\ q &= \frac{1}{\gamma}(c_D - c - m) \\ \pi(c, m) &= \frac{1}{\gamma}m(c_D - c - m) \end{aligned}$$

We next describe the innovation decision of the firm.

2.2 Firm innovation decisions

We assume that the cost of innovation is quadratic in the probability of success, that is a firm pays $C(I) = \frac{1}{2\phi} I^2$ to achieve a probability$I$ of improving its productivity by a fixed step size Δ.[4] The firm's expected return is then equal to:

$$\Pi(I, c) \quad = \quad I \cdot \mathbb{E}\pi(\Delta c) + (1 - I) \cdot \mathbb{E}\pi(c)$$

The first order derivative for the firm problem delivers an optimal level of investment that is proportional to the expected increase in profits due to the cost improvement:$I(c) = \phi(\mathbb{E}\pi(\Delta c) - \mathbb{E}\pi(c))$. Indicating by $\pi(c, m)$ the profit for firms with cost c and markup m we can rewrite the investment as follows:

$$\begin{aligned}\frac{I(c)}{\phi} \quad = \quad & \int_{\Delta c}^{\Delta c + \bar{m}(\Delta c)} \pi(\Delta c, c^* - \Delta c)\, dF(c^*) + \int_{\Delta c + \bar{m}(\Delta c)}^{c_D} \pi(\Delta c, \bar{m})\, dF(c^*) \\ & - \int_{c}^{c + \bar{m}(c)} \pi(c, c^* - c)\, dF(c^*) - \int_{c + \bar{m}(c)}^{c_D} \pi(c, \bar{m})\, dF(c^*)\end{aligned}$$

In order to write the profit for firm of productivity c we have to distinguish different cases.

i) Profits are equal to $\pi(\Delta c, c^* - \Delta c)$ if the home firm successfully innovates and the foreign firm's cost is low enough to force the domestic firm to engage in limit pricing

ii) Profits are equal to $\pi(\Delta c, \bar{m})$ if the home firm innovates and the foreign firm is not productive enough to affect pricing

iii) Profits are equal to $\pi(c, c^* - c)$ if the home firm does not innovate and the foreign firm is productive enough to induce limit pricing

iv) Profits are equal to $\pi(c, \bar{m})$ if the home firm does not innovate, but can charge the unconstrained markup

[4] The fixed step size is an assumption common to the literature, e.g. Aghion et al. (2001) and Aghion et al. (2009) but can be micro founded easily by assuming that the firm draws from the cost distribution conditional on the cost being below its current one. Under common productivity distributions like Pareto this in expectation leads to an average step that is a constant.

v) Profits are equal to zero if the foreign is more productive than either Δc (if the home firm innovates) or c (if the home firm does not innovate)

Replacing profits with their expressions, we find the following expression for the value of investment:

$$\begin{aligned}\frac{I(c)}{\phi} = {} & \frac{1}{\gamma}\int_{\Delta c}^{\Delta c+\bar{m}(\Delta c)} (c^* - \Delta c)(c_D - c^*)\,dF(c^*) + \frac{1}{4\gamma}\int_{\Delta c+\bar{m}(\Delta c)}^{c_D} (c_D - c)^2\,dF(c^*) \\ & -\frac{1}{\gamma}\int_{c}^{c+\bar{m}(c)} (c^* - c)(c_D - c^*)\,dF(c^*) - \frac{1}{4\gamma}\int_{c+\bar{m}(c)}^{c_D} (c_D - c)^2\,dF(c^*)\end{aligned}$$

The difference in profits due to innovation is depicted in figure 1. The figure is drawn against possible values of the Foreign cost c^* given Home cost c. The expected profit gain from innovation can be derived by aggregating the red line over the distribution of c^*. Given cost cutoff c_D, the expected profit gain from innovation is the highest when foreign firms enter more where the gain in profit is the most, that is, around the Home cost c.

2.3 The price index

So far we have expressed the innovation decision as a function of the average price $\bar{p}$. To derive the average price we first express the expected price for a good that was initially produced by domestic firm with cost c:

$$\bar{P} \equiv E(p|c) = I(c)\,p_1(c) + (1 - I(c))\,p_0(c)$$

where $p_1(c)$ and $p_0(c)$ are defined as follows:

$$\begin{aligned}p_1(c) = {} & \Lambda\left(\Delta c > \frac{1}{2}c_D\right)\int_0^{c_D-2(c_D-\Delta c)} \frac{c_D + c^*}{2}dF(c^*) \\ & + \int_{\max\{0,c_D-2(c_D-\Delta c)\}}^{\Delta c} \Delta c\,dF(c^*) + \int_{\Delta c}^{\bar{m}(\Delta c)+\Delta c} c^*dF(c^*) + \int_{\bar{m}+\Delta c}^{c_D} \frac{c_D + \Delta c}{2}dF(c^*) \\ p_0(c) = {} & \Lambda\left(c > \frac{1}{2}c_D\right)\int_0^{c_D-2(c_D-c)} \frac{c_D + c^*}{2}dF(c^*) \\ & + \int_{\max\{0,c_D-2(c_D-c)\}}^{c} c\,dF(c^*) + \int_{c}^{\bar{m}(c)+c} c^*dF(c^*) + \int_{\bar{m}+c}^{c_D} \frac{c_D + c}{2}dF(c^*)\end{aligned}$$

where $\Lambda()$ is an indicator function. Whether the firm successfully innovates or not, there are four possible cases for the final price of a good. In the first case, the foreign cost is significantly lower than the domestic one, so that the foreign firm can charge a monopoly price. In the second case, the foreign cost is lower than the domestic, but not sufficiently low, so the foreigner firm has to do limit pricing and charge the domestic firm's cost. In the third case, the foreign firm has slightly higher cost than the domestic firm and the domestic firm has to do limit pricing. In the fourth case, the foreign firm is so unproductive that the domestic firm can still charge the monopoly price. The four cases for given c_D and the average price are illustrated in figure 2. For illustration purposes, we make the assumption that $\Delta c > \frac{1}{2}c_D$, i.e. $c > \frac{c_D}{2\Delta}$. This ensures the existence of case one. In other words, if the domestic cost is low enough, foreign firms could never come in and charge the monopoly price.

2.4 Simulation

For our numerical simulation we assume that productivity in both countries follows a Fréchet distribution, i.e. $Z = \frac{1}{c}$

$$\text{Prob}\left(Z < z\right) = e^{-Tz^{-\theta}}$$

so that the domestic and foreign costs $c = \frac{1}{z}$ and $c^* = \frac{d}{z^*}$ distribute as Weibull. We adopt the following parameters for the simulation.

Parameter	Value	Parameter	Value
θ	5	μ	0.1
T	4	ρ	1
T^*	10	Δ	0.5
d_0	1.6	d_1	1.1

The steps for the simulation are as follows:

1. Simulate 1000 domestic and 1000 foreign firms according to the distribution parameters θ, T, T^* and the iceberg cost d.

2. Solve for the optimal price and investment decision for an initial guess of the cutoff cost c_D. We set it to the maximum value of the Home cost distribution draws;

3. Construct the average price and the new cutoff production cost based on the pricing and innovation decisions in step 2;

4. Iterate on steps 2 and 3 until individual pricing decisions and the average price are mutually consistent.

We compute this equilibrium under two levels of trade costs: an initial d_0 and a lower d_1. Figure 3 shows how effective foreign costs decrease with a decrease in the transport cost.

Figure 4 shows how, when the iceberg cost decreases, the top firms increase innovation, while the bottom firms do not. This is the escape-competition effect as in Aghion et al. (2009): only the most productive firms have a sufficiently high probability of surviving the increase in foreign competition, so for those firms the overall decline in profits due to entry of potentially more productive firms firms is dwarfed by this incentive to innovate that would not have been present in the absence of foreign competition. Having illustrated how this prediction can emerge even in a model that is more general and rich than the stylized version in Aghion et al. (2009), we proceed to show how this prediction is borne out in the context of import liberalization during China's accession to the WTO.

3 Data

3.1 International trade

Industry level

Our baseline measure of import competition uses the average import tariff China imposes on the products of each four-digit industry. The import tariff information is obtained from China's WTO accession document, which specifies the tariff target for each year since 2001 for each six-digit HS product. Figure 5 plots the actually applied tariff against the bounded tariff for 2001 and 2005. In the early years, the actual tariff did not completely comply with the bounded tariff. In 2001, only 32% of the 5,085 six-digit HS products complied with the WTO bounded tariff. The compliance rate increased to 97% in 2005. Figure 6 shows the average and inter-quartile range of the WTO accession tariff and the actual tariff during 2001-2007. During this period, the average bounded tariff dropped from 0.1372 to 0.1002, and the average actual tariff dropped from 0.1588 to 0.0982. Both tariffs exhibit variation across products and time.

We map the products into the China Industrial Classification (CIC) system at the four-digit level (424 sectors), using the concordance developed in Brandt et al. (2017)[5], and take simple average[6] to arrive at the industry level output tariff. Then we take log plus one to arrive at our measure of log output tariff,

$$\tau_{st}^{\text{output}} = \ln\left(1 + \frac{1}{H_s}\sum_{p=1}^{H_s} \text{tariff}_{pt}^{\text{import}}\right). \tag{4}$$

For product p that is matched to industry s, $\text{tariff}_{pt}^{\text{import}}$ is the WTO specified import tariff for China in year t. H_s denotes the total number of six-digit HS products within industry s.

We use the accession tariff instead of the actually applied tariff, because the actual tariff may be subject to the same contemporaneous forces that affect firms' innovation incentives. While the pre-determined accession tariff is exempt from such endogeneity concerns, we require it to be also independent from any expectations in future innovation trends. We test such restriction by regressing the change in the accession tariff from 2001 onward on the change in patenting or firm productivity during 1998-2000. Table 3 shows that we cannot reject the hypothesis that the accession tariff is not correlated with pre-trend in patenting or productivity growth.

Any effect that industry output tariff have on the industry could affect other industries through the input-output linkages. If the upstream industries experienced higher competitive pressure, the downstream firms would likely to get cheaper and higher quality inputs. We capture such effect through the change in input tariff. Specifically, we define input tariff as

$$\tau_{st}^{\text{input}} = \ln\left(1 + \sum_{k} c_{sk} \text{tariff}_{kt}^{\text{output}}\right). \tag{5}$$

The input share of industry k good used in industry s, c_{sk}, is obtained from China's 2002 input-output table. The sum of c_{sk} is smaller than 1, and the other shares include non-manufacturing inputs, and labor and capital inputs. The effect of these other inputs are subsumed into the error term of our specification and is assumed to be independent from our main explanation variable:

[5] Their concordance is based on the HS-CIC concordance table constructed by the National Bureau of Statistics (NBS).

[6] There is a possible bias with trade volume weighted averages: Trade volume is negatively correlated with tariff levels. Taking weighted average will tend to give more weight to the most liberalized product lines and thus underestimate the change in effective protection and could cause an upward bias in the estimated effect of trade liberalization. To add: result using weighted tariff in the appendix.

change in trade induced competition in the manufacturing sector. The input tariff captures any competition effects transferred from import liberalization in input industries. This is what Fieler et al. (2016) call the magnifying effect in their quantitative analysis.

For the importers, the input tariff calculated in equation (5) also captures the direct effect of getting access to cheaper or better foreign inputs. Therefore, we also control for an importer dummy and the interaction between the input tariff and the dummy. A firm is defined as importer after its initial appearance in the customs importer registry.

Another channel through which trade could affect innovation is the market size effect brought by export liberalization as studied in Aghion et al. (2017) and Trefler and Yu (2017). We control for such effect through export demand shock from other countries, which is defined as

$$E_{st}^{\text{demand}} = \sum_{p,c} \frac{X_{pcs,2000}}{X_{s,2000}} \log M_{pct} \tag{6}$$

where M_{pct} denotes country c's import from the world other than China of product p at time t. After taking log, we weight the country-product demand shocks by the export share of China during year 2000. $X_{pcs,2000}$ denotes China's export of product p to country c in industry s in year 2000.[7]

Finally, we focus on year 2001-2005 because this is the period that experienced highest tariff change after the WTO accession for most products and industries.

Firm Level

In addition to the industry level measure of trade shocks, we also construct firm level trade shocks.

$$\begin{aligned}
\tau_{ist}^{\text{output}} &= \ln\left(1 + \sum_{p} \frac{X_{pi,t-1}}{\sum_{p'} X_{p'i,t-1}} \text{tariff}_{pt}^{\text{import}}\right); && (7) \\
E_{ist}^{\text{demand}} &= \ln\left(1 + \sum_{p,c} \frac{M_{pci,t-1}}{\sum_{p'c'} M_{p'c'i,t-1}} \log M_{pct}\right); && (8) \\
\tau_{ist}^{\text{input}} &= \ln\left(1 + \sum_{p} \frac{X_{pi0}}{\sum_{p'} M_{p'i,t-1}} \text{tariff}_{pt}^{\text{import}}\right). && (9)
\end{aligned}$$

[7]The definition of demand shock in equation (6) is consistent with those in Bombardini et al. (2016) and Aghion et al. (2017). An alternative measure is $E_{st}^{\text{alternative}} = \log\left(\sum_{p,c} \frac{X_{pcs,2000}}{X_{s,2000}} M_{pct}\right)$. This measure gives similar results.

where X_{pit-1} and M_{pit-1} denotes firm i's export and import in product p in the previous year, respectively. To reduce missing values, for firms that import (export) with gap years, we use the most recent year that it had imported (exported) to calculate the weight. The firm level export demand shock is constructed from the product-country level export demand faced by China, where c denotes destination countries.

3.2 Patent and other Firm-Level Data

The firm level sample of our study comes from the Annual Industrial Survey conducted by the National Bureau of Statistics (NBS) of China (Hereafter referred to as the NBS data), 1998-2007. The survey covers all state-owned firms, and private firms with annual sales larger than 5 million RMB. It has become a standard data set for studying firm level behavior in China's manufacturing sector (Brandt et al., 2012; Hsieh and Song, 2015). In addition, we match the NBS data the customs data and patent data to get firm level trade and patenting information.

We distinguish between processing and non-processing firms. A firm is defined as processing firm if during all years with available customs data (2000-2007), over 90% of its total export is through processing export. Among the firms defined as processing firms, 88% are foreign or HMT owned. On the one hand, processing trade is not subject to any import tariffs, and since most processing firms are oriented abroad, they are not likely to be subject to domestic competition either. On the other hand, fall in import tariff could affect firm's choice between ordinary and processing trade mode (Brandt and Morrow, 2016) , thus indirectly affect firms' incentive to innovate. To avoid such complication, we drop the processing firms from our NBS sample (account for 12% in terms of patents filed during 2003-2007).

We measure innovative activity using invention patent applied by firms. There are three categories of patents in the Chinese system: invention, utility and industrial design. The invention patents are equivalent to the utility patents in the US, and is subject to the agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), which requires, for example, a search in the international patent database to determine the novelty of patents during examination. Each application under the invention category needs to go through two rounds of examination for novelty and non-obviousness, while the other two categories got granted immediately[8]. It takes on aver-

[8]The granted utility or design patents can be revoked if another party sue the patent holder in the court.

age two to four years from application to patent granting. The length of protection for invention patents is twenty years, while that for the other two categories is only ten years. For these reasons, we focus on the invention patent category as innovation outputs.

Patent data is obtained from the State Intellectual Property Office (SIPO) of China. It covers all invention patents applied during 1985-2015. We identify whether a patent belongs to an NBS firm by matching assignee name to the list of NBS firms. Since the NBS data is an unbalanced panel, there are years during which an NBS firm does not have observation in the NBS data (most likely because it is not big enough), but it has observation in the patent data. Table 1 shows the total patent count and the matched patent count for year 2007. Of all invention patents, 72% were applied by firms, among which 39% belonged to firms located in China. The NBS firms cover 62% of all patents applied by Chinese corporates. For comparison, Autor et al. (2016) found that the share of US corporate patents applied by Compustat firms in the manufacturing sector is around 56% in 1999 and around 50% in 2007[9]. Our percentage is higher than theirs because their firm data set only include publicly traded firms, whereas ours cover a larger universe of Chinese firms. Out of the patents belonging to NBS firms, 81% falls in our sample of non-processing firms with non-missing data. 5,904 firms in our final sample filed for at least one patent in 2007.

Autor et al. (2016) emphasized the importance of controlling for different industry trends. Table 2 shows the evolution of patent distribution and application per firm for 1999, 2003 and 2007. The sample used is the primary sample without Huawei and ZTE. As with the US, we do see different trends among sectors. The share of patent count in chemicals and petroleum declined from 39% in 1999 to 23.8% in 2007; the share metal and metal products sector decreased from 12.9% in 1999 to 7.5% in 2007. On the other hand, computers and electronics sector experienced increase in patenting share from 20.3% in 1999 to 34.6% in 2007. Machinery and equipment sector also experienced an increase, from 9.2% in 1999 to 17.2% in 2007. In terms of application per firm, all sectors experienced an increase, with the most notable increase happening for the computers and electronics sector. In 2003 and 2007, the top three patenting sectors are chemicals and petroleum, computers and electronics, and machinery and equipment sector, and they together account for over a quarter of manufacturing patent application. Therefore, when controlling for sectoral trends, we

[9] In Autor et al. (2016), the percentage of US corporate patents in Compustat is 72%. Out of these patents, the share of manufacturing patents is 77.2% and 70% in 1999 and 2007, respectively. That is how we arrive at 56% and 50%.

control for these three sectors.

3.3 Tariff reforms and industry competition

Since our hypothesis is that the WTO accession tariff reduction affect innovation incentives through change in the competition environment, we now examine the industry market structure and its relationship with tariff and productivity.

Following Aghion et al. (2015), we measure competition through variations of the Lerner Index, which is usually defined as total profit net of financial cost, divided by total revenue or value added. We test three versions of the Lerner Index definition for robustness:

$$\begin{aligned}\text{Lerner I}_{st} &= \frac{\sum_{is}\text{Profit}_{ist}-\sum_{is}\text{Finance Fee}_{ist}}{\sum_{is}\text{Value Added}_{ist}}\\ \text{Lerner II}_{st} &= \frac{\sum_{is}\text{Profit}_{ist}}{\sum_{is}\text{Value Added}_{ist}}\\ \text{Lerner III}_{st} &= \frac{\sum_{is}\text{Profit}_{ist}-\sum_{is}\text{Finance Fee}_{ist}}{\sum_{is}\text{Revenue}_{ist}}.\end{aligned}$$

The indices are measured at the sector s - year t level, by aggregating up firm level values. We regress them on the WTO accession tariffs,

$$\log\ \text{Lerner}_{st}=\beta_0+\beta^{\tau}\tau_{st}^{\text{output}}+\delta_s+\delta_t+\varepsilon_{st}. \tag{10}$$

Table 4 shows the results. Taking column (1) as our baseline, a one percentage point drop in tariff is related to 5.6% drop in the Lerner index, which is 5.6% more competition.

4 Estimation Framework

In the empirical analysis, we estimate the effect of tariff reduction on firm's innovation capacity measured by patent application. We assume firms apply for patent at Poisson rate λ_{ist}, so that $\text{Pat}_{ist}|\lambda_{ist}\sim\text{Poisson}\left(\lambda_{ist}\right)$, and $E\left(\text{Pat}_{ist}|\lambda_{ist}\right)=\lambda_{ist}$. The Poisson arrival rate is affected by firm and industry characteristics, as well as changes in market structure.

We run the following baseline specification:

$$\begin{aligned}\lambda_{ist} \quad = \exp(\quad & \beta_1 \tau^{output}_{s,t-2} \times \text{Top}_{is,t-2} + \beta_2 \tau^{output}_{s,t-2} \\ & + \text{EXP CONTROL}_{ist-2} + \text{IMP CONTROL}_{ist-2} \\ & + \text{Top}_{is,t-2} + \delta_s + \delta_{ct})\end{aligned} \tag{11}$$

where Pat_{ist} denotes patent applied at time t for firm i in sector s. $\tau^{output}_{s,t-2}$ is the industry import tariff as defined in equation (4), $\text{EXP CONTROL}_{ist-2}$ and $\text{IMP CONTROL}_{ist-2}$ control for effects brought by shocks on exports and imported inputs,

$$\text{EXP CONTROL}_{ist-2} \quad = \quad \alpha_1 \text{D}^{\text{exporter}}_{ist-2} + \alpha_2 E^{\text{demand}}_{s,t-2} + \alpha_3 E^{\text{demand}}_{s,t-2} \times \text{D}^{\text{exporter}}_{ist-2} \tag{12}$$

$$\text{IMP CONTROL}_{ist-2} \quad = \quad \gamma_1 \text{D}^{\text{importer}}_{ist-2} + \gamma_2 \tau^{\text{input}}_{s,t-2} + \gamma_3 \tau^{\text{input}}_{s,t-2} \times \text{D}^{\text{importer}}_{ist-2}. \tag{13}$$

$E^{\text{demand}}_{s,t-2}$ measures the market size effect brought by export tariff changes, as defined by equation (6). $\tau^{\text{input}}_{is,t-2}$ is the two period lagged input tariff measure which is defined by equation (5). We use two-period lagged tariff shocks to take into account that it takes a while for innovative ideas to be turned into patents. Further, we control for industry fixed effect δ_s at the four-digit level, and sector-year fixed effect δ_{ct} to take into account the different sectoral trends. c is a categorical variable on four sectors: chemicals and petroleum, computers and electronics, machinery and equipment sector, and others .

Following Bustos (2011), we divide firms into four groups for any industry-year cell, according to two period lagged TFP quartiles. The TFP estimation procedure follows Ackerberg et al. (2015), De Loecker and Warzynski (2012) and Brandt et al. (2017). $\text{Top}_{is,t-2}$ is then defined to be a dummy which equals to 1 if the firm is above 75 percentile in terms of productivity among industry s firms two periods before. Coefficient $-\beta^{out}_{top}$ measures the percentage change in patenting rate after the industry output tariff decreases by 0.01.

For firms with product composition information, we could also construct competition, export, and imported input shocks at the firm level, which are defined by equations (7)-(9). We run the following firm level specification:

$$\begin{aligned}\lambda_{ist} \quad = \exp(\quad & \beta_1 \tau_{s,t-2}^{\text{output}} \times \text{Top}_{is,t-2} + \beta_2 \tau_{s,t-2}^{\text{output}} + \text{Top}_{is,t-2} \\ & + \alpha E_{s,t-2}^{\text{demand}} + \gamma \tau_{s,t-2}^{\text{import}} + \delta_s + \delta_{ct})\end{aligned} \tag{14}$$

Since import tariff declined most during 2001-2005, we restrain our time period of analysis to 2001-2005 for the tariff shock. And since we assumed it takes one to two years for patents to come out, our patent variables cover years 2003-2007.

5 Main Results

5.1 Baseline Estimates

Table 5 shows the regression results for specification (11). From left to right, we gradually add in export and input tariff controls. All columns control for the four-digit industry fixed effects and sector-year effects. For firms below 75 percentile of TFP, the effect of import competition is almost zero, with big standard errors. Relative to them, the top firm are highly responsive to import tariff drops. Taking column (4) as our baseline result, after a one percentage point drop in import tariff, the top firms increase their patent application effort by 3.6 percentage points more, relative to the less productive firms.

Being an exporter increases average patent application per firm by 0.9. Decrease in export tariffs in general discourages non-exporters to innovate, while it tends to encourage exporters. This result is consistent with what is found for French firms in Aghion et al. (2017).

For the effect of accessing imported inputs, importers on average file for one more patent than non-importers. While change in input tariff has no effect for non-importers, the encouragement effect of innovation for importers is quite big. A one standard deviation decrease in input tariff increases patenting rate by 3.7%.

Table 6 shows the results for firm level specification (14). The coefficients on the heterogeneous effect of output competition remain stable across columns, and the magnitude is close to the industry specification in Table 5. Controlling for firm fixed effects significantly decreased the number of observation, as the Poisson routine would drop the firms that never patent. In Table B3 in the appendix, we show regressions with firm fixed effect in an OLS specification, which would preserve firms that never patent.

In all the specifications so far, we use patent application counts as the measure of innovation outcome. The granting rate for the patent applications is around 60% during the sample period. To better control for the quality of patent application, in Table B1, we run the same specification as in column (4) of Table 5 using patent grants and citation weighted patent counts as our outcome variables. The effect of a one percentage point drop in output tariff remains the same as in our benchmark. One may also be concerned that firms file for multiple patents under the same technology to better protect itself in case of law suits. Therefore, giving each application the same weight would possibly overstate the effort to innovate. Further more, if firms become more strategic due to competition, our estimate would be upward biased. We check for the specification with patent dummy, instead of patent counts, as our dependent variable. The coefficient magnitude is not readily comparable, but the direction and significance of the effect remains. In column (4) and (5) of Table B1, we use alternative specifications that have been used in the literature, other than Poisson, and still the direction and significance of the estimated effect remains.

In Table 7 column (1)-(2), we show the long term regression by running the industry specification on years 2003 and 2007 only. Both columns controlled for ownership, region, year and industry dummies. Column (2) also includes the export and import controls. The long term effect of a one percentage point decrease in output tariff encourages top firms to increase patent rate by 4.6 percentage points.

The time period we look at is one where the patent rate in China picked up rapidly. One concern is that the differential patenting behavior between top and other firms and across industries is caused by an unobservable factor that also determined the tariff measures. Therefore, in columns (3)-(4), we first added to columns (1)-(2) firms' patent applications in the pre-exposure years as additional control. Indeed, patent application is a rather persistent feature for firms. The coefficient in front of past patent is highly significant and positive. Since patenting was a rather high-tech activity, we should expect that firms that patent before the WTO accession would continue patenting. The point estimate of the interaction term becomes smaller, with slightly higher standard errors, making the estimate less precise. Second, we run a falsification test in columns (5)-(6) by regressing the pre-exposure patent application in 1998 and 2001, on the future tariff rates in 2001 and 2005.

The interaction term is weakly negative, and not significant at the 10 percent significance level. Therefore, we do not find evidence that the pre-exposure patenting behavior is related to the WTO accession tariffs.

5.2 Technology deepening v.s. technology scope

Next, we further investigate the dimensions of innovation that are induced by import competition. Specifically, we decompose the total patent count into patents filed in the core technology of a firm, versus the total number of technology classes the firm file patents into. Technology class is defined according to the six-digit International Patent Classification (IPC)[10]. A technology class is defined as the core technology if a firm has accumulated the most patent applications in that class up to the previous year. The technology scope is the sum of the number of classes a firm files patent in a specific year.

Table 8 shows the estimation result for the industry specification applying on core technology and technology scope. Column (1) is repeating column (4) in Table 5 as benchmark. The results suggest that the top firms react to increase in import competition by both increasing innovation in the core technology as well as broadening its technology space. The point estimate for the effect on patent scope (column 2) is smaller than the overall effect (column 1), whereas the point estimate for the core patent (column 3) is larger than the overall effect. The result remains very similar when we only look at firms that have applied for patents before (columns 4-6). Column (7) shows the effect on the ratio of scope to core. The second row show that on average, firms react more by increasing their patent in core technology, which is consistent with previous columns. There isn't a differential effect for the top firms in terms of the relative magnitude of core and scope innovation.

5.3 Effect on firm scale and productivity

In this section, we look at the effect of import liberalization on other firm outcome variables.

First, we are interested in whether surviving firms get bigger. Table 9 runs OLS regressions of log domestic output on the industry output tariff and other import and export controls. There is

[10]There are 4944 six digit IPC in 2007. For example, in 2007, Huawei filed patents in 144 technology classes. According to our definition, its core patent class was H04L12, "Data switching networks". Other technology classes that it filed patent in are H04L29, "Arrangements, apparatus, circuits or systems", and H04L1, "Arrangements for detecting or preventing errors in the information received", etc.

a weak increase in the domestic output for firms surviving the competition, 0.43 percent increase, after a one percentage point drop in output tariff.

The effect on productivity is more pronounced. After a one percentage point drop in output tariff, the top firms see increase in productivity by 0.17 percent. This is consistent with the estimate of 0.19 percent in Brandt et al. (2017). In column (2), we estimate the effect of import competition on the R&D input. Consistent with the result for the patent application, the top firms react more to import competition and put more effort into research and development in the face of more liberalized import market. Column (3) and (4) shows that the elasticity of capital and labor on output tariff is 1.12 and 0.36, respectively.

6 Conclusion

The China Miracle has been a manufacturing success. But after over forty years of rapid growth with cheap labor, imitation, and institutional reforms, China's manufacturing sector has arrived at a crossroad where further growth depends much on indigenous innovation. In this paper, we study the impact of change in competition environment brought by foreign imports on Chinese firm's innovation capacity, measured by patent application. Using a newly combined data set that covers the universe of medium to large manufacturing firms, and more than 60% of corporate innovators, we find that the increase in import competition following China's accession to the WTO during 2001-2005 induced more productive firms to innovate more. We explain this phenomenon using a model with step-by-step innovation and monopolistic competition which could generate an escape competition effect for the top firms.

Our finding adds to the debate on the effect of international competition on innovation. For a developing country like China, opening to international competition served as a stimulating mechanism for the top firms to invest in research to improve products and processes. In the mean time, a less productive firm may find it not as attractive to innovate. Whether the aggregate effect is positive or negative depends on the extent of technology spillover and other policy environments. We believe this is a fruitful future research path to pursue.

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Figures

Figure 1: Difference in expected profits due to innovation

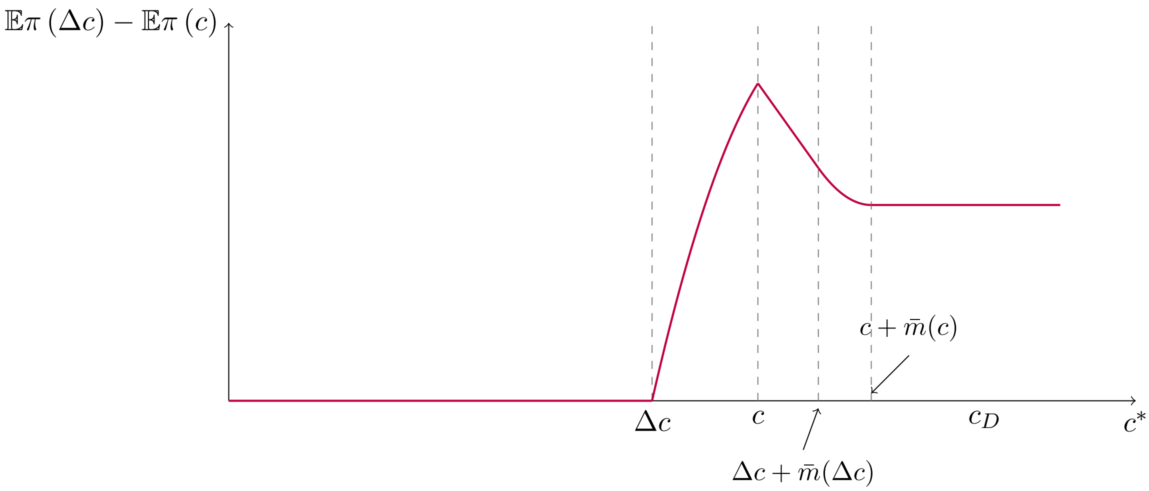


Figure 2: $p\,(c)$ as function of foreign cost c^*

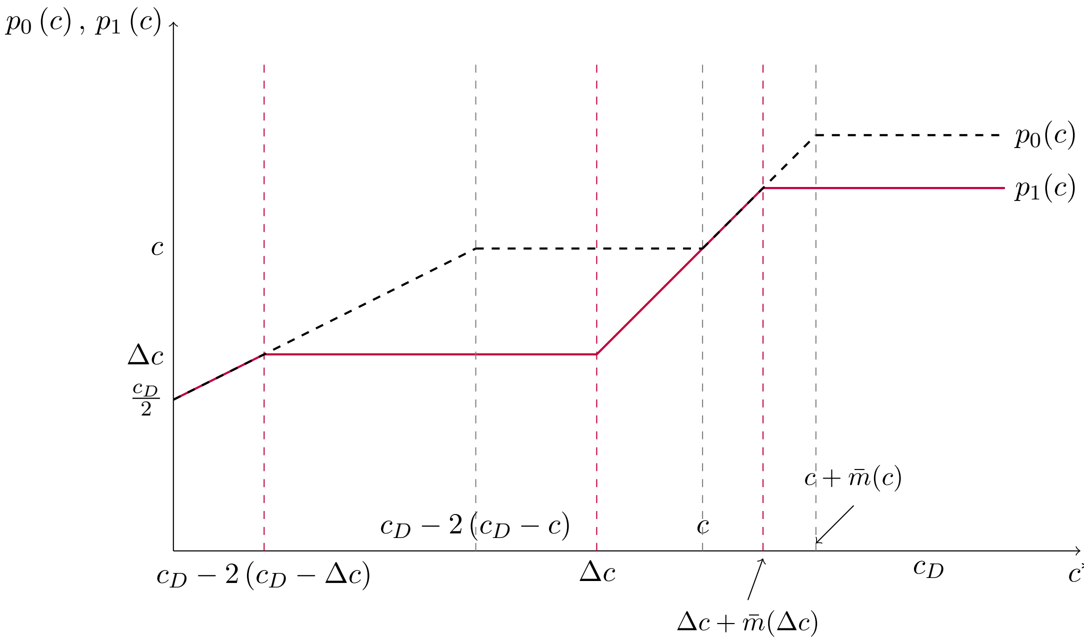


Figure 3: The Cost Distribution

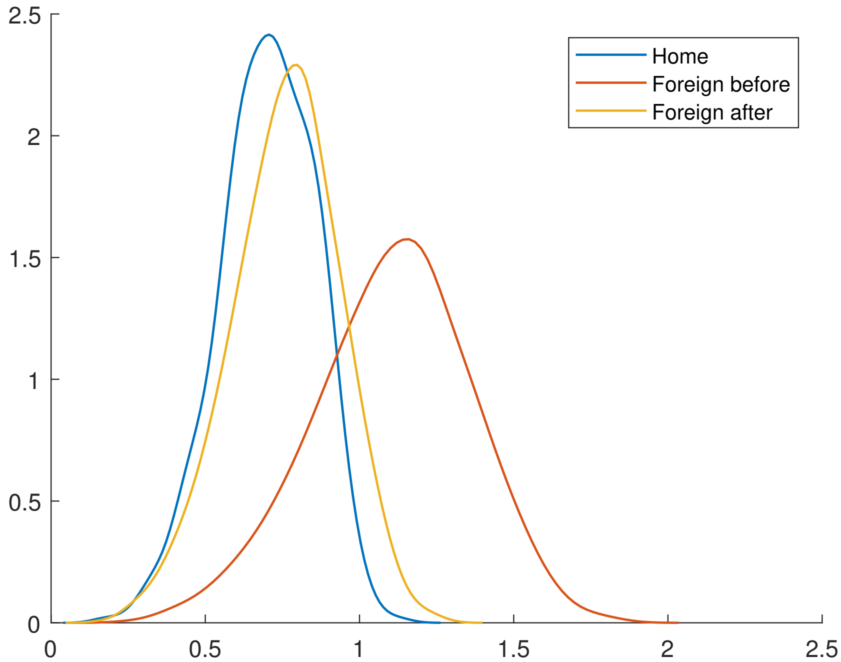


Figure 4: Change in Innovation

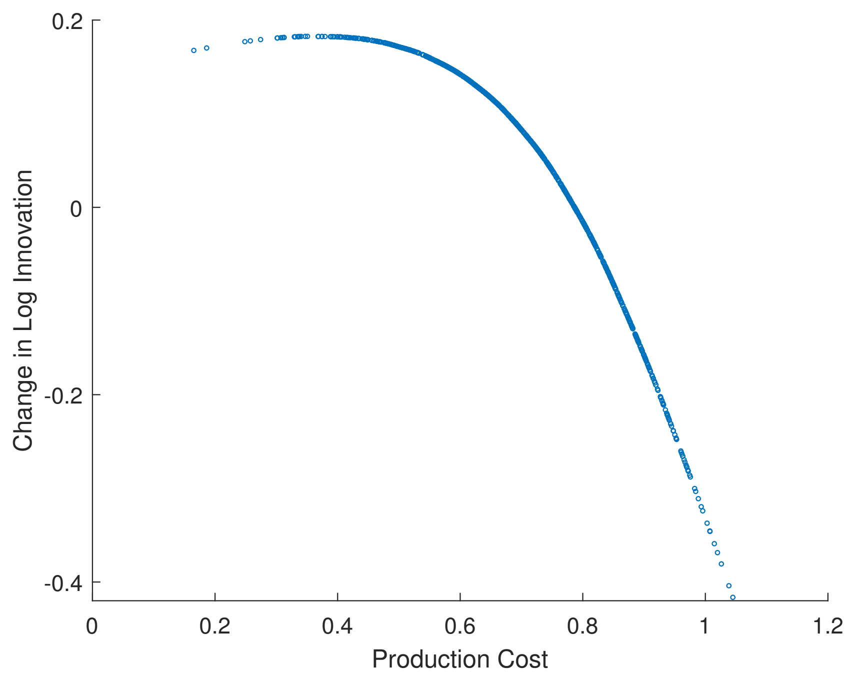


Figure 5: Actually applied tariff and bounded tariff

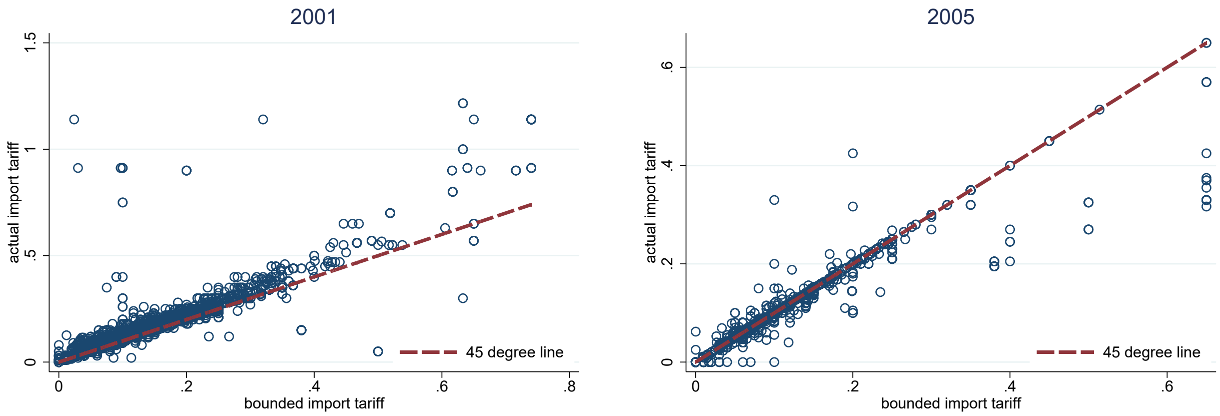
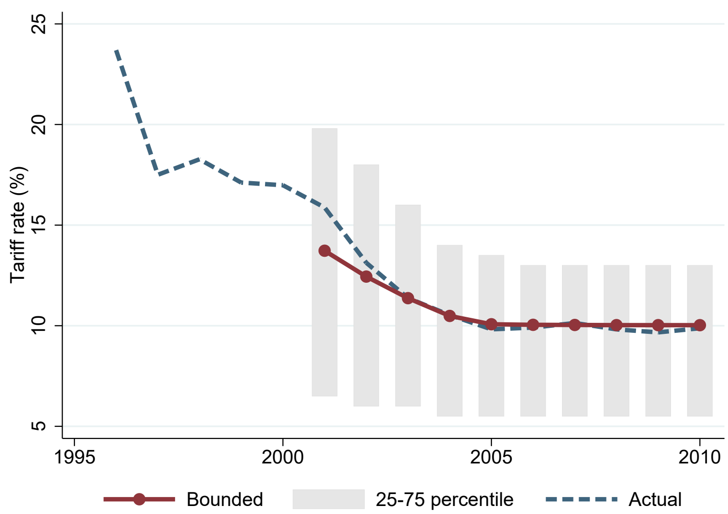


Figure 6: Tariff trends



Tables

Table 1: Patent sample construction

	# application	# patenting firms	patent per firm
SIPO data			
All assignee	233,271		
Firm assignee	167,670	29,212	5.74
Firm located in China	65,621	13,799	4.76
matched to NBS	40,057	7,279	5.50
and non-processing	32,348	5,904	5.48
NBS data		# firms	
All		329,836	
Non-processing		317,467	

Notes: Statistics for year 2007.

Table 2: Patent distribution across sectors

	(1)	(2)	(3)	(4)	(5)	(6)
	Patent share			No. patents per firm		
Application year	1999	2003	2007	1999	2003	2007
Chem., Petrol., Rubber	39.0%	35.5%	23.8%	1.79	2.30	3.64
Computers, Electronics	20.3%	30.6%	34.6%	2.39	5.35	8.38
Metal, Metal Products	12.9%	6.7%	7.5%	2.20	2.72	4.42
Machinery, Equipment	9.2%	11.8%	17.2%	1.40	1.74	2.91
Food, Tobacco	6.6%	4.4%	4.3%	1.45	1.91	3.85
Clay, Stone, Glass	5.0%	3.2%	2.2%	1.20	1.84	2.15
Transportation	3.3%	4.2%	6.0%	1.56	2.43	4.35
Paper, Print	1.3%	1.6%	1.3%	1.38	1.68	3.16
Textile, Apparel, Leather	1.2%	1.3%	2.2%	1.11	1.44	3.01
Wood, Furniture	1.1%	0.4%	0.5%	1.29	1.38	2.00
Other Manufacturing	0.1%	0.3%	0.2%	1.00	1.39	2.33

Notes: The sample used is the primary sample of non-processing NBS firms, dropping Huawei and ZTE. Industries are ordered by column (1), ranking of patent share in 1999. Columns (1)-(3) show the share out of total patent count for each sector. Columns (4)-(6) shows the average number of patent application per patenting firm.

Table 3: WTO accession tariff and initial period growth rates

	(1) $\tau_{2002}^{output} - \tau_{2001}^{output}$	(2) $\tau_{2003}^{output} - \tau_{2001}^{output}$	(3) $\tau_{2004}^{output} - \tau_{2001}^{output}$	(4) $\tau_{2005}^{output} - \tau_{2001}^{output}$
Panel A: Initial TFP growth				
tfp_{2000}-tfp_{1998}	0.001	0.001	-0.001	-0.003
	(0.005)	(0.009)	(0.013)	(0.015)
R^2	0.330	0.344	0.373	0.373
Obs	424	424	424	424
Panel B: Initial patent growth				
patent_{2000}-patent_{1998}	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.333	0.349	0.376	0.375
Obs	424	424	424	424

Notes: Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

Table 4: WTO accession tariff and Lerner Index

	(1) Lerner I_{st}	(2) Lerner II_{st}	(3) Lerner III_{st}
τ_{st}^{output}	5.624***	2.990***	5.149***
	(1.111)	(0.761)	(1.132)
R^2	0.458	0.465	0.509
Obs	1848	2016	1848

Notes: Time period, 2001-2005. Industry fixed effects and year fixed effects controlled. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Effect of import competition on patenting, industry level result

	(1)	(2)	(3)	(4)
Dep. var: Patent application counts				
Output competition				
$\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-3.525**	-3.675**	-3.418**	-3.577**
	(1.412)	(1.428)	(1.474)	(1.466)
$\tau^{output}_{s,t-2}$	-0.506	-0.161	0.966	1.275
	(1.643)	(1.655)	(1.896)	(1.883)
$Top_{is,t-2}$	1.210***	1.234***	1.177***	1.209***
	(0.142)	(0.143)	(0.147)	(0.146)
Export control				
$\mathrm{D}^{\mathrm{exporter}}_{ist-2}$		1.278***		0.909***
		(0.333)		(0.329)
$E^{demand}_{s,t-2}$		0.063***		0.066***
		(0.021)		(0.021)
$E^{demand}_{s,t-2} \times D^{exporter}_{ist-2}$		0.026		0.023
		(0.025)		(0.025)
Import control				
$\mathrm{D}^{\mathrm{importer}}_{ist-2}$			1.799***	0.984***
			(0.188)	(0.168)
$\tau^{input}_{is,t-2}$			-0.336	-4.936
			(11.268)	(10.972)
$\tau^{input}_{is,t-2} \times D^{importer}_{ist-2}$			-11.314***	-7.385**
			(3.848)	(3.639)
obs	800,292	800,292	800,292	800,292

Notes: The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. All columns control for four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. The four sectors are: chemicals and petroleum, computers and electronics, machinery and equipment sector, and others. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Effect of import competition on patenting, firm level result

	(1)	(2)	(3)	(4)
Dep. var: Patent application counts				
Output competition				
firm $\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-3.735***	-3.662***	-4.069***	-3.992***
	(1.086)	(1.101)	(1.082)	(1.105)
firm $\tau^{output}_{s,t-2}$	-1.763	-1.619	-2.301	-1.974
	(2.094)	(2.098)	(2.597)	(2.566)
$Top_{is,t-2}$	0.368***	0.369***	0.423***	0.423***
	(0.118)	(0.112)	(0.127)	(0.119)
Export control				
firm $\tau^{export}_{is,t-2}$		-0.007		0.004
		(0.051)		(0.056)
Import control				
firm $\tau^{input}_{is,t-2}$			2.159	2.066
			(6.976)	(6.417)
obs	11,483	11,111	8,461	8,210

Notes: Poisson specification. Firm fixed effects and time fixed effects are controlled. See Table B3 for an OLS specification. The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Long term effects and falsification test

	I. 2003-2007				II. 1998-2001 (pre-exposure)	
Dep. var	$\text{Pat}_{2003,\ 2007}$				$\text{Pat}_{1998,\ 2001}$	
	(1)	(2)	(3)	(4)	(5)	(6)
Past output competition						
$\tau_s^{output} \times Top_{is2001,2005}$	-4.587***	-4.685***	-3.005*	-2.982*		
	(1.534)	(1.576)	(1.546)	(1.622)		
$\tau_s^{output}{}_{2001,2005}$	-0.029	0.646	-0.333	0.733		
	(2.523)	(2.623)	(2.323)	(2.709)		
$Top_{is2001,2005}$	1.335***	1.338***	1.225***	1.197***		
	(0.152)	(0.156)	(0.143)	(0.145)		
Pre-exposure trends						
$\text{Pat}_{1998,\ 2001}$			0.128***	0.117***		
			(0.015)	(0.013)		
Future output competition						
$\tau_s^{output} \times Top_{is2001,2005}$					-1.768	-1.815
					(2.189)	(2.193)
$\tau_s^{output}{}_{2001,2005}$					0.099	0.920
					(2.724)	(3.400)
$Top_{is2001,2005}$					0.897***	0.859***
					(0.193)	(0.190)
obs	337,029	337,029	141,190	141,190	119,146	119,146

Notes: The specifications are Poisson with two years stacked. All columns control for ownership and region dummies, four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. The even columns include the export and import controls in addition. Standard errors are clustered at the industry-year-top level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8: Technology core vs. scope

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample		All			Patented before		$\frac{\text{scope}}{\text{core}}$
Dep. var	application	scope	core	application	scope	core	
Output competition							
$\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-3.577**	-2.397**	-3.968**	-3.659***	-2.323**	-4.833**	-0.472
	(1.466)	(0.974)	(1.832)	(1.591)	(1.092)	(2.063)	(0.821)
$\tau^{output}_{s,t-2}$	1.275	1.188	1.334	1.247	2.281	0.705	3.654**
	(1.883)	(1.337)	(1.564)	(2.333)	(1.650)	(1.917)	(1.454)
$Top_{is,t-2}$	1.209***	0.933***	1.091***	1.020***	0.768***	0.953***	0.205***
	(0.146)	(0.090)	(0.192)	(0.152)	(0.088)	(0.217)	(0.071)
Export control							
$\mathrm{D}^{\mathrm{exporter}}_{ist-2}$	0.909***	1.582***	0.401	-0.022	0.517*	-1.163**	0.287
	(0.329)	(0.252)	(0.409)	(0.455)	(0.308)	(0.502)	(0.196)
$E^{demand}_{s,t-2}$	0.066***	0.079***	0.082***	0.059*	0.052**	0.056*	0.018
	(0.021)	(0.019)	(0.022)	(0.030)	(0.022)	(0.033)	(0.018)
$E^{demand}_{s,t-2} \times D^{exporter}_{ist-2}$	0.023	-0.040**	0.028	0.068**	0.012	0.124***	-0.003
	(0.025)	(0.020)	(0.033)	(0.034)	(0.023)	(0.039)	(0.016)
Import control							
$\mathrm{D}^{\mathrm{importer}}_{ist-2}$	0.984***	0.968***	0.631***	0.469**	0.174	-0.043	0.172
	(0.168)	(0.163)	(0.202)	(0.205)	(0.176)	(0.195)	(0.172)
$\tau^{input}_{is,t-2}$	-4.936	-9.983	-6.497	-2.990	-13.008	-4.033	-5.160
	(10.972)	(6.907)	(7.036)	(12.473)	(8.584)	(9.981)	(8.317)
$\tau^{input}_{is,t-2} \times D^{importer}_{ist-2}$	-7.385**	-4.063	1.744	-6.094	-0.314	7.254*	-4.132
	(3.639)	(3.685)	(3.905)	(5.047)	(4.247)	(4.330)	(4.427)
obs	800,292	800,005	800,005	23,931	23,917	23,917	12,721

Notes: All columns control for ownership, region, four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Effects on domestic output

	(1)	(2)	(3)	(4)
Dep. var: log domestic output				
Output competition				
$\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-0.482**	-0.468*	-0.424*	-0.426*
	(0.244)	(0.242)	(0.239)	(0.239)
$\tau^{output}_{s,t-2}$	-0.008	-0.039	-0.373	-0.386
	(0.401)	(0.397)	(0.438)	(0.439)
$Top_{is,t-2}$	0.656***	0.656***	0.650***	0.649***
	(0.033)	(0.032)	(0.032)	(0.032)
Export control				
$\mathrm{D}^{\mathrm{exporter}}_{ist-2}$		0.546***		0.394***
		(0.118)		(0.119)
$E^{demand}_{s,t-2}$		0.008		0.008*
		(0.005)		(0.005)
$E^{demand}_{s,t-2} \times D^{exporter}_{ist-2}$		-0.034***		-0.037***
		(0.010)		(0.010)
Import control				
$\mathrm{D}^{\mathrm{importer}}_{ist-2}$			0.711***	0.745***
			(0.075)	(0.083)
$\tau^{input}_{is,t-2}$			4.634***	4.736***
			(1.657)	(1.644)
$\tau^{input}_{is,t-2} \times D^{importer}_{ist-2}$			-7.408***	-7.447***
			(1.700)	(1.764)
R^2	0.170	0.171	0.178	0.178
obs	737,768	737,768	737,768	737,768

Notes: All columns control for four-digit CIC industry fixed effects, aggregate sector by year fixed effects. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

Table 10: Effect on TFP, R&D, capital and labor

	(1)	(2)	(3)	(4)
Dep var	TFP	ln (R&D)	ln (capital)	ln (labor)
	OLS	*OLS*	*OLS*	*OLS*
Output competition				
$\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-0.167***	-1.333***	-1.122***	-0.365**
	(0.036)	(0.226)	(0.264)	(0.152)
$\tau^{output}_{s,t-2}$	-0.447*	0.276	0.522	-0.462*
	(0.236)	(0.374)	(0.364)	(0.279)
$Top_{is,t-2}$	0.221***	0.302***	-0.003	0.051**
	(0.005)	(0.027)	(0.036)	(0.021)
Export control				
$\mathrm{D}^{\mathrm{exporter}}_{ist-2}$	0.043***	0.140	0.339***	0.242***
	(0.015)	(0.158)	(0.075)	(0.046)
$\tau^{export}_{s,t-2}$	0.002	-0.000	-0.006	-0.005*
	(0.002)	(0.006)	(0.004)	(0.003)
$\tau^{export}_{s,t-2} \times D^{exporter}_{ist-2}$	-0.003***	0.022*	0.009	0.019***
	(0.001)	(0.013)	(0.006)	(0.004)
Import control				
$\mathrm{D}^{\mathrm{importer}}_{ist-2}$	-0.007*	0.639***	0.957***	0.449***
	(0.004)	(0.101)	(0.048)	(0.024)
$\tau^{input}_{is,t-2}$	-0.822	-0.121	8.180***	4.130***
	(0.808)	(2.096)	(1.270)	(1.481)
$\tau^{input}_{is,t-2} \times D^{importer}_{ist-2}$	0.180**	-4.153	-4.012***	-1.105**
	(0.080)	(2.537)	(0.960)	(0.473)
R^2	0.567	0.137	0.228	0.196
obs	802598	563144	798414	802598

Notes: The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. All columns control for four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. The four sectors are: chemicals and petroleum, computers and electronics, machinery and equipment sector, and others. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

Appendix

A Control function approach

In Table 5 of the main text, we showed a reduced form relationship between firm patenting and import competition measured by import tariffs. In this section, we take a further look at the mechanism. We test whether more patenting is caused by increase in industry imports. To account for the endogeneity of trade volumes, we use the control function approach that is widely used in the literature when dealing with Poisson count data regression (Aghion et al., 2009; Wooldridge, 2010; Blundell and Powell, 2003). Table A1 shows the results. The odd columns shows the OLS regression, adding export or import controls, one at a time. The even columns shows the corresponding second stage result of the control function approach.

Table A1: Effect of import competition on patenting, industry level result

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var: Patent application counts						
Specification	OLS	CF	OLS	CF	OLS	CF
Output competition						
$\ln M^{output}_{s,t-2} \times Top_{is,t-2}$	0.102**	0.121***	0.107***	0.126***	0.104**	0.112**
	(0.040)	(0.045)	(0.039)	(0.045)	(0.042)	(0.047)
$\ln M^{output}_{s,t-2}$	0.023	0.476	0.035	0.443	0.018	0.219
	(0.025)	(0.322)	(0.028)	(0.318)	(0.025)	(0.370)
$Top_{is,t-2}$	0.768***	0.750***	0.787***	0.770***	0.740***	0.749***
	(0.088)	(0.090)	(0.087)	(0.089)	(0.088)	(0.090)
Export control						
$\mathrm{D}^{\mathrm{exporter}}_{ist-2}$			1.586***	1.588***		
			(0.102)	(0.102)		
$\ln X^{exp}_{s,t-2}$			-0.184***	0.034		
			(0.046)	(0.066)		
$\ln X^{export}_{s,t-2} \times D^{exporter}_{ist-2}$			0.206***	0.217***		
			(0.041)	(0.044)		
Import control						
$\mathrm{D}^{\mathrm{importer}}_{ist-2}$					1.756***	1.731***
					(0.250)	(0.251)
$\ln M^{input}_{is,t-2}$					-4.439	0.392
					(11.949)	(14.453)
$\ln M^{input}_{is,t-2} \times D^{importer}_{ist-2}$					-11.713**	-11.607**
					(5.161)	(5.202)
First Stage						
Endogenous var.		$\ln M^{output}_{s,t-2}$		$\ln X^{export}_{s,t-2}$		$\ln M^{input}_{s,t-2}$
Instruments	$\tau^{output}_{s,t-2}$	-5.544***	$\tau^{export}_{s,t-2}$	0.406***	$\tau^{input}_{s,t-2}$	-12.975***
		(1.641)		(0.021)		(2.299)
obs	802,410	802,410	802,410	802,410	802,410	792,963

Notes: The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. All columns control for four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. The four sectors are: chemicals and petroleum, computers and electronics, machinery and equipment sector, and others. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

B Robustness checks

B.1 Alternative measures

Table B1 shows the estimation result for different dependent variable measures and econometric specifications. The first two columns use patent grants and citation weighted application as dependent variables. The estimated elasticity for the heterogeneous effect is comparable to column (4) of Table 5. To minimize the concern for strategic patent portfolio construction (the incentive to file for more patent is only to complete a patent portfolio rather than reacting to competition), we use patent dummy instead of patent count in column (3). Columns (4) and (5) perform OLS regressions directly on patent counts and log patents. The heterogeneous effect of import competition for top firms remain significant.

Table B1: Alternative measures of innovation

Dep var	(1) Granted application *Poisson*	(2) Citation weighted *Poisson*	(3) Patent dummy *OLS*	(4) Patent count *OLS*	(5) $\ln(Pat+1)$ *OLS*
Output competition					
$\tau_{s,t-2}^{output} \times Top_{is,t-2}$	-2.750*	-2.836**	-0.057***	-0.917***	-0.096***
	(1.483)	(1.303)	(0.008)	(0.229)	(0.014)
$\tau_{s,t-2}^{output}$	2.732	-0.454	-0.019	-0.002	-0.020
	(2.370)	(2.094)	(0.015)	(0.167)	(0.021)
$Top_{is,t-2}$	1.126***	1.048***	0.012***	0.165***	0.019***
	(0.142)	(0.122)	(0.001)	(0.032)	(0.002)
Export control					
$\mathrm{D}_{ist-2}^{\mathrm{exporter}}$	0.928***	0.875***	0.042***	0.293***	0.055***
	(0.159)	(0.141)	(0.003)	(0.047)	(0.004)
$E_{s,t-2}^{demand}$	1.477**	1.001	0.015**	0.238***	0.029***
	(0.626)	(0.639)	(0.007)	(0.071)	(0.009)
$E_{s,t-2}^{demand} \times D_{ist-2}^{exporter}$	-0.227	-1.143	-0.275***	-2.063***	-0.374***
	(1.954)	(1.679)	(0.025)	(0.373)	(0.035)
Import control					
$\mathrm{D}_{ist-2}^{\mathrm{importer}}$	1.599***	1.415***	0.049***	0.273***	0.063***
	(0.284)	(0.240)	(0.004)	(0.047)	(0.005)
$\tau_{is,t-2}^{input}$	-0.114	0.120	0.240***	0.569	0.257***
	(19.535)	(13.923)	(0.046)	(0.459)	(0.062)
$\tau_{is,t-2}^{input} \times D_{ist-2}^{importer}$	-16.220**	-11.554**	-0.556***	-3.599***	-0.739***
	(6.997)	(5.686)	(0.077)	(0.911)	(0.105)
R^2			0.038	0.008	0.037
obs	762,640	770,316	770,978	770,978	770,978

Notes: The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. All columns control for four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. The four sectors are: chemicals and petroleum, computers and electronics, machinery and equipment sector, and others. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1

B.2 Dropping 2-digit sectors one at a time

Table B2: Drop 2-digit sectors, one at a time

	(1)	(2)	(3)	(4)	(5)
Dep. var: Patent application counts					
Sector Dropped	**Food**	**Drinks**	**Tobacco**	**Textile**	**Furniture**
firm $\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-2.417*	-2.653*	-2.943**	-2.919**	-2.890**
	(1.415)	(1.416)	(1.412)	(1.387)	(1.362)
firm $\tau^{output}_{s,t-2}$	-1.095	-0.723	0.377	1.183	-0.465
	(2.071)	(2.218)	(2.231)	(2.025)	(1.965)
$Top_{is,t-2}$	1.099***	1.104***	1.117***	1.112***	1.116***
	(0.133)	(0.133)	(0.132)	(0.131)	(0.131)
obs	738657	790877	803282	681173	778623
Sector Dropped	**Paper**	**Chemical**	**Stone**	**Metal**	**Machinery**
firm $\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-2.852**	-3.217**	-2.874**	-2.656*	-3.151**
	(1.377)	(1.400)	(1.383)	(1.428)	(1.334)
firm $\tau^{output}_{s,t-2}$	0.117	-1.629	-0.466	-0.102	-0.272
	(2.062)	(2.051)	(1.999)	(1.939)	(2.077)
$Top_{is,t-2}$	1.108***	1.212***	1.120***	1.038***	1.226***
	(0.133)	(0.150)	(0.131)	(0.140)	(0.134)
obs	752471	665091	732278	724141	692330
Sector Dropped	**Transportation**	**Computers**	**Other**		
firm $\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-2.083	-4.202***	-2.884**		
	(1.585)	(1.181)	(1.371)		
firm $\tau^{output}_{s,t-2}$	-1.360	-0.687	-0.372		
	(2.112)	(1.656)	(1.960)		
$Top_{is,t-2}$	1.097***	0.985***	1.114***		
	(0.142)	(0.128)	(0.131)		
obs	764506	731702	791453		

Notes: The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. All columns include the export and import controls, the four-digit CIC industry fixed effects, as well as four-sector by year fixed effects. The four sectors are: chemicals and petroleum, computers and electronics, machinery and equipment sector, and others. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1.

B.3 Firm Level regression

Table B3: Effect of import competition on patenting, linear firm level result

	(1)	(2)	(3)	(4)
Dep. var: Patent application counts				
Output competition				
firm $\tau^{output}_{s,t-2} \times Top_{is,t-2}$	-2.737**	-2.775**	-4.770**	-4.841**
	(1.196)	(1.255)	(2.122)	(2.212)
firm $\tau^{output}_{s,t-2}$	1.095*	1.220*	1.496	1.748
	(0.617)	(0.653)	(1.175)	(1.244)
$Top_{is,t-2}$	0.365**	0.374**	0.615**	0.632**
	(0.153)	(0.160)	(0.251)	(0.263)
Export control				
firm $\tau^{export}_{is,t-2}$		0.004		0.014
		(0.017)		(0.032)
Import control				
firm$\tau^{input}_{is,t-2}$			2.360	2.397
			(1.965)	(2.070)
R^2	0.580	0.581	0.596	0.597
obs	134,534	128,104	71,247	68,779

Notes: OLS regression instead of Poisson. The Top dummy equals to 1 if the firm is above 75 percentile in industry s at time $t-2$. All columns control for firm fixed effects and year fixed effects. Standard errors are clustered at the industry-year level. *** p<0.01, ** p<0.05, * p<0.1