Intermediate Input Imports and Innovations: Evidence from Chinese Firms

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Abstract

Innovation plays a key role in economic growth. In this paper, we investigate the effects of intermediate input tariff reduction on the innovation activities of domestic firms. Input tariff reduction exerts two opposite effects on the innovation decision of a firm: It may promote innovation as the cost of doing innovation becomes lower, but it may also decrease innovation because external technologies become cheaper. By using Chinese firm-level data from 1998 to 2007, which features a drastic input tariff cut in 2002 because of China' WTO accession, we find that input tariff cut results in less innovation undertaken by Chinese firms. The result is obtained using the difference-in-differences technique and is robust to many specifications checks of the model. This empirical finding does not seem to be in line with existing empirical results about trade liberalization on the performance of Chinese firms.

Keywords: Trade liberalization; Intermediate Input; Innovation

JEL Codes: F13, F15, O14, O31

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1 Introduction

Innovation and technological progress are key determinants of economic growth. In his 2014 State of the Union Address, U.S. President Barack Obama claimed that "the nation that goes all-in on innovation today will own the global economy tomorrow". The past few decades have witnessed innovation race as well as deeper globalization around the globe. How does globalization in general and trade liberalization in particular influence the incentive of firms to engage in innovation activities? This important question has been addressed by a large body of literature. Most of the existing studies have confirmed that trade is one of the important factors that drive innovation (Kiriyama, 2012). However, evidence based on micro-level data is scant (Bloom *et al.*, 2015). In this paper, we reexamine the trade-innovation issue from a special perspective based on Chinese firm-level data, that is, the impact of intermediate input tariff (or simply, input tariff) liberalization on the innovation activities of domestic firms.

A growing share of international trade is in capital goods and intermediate inputs. At the global level, the share of capital goods in total trade increased from 21.0% in 1970 to 26.5% in 2006 and the share of intermediate goods in total trade increased from 7.5% to 13.0% (Onodera, 2009). From 2000 to 2006, the total value of China's capital import and intermediate input import increased by 151% and 256%, respectively. Another notable change in China is its growing innovations. For example, China's share of global research and development (R&D) jumped from 2.2% in 2000 to 14.5% in 2011.[1] In 2011, China's patent office received more applications than any other country's.[2] Thus, China is a good case for analyzing the effect of intermediate input imports on innovations. Drastic trade liberalization in China also makes China a good case for valid empirical investigation of such an issue. On the one hand, the average input tariff rate in China dropped from 13.74% in 1998 to 8.13% in 2007, with the greatest cuts after 2001 when it became a WTO member. On the other hand, the degrees of input tariff liberalization differ tremendously across industries. By making use of these two features, namely, large and sudden tariff cuts due to the WTO accession and cross-industry variations of the cuts, we empirically assess the impacts of input tariff cuts on the innovation activities of domestic firms.

Our analysis shows that China's input tariff liberalization *reduces* the innovation activities of

[1] *Foreign Policy*, "It's official: China is becoming a new innovation powerhouse", Feb 6th, 2014.
[2] *The Economist*, "How innovative is China? Valuing patents", Jan 5th, 2013.

firms, as measured by patent filings. This negative effect is both statistically significant and economically important: A one-percent cut in input tariff rate results in about 0.15 to 0.28 percent drop in innovations. This finding is obtained using the difference-in-differences (DID) technique and is qualitatively robust to different model specifications and concerns of the model. This key finding is both important (to the economy) and interesting (academically) because it is neither obvious nor expected.

Conceptually, intermediate input imports and firm innovation can be complements or substitutes with regard to productivity enhancement and/or product quality improvement. Two conflicting forces on domestic firms' incentives to undertake innovation came about in response to input tariff cuts in China. On the one hand, input tariff reductions enable a firm to purchase its inputs at a low cost and import high-quality inputs. This capability lowers a firm's incentive to do innovation (see a similar argument in the effective protection literature, for example, Corden 1971). This "input price effect" underlies a "substitute" relation between input imports and innovation. On the other hand, a firm may undertake R&D by using some intermediate inputs (such as capital goods), and its innovation activities may benefit from the transfer of the technology embedded in imported inputs. In this case, the R&D cost will decrease and innovation productivity will increase after input tariff reduction. This "innovation cost effect" raises a firm's incentive to do R&D and brings out more innovations, leading to a "complementary" relation between input imports and innovation. Our empirical results imply that the input price effect dominates the innovation cost effect, and the net effect is intermediate input imports substituting for innovations.

This paper is related to two distinct strands of literatures. The first strand is related to the literature on trade and innovation (e.g., Grossman and Helpman, 1991). Our study differs from existing ones in this literature for its focus on the effects of trade liberalization in intermediate inputs as opposite to the effects of trade liberalization in final goods (e.g., Atkeson and Burstein, 2010; Lileeva and Trefler, 2010; Aw *et al.,* 2011; Bustos, 2011; Burstein and Melitz, 2013; Bloom *et al.*, 2015). Generally speaking, trade affects innovation through various channels such as embedded technology transfer, increasing market size, changing competition, realizing scale economies, and generating spillovers. Earlier empirical studies are based on country-level or industry-level data. For example, Coe and Helpman (1989) find strong international R&D spillovers through trade, based on evidence that the productivity growth of a country depends not only on its domestic R&D capital

stock but also on the R&D capital stock of its foreign trading partners. Recent studies make use of firm-level data. For example, Baldwin and Gu (2004) find that Canadian exporting firms have higher rates of innovation than non-exporters. According to the studies in a book edited by de Negri and Turch (2007), the technological innovation efforts in Brazil and Argentina are mainly driven by the purchase of capital goods. Using firm-level data that cover 43 developing countries, Almeida and Fernandes (2008) report that on average 53% of the technological innovations are embodied in new machinery or equipment and transferred from developed to developing countries through exports and multinational firms. In their analysis of 43595 firms, de Negri and Araujo (2007) find that national exporters are in general more innovative than national non-exporters, with the percentage of innovating firms in these two categories as 48% and 36%, respectively. Bloom *et al.* (2015) find that Chinese import competition leads to more innovations of European firms, but developed countries' imports have no significant effect.

The second strand of literature includes the recently emerging empirical studies on the effects of intermediate input imports on firm's performance.[3] Some studies (Halpern *et al.*, 2011, on Hungarian firms; Kasahara and Rodrigue, 2008, on Chilean firms) find that imports of intermediates or declines in input tariffs are conducive to productivity gains. Productivity can increase through three channels via imported intermediate inputs: learning, improved input quality and increase in input variety. Using Indonesian manufacturing plant-level data, Amiti and Konings (2007) find that a 10% fall in input tariffs leads to a 12% gain in the productivity of importing firms, much higher than the productivity gain from reducing output tariffs. Qualitatively similar results are also found by Topalova and Khandelwal (2011) based on Indian data. Goldberg *et al.* (2010) examine the effects of trade liberalization in India during the 1990s and find that domestic firms increase their product scope because they are able to access new input varieties that were previously unavailable. Approximately 31% of the new products are results of lower input tariffs. Using firm-level data from the French agrifood sector, Chevassus-Lozza *et al.* (2013) find that lowering input tariffs increases the export sales of high-productivity firms at the expense of low-productivity firms. Bas (2012) shows that Argentine firms in industries experiencing larger input tariff reductions have higher probability of entering the export market. However, not all results are positive. For example, van Biesebroeck

[3] Theoretical studies have painted a clear picture (e.g., Ethier, 1982). Firms' performance can improve from intermediate input imports due to the increased variety of inputs and the utilization of technology embeded in imported inputs.

(2003) finds that there is no productivity improvement for Columbia firms through the use of inputs import.[4] Muendler (2004) also finds that the use of foreign inputs plays a minor role in the productivity change of Brazilian firms.

Similar to the present research, several studies have also examined the effects of Chinese input tariff reductions, but with different focuses. Using Chinese firms' data from 2000 to 2006, Yu (2014) finds that both input tariff reduction and output tariff reduction improve firm productivity, for both processing-trade firms and non-processing-trade firms. In particular, the productivity impact of input tariff is stronger than that of output tariff reduction. Ge *et al.* (2011) investigate the channels of firm productivity gains from input tariff cut and find supports for the learning, variety, and quality channels. Fan *et al.* (2014) and Bas and Strauss-Kahn (2015) examine the effect of Chinese input tariff reduction on the change in quality of export goods and find significant quality upgrade. Feng *et al.* (2012) study the connection between firm imports and exports, based on Chinese firm-level data from 2002 to 2006. They find that firms that expand their intermediate input imports raise the volume of their exports and increase their export scope. Their research also suggests (but not directly test) that the channel for such a connection is product upgrading that is facilitated by the technology or quality embedded in imported inputs.

Although each of the above-mentioned studies focuses on some specific performance measure of firms, none of them directly touches on *firm innovation,* which is the focus of the present study and distinguishes the present study from the existent literature.[5] Indeed, those performance measures included in the above-mentioned studies are not independent of innovation. For example, the new products introduced by firms may be the result of the firms' product R&D, and the improved quality of their products could be the outcome of their R&D specifically designed for quality improvement. However, those measures are not equivalent to innovation. The improvements of those performance could be the results of other efforts by the firms, such as improved management practice or changes in organizational form along with trade liberalization, or as Ethier (1982) rigorously shows, improved performance could be the results of intermediate input imports due to the increased variety of inputs and the utilization of technology embedded in imported inputs. Furthermore, the findings of the

[4] Zhang (2014) decomposes productivity gains to static gains and dynamic gains. Dynamic gains come from the increase in knowledge and/or the innovation of the importers due to importing intermediate inputs. He uses Columbia data to show that the dynamic gains are more important than static gains.

[5] Hu and Jefferson (2009) observe five reasons to explain the surge of patents in China, namely, (1) amendments to the Patent Law, (2) intensification of R&D in the economy, (3) foreign direct investment inflows, (4) industry structure change, and (5) SOE reform. However, they do not explore the possibility of trade liberalization.

existing studies do not have clear implications about the effect of input tariff liberalization on firm innovation. On the one hand, the positive productivity effect may imply more innovations; on the other hand, if firms can improve their performance simply from increased variety of inputs and utilization of technology embedded in imported inputs, then the incentives of firms to invest in risky R&D should be lowered by input tariff cuts, and the positive productivity effect may, in turn, imply less innovations. Therefore, innovation is different from other performance measures and separately investigating the innovation of firms is important.

Our study has three unique features: (1) it deals with innovation *directly*, (2) it includes *all* types of innovation activities (e.g., invention, utility model, and design), and (3) it produces results just opposite to those in the literature with regard to their innovation aspect.

The remainder of this paper is organized as follows. In the next section, we describe our estimation strategy and data. We present and discuss our empirical findings in Section 3 and we explore the underlying mechanisms in Section 4. We provides some concluding remarks in Section 5.

2 Policy Background, Empirical Strategy and Data

2.1 China's Accession to WTO

China began its economic reform and adopted an opening-door policy in 1979. The economy was very closed at the beginning of the reform period. To open up its economy, the Chinese government introduced a series of trade liberalization policies, including decentralizing foreign trade decisions, allowing manufacturing firms to engage directly in imports and exports, reducing import and export controls, removing import quotas, and lowering tariff rates. To integrate fully to the global market and make a strong commitment to trade liberalization, China started to apply for WTO entry in the late 1980s and was eventually accepted by the end of 2001. China had unilaterally cut its tariffs many times during the long negotiation period of WTO accession, and its tariff cut in 2002, right after the accession, was very drastic. China's simple average tariff rates (including both intermediate inputs and final goods) dropped from 42.9% in 1992 to 26.6% in 1996, 17% in 2000, and 9.8% after the WTO accession.

Figure 1 plots the time trend of China's simple average *input* tariffs during the period 1996–2007. The figure shows that tariff rates dropped substantially in 1997, remained more or less unchanged

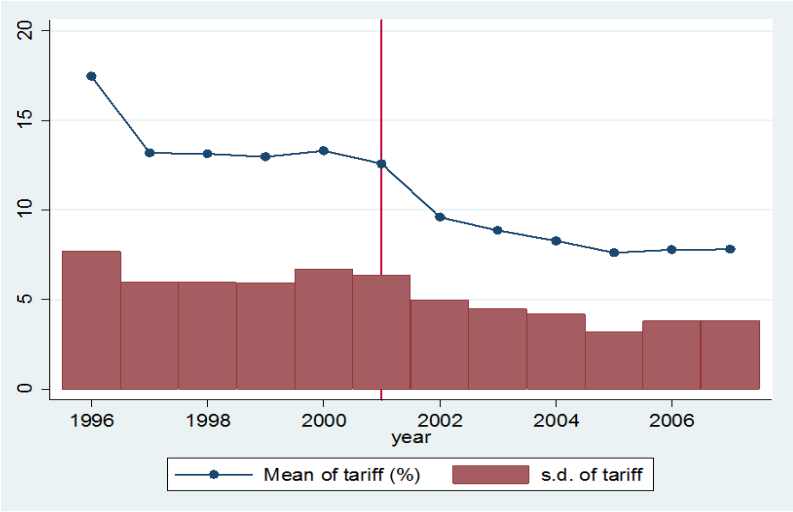

Figure 1: China's Input Tariff Trend: 1996-2007

during 1997–2001, and started to decrease in 2002 until reaching a steady state in 2005. While Figure 1 shows the general pattern of changes in input tariffs from all industries, there is clear heterogeneity across industries behind the graph. Figure 2 shows the relation between input tariffs in 2001 and the decrease in average input tariffs between the pre-WTO accession (1998-2001) and post-WTO accession (2002-2007) periods across industries. Clearly, there is a strong positive correlation between the initial tariff level and the change of the tariff due to the WTO accession. That is, there are larger reductions in industries whose initial tariff levels are higher. As a result, input tariff levels in the post-WTO accession period are more uniform across industries than the levels in the pre-WTO accession period.

The input tariff liberalization of China offers us a great opportunity to examine the impact of input tariff reductions on firm behavior because of its large variations of changes over time and across industries, the two features described above.

2.2 Estimation Specification

Our analysis is based on the period of 1998-2007. Our objective is to estimate the effects of input tariff reduction on the innovation activities of domestic firms. We overcome the identification problem by exploiting the fact that there are large variations in input tariff reduction across industries owing to China's WTO accession, which is treated as an exogenous shock in most empirical studies using Chinese trade data (Fan *et al.*, 2014; Bloom *et al.*, 2015). We employ the DID technique to conduct

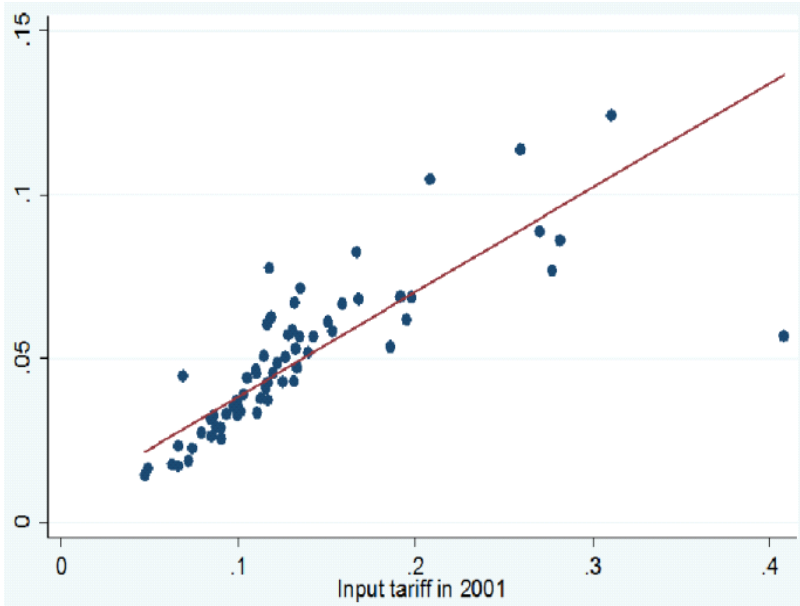

Figure 2: Decrease in Input Tariff between pre- and post-Reform – Fitted Value

the estimation. Industries with larger input tariff cuts are expected to make bigger adjustments. Inspired by the work of Guadalupe and Wulf (2010), we examine the difference between the change in innovation activities by firms in industries with larger input tariff reductions because of the WTO accession (the treatment group) and the corresponding change by firms in industries with smaller input tariff reductions (the control group).

Specifically, we propose the following specification for our DID estimation:

$$y_{fit} = \beta InT01_i \cdot Post02_t + \mathbf{X}'_{fit}\boldsymbol{\gamma} + \lambda_f + \lambda_t + \varepsilon_{fit}, \tag{1}$$

where y_{fit} is the innovation activity of firm f in industry i in year t; $InT01_i$ is the average tariff rate of inputs employed in the production of industry i in year 2001, which is used to measure the degree of input tariff reduction in industry i due to the WTO accession given that this initial tariff level is positively correlated with the degree of tariff cut; $Post02_t$ is an indicator of the post-WTO accession period, which equals one if $t \geq 2002$, and zero otherwise; λ_f is the firm fixed effect, used to control for all time-invariant characteristics of firms (as well as industries and regions); λ_t is the year fixed effect, used to control for all yearly shocks common to all industries, such as business cycles; $\mathbf{X}_{fit}$ is a set of time-varying firm characteristics; and ε_{fit} is the error term. Following Bertrand *et al.* (2004) and Amiti and Konings (2007), we cluster the standard errors at the firm level to deal with the potential

heteroskedasticity and serial autocorrelation. We control for time-varying firm characteristics ($\mathbf{X}_{fit}$) that may affect innovation activities. The characteristics include firm age, firm size, capital–labor ratio, exporting status, and equity share owned by foreign investors. The innovation of a firm may have a life cycle, and so we particularly include the square term of firm age, in addition to the linear term.

Our main interest focuses on parameter β. A positive sign of β indicates that input tariff cut increases the innovation activity of a firm, while a negative sign indicates the opposite effect. After obtaining our main empirical result from the above specification, we will conduct a series of robustness checks to confirm the finding.

2.3 Key Variables

Our empirical model (1) has two key variables: one is firm-level innovation activity (the dependent variable) and the other is industry-level input tariff (the key explanatory variable).

We can measure innovation activities by using either innovation input (e.g., R&D expenditure) or innovation output (e.g., patent applications). Different disadvantages and advantages are associated with each of these measures. Many people regard patent filing as a better measure of innovation activities because patent filing captures the effectiveness of the innovation effort (including both observable and unobservable inputs), whereas R&D expenditure is only one particular (observable) input for innovation and fails to capture the quality of innovation. Following some studies in the literature (e.g., Aghion *et al.*, 2009; Hu and Jefferson, 2009; Hashmi, 2013), we use patent filing as the measure of innovation in this study.

Our dependent variable is innovation by a firm in a given year. Consequently, we have numerous observations of zero patent filing because many firms do not have patent applications in some years. To avoid the problem of too many zeros, we construct and use the following transformed measure as our dependent 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 filing and to interpret our estimate β as the percentage change in patent filing. We prefer this transformation to other log-like transformations, such as

$\ln(Y_{fit}+1)$, because it is more flexible. However, our results are robust to using $\ln(Y_{fit}+1)$ as the dependent variable.[6]

Our key explanatory variable is the industry-level input tariffs. We construct this measure following the approach of Amiti and Konings (2007), Goldberg *et al.* (2010), and Topalova and Khandelwal (2011), who use the Input-Output Table. Specifically, the input tariff for industry i (classification in the Input-Output Table) in year t is defined as the weighted average of the tariffs of goods that are used as inputs for industry i; that is,

$$InT_{it} = \sum_j CostShare_{ij} \cdot OutT_{jt},$$

where InT_{it} is the input tariff of industry i in year t, $OutT_{jt}$ is the output tariff of industry j in year t (calculated as the simple average of tariffs of the Harmonized System (HS) 6-digit products covered in industry j), and $CostShare_{ij}$ is the cost share of industry j in the production of a good in industry i. $CostShare_{ij}$ is based on China's Input-Output Table of year 2002. Therefore, the industry classification in our study is also defined following the 2002's Input-Output Table. We use the year 2002 because the Input-Output Table is only available every five years and 2002 is the middle year of our sample period. With this construction, we define the input tariff of industry i in year 2001 as $InT01_i \equiv InT_{i2001}$, which is the main regressor we will employ in our empirical analyses.

As pointed out by Amiti and Konings (2007), one drawback of using the Input-Output Table to construct input tariff is that the industrial classification of the Input-Output Table is somewhat aggregate, and thus input tariff can only be constructed at a highly aggregate level. To obtain input tariffs at a more disaggregate level, we also construct InT_{it} by using the share of imports of industry j goods in the total imports by industry i from China's Customs Data to proxy $CostShare_{ij}$. In this latter measure, industries are defined at the 4-digit level of the China Industrial Classification (CIC). Although this measure has other drawbacks (for example, input imports are affected by tariffs, and the share does not take domestic intermediate inputs into account), it has the advantage of being more disaggregate, and we use it in our robustness checks.

[6] Another way of dealing with the zero patent filing problem is to use the Poisson model or the zero-inflated negative binomial model. However, we cannot get convergence in estimating these models, maybe because we have a large set of firm dummies and year dummies.

2.4 Data

Our empirical analysis relies on data that include information on firm-level operation, firm-level innovations, and industry-level input tariffs. To this end, we construct our unique dataset by manually merging three data sources.

Our first data source is the Annual Survey of Manufacturing Enterprises, which is maintained by the National Bureau of Statistics (NBS) of China. It includes every year from 1998 to 2007. This is the most comprehensive firm-level dataset in China; it covers all state-owned enterprises and large non-state-owned enterprises with annual sales above five million yuan Renminbi (around US$600,000). The number of firms in this dataset varies from over 140,000 in the late 1990s to over 336,000 in 2007. Firms are from all 31 provinces and direct-controlled municipalities in China and all manufacturing industries. The dataset provides detailed information of each firm, including official name, industry, and location. It also contains most operation and performance items of each firm, based on the firm's accounting statements, such as age, employment, capital, intermediate inputs, new product sales, and ownership.

Following Feenstra *et al.* (2013), we clean this dataset by dropping observations according to the basic rules of the Generally Accepted Accounting Principles. In particular, we drop firms from the data if any of the following is observed: (1) liquid assets are greater than total assets, (2) total fixed assets are greater than total assets, and (3) the net value of fixed assets is greater than total assets. We further drop firms with fewer than eight workers because they fall under a different legal regime (Brandt *et al.*, 2012), firms with obviously wrong establishing years (e.g., later than 2007 or earlier than 1900), and non-manufacturing firms (i.e., firms in mining, tobacco, and public utility industries according to the China Industrial Classification System).

Processing trade is popular in China. However, we need to drop processing-trade firms from our data for two reasons. First, according to the government policy, processing trade is exempted from import duties on imported inputs and materials; thus, the effective rate of input tariffs for processing-trade firms is zero, in both the pre-WTO and post-WTO accession periods. Input tariff reduction does not have direct effects on them. Second, processing-trade firms may have very different production functions and innovation motivation because they are provided with technologies, intermediate inputs, or product design by foreign parties.[7] However, firms engage in processing trade at different degrees.

[7] Some recent papers, for example, Ge, *et al.* (2011) and Yu (2014), use processing-trade firms as the control group

We only drop those manufacturing firms whose ratio of processing exports over their total exports is higher than 0.5.[8]

The second data source is from the State Intellectual Property Office (SIPO) of China. The dataset contains detailed information of each patent filing since 1985, including date of filing, official name and address of the applicant, name of the patent, and type of the patent classified according to China's Patent Law, i.e., whether it is an invention patent, a utility model patent, or a design patent.

We match the NBS data and the SIPO data using some common information included in both datasets. Specifically, we first merge the two datasets using the official names of firms, and then double-check the matched outcomes using the location information of the firms. Our matching outcome is reasonably good for two reasons. First, according to a report by the NBS, about 8.8% of the manufacturing firms in China ever applied for patents during 2004–2006. In this same period, the number of firms in our matched dataset constitute about 4% of the total number of firms in the NBS dataset. Given that the NBS dataset is very large (with more than 1.3 million observations after cleaning), this is a reasonably good match. Second, our matching technique is based on the names and location of firms, and we use the same technique for all industries and in the whole sample period (before and after WTO accession). Therefore, the degree of mismatch across industries does not seem to be correlated with the degree of input tariff reduction across industries. This greatly helps alleviate the potential estimation biases arising from the matching process.

Our third data source is the World Integrated Trade Solution (WITS) database, which is maintained by the World Bank. It contains tariff data at the HS 6-digit level.[9] Since the data is given at different HS versions over the years, we convert them to the HS02 version through the UN Statistics Division Concordance Table. We calculate industrial-level input tariffs by using this dataset together with 2002 Input-Output Table of China.

in their DID estimation when investigating the productivity effect of input tariff cut in China. In our view, processing-trade firms are not a proper control group for other manufacturing firms as far as innovation is concerned because the two types of firms are qualitatively incomparable and should not share a common innovation trend. Thus, using processing-trade firms as the control group will result in biased estimates. For example, if processing-trade firms do not do any innovation and there is an upward trend for the innovation of other manufacturing firms, then using the processing-trade firms as the control group will significantly overestimate the impact of the tariff cut and may even change the sign of the estimate from negative to positive.

[8] The processing export ratio of a firm is calculated using China's Customs Data, which reports information about the type of export by each exporter. We pool together a firm's exports over the period 2000-2006 in the calculation to obtain the average processing trade ratio. Our results are robust to using the annual ratio (instead of the average ratio) to identify the processing firms. The results are also robust to dropping those manufacturing firms whose processing export ratios are higher than 0.9.

[9] WITS does not provide the 2002 data and we obtain the 2002 data from the WTO.

We construct our unique dataset by merging the above three databases. The matched dataset has an unbalanced panel of 337,257 firms and a total of around 1.3 million observations, with both detailed patent filing information and firm characteristics in the period of 1998–2007. Our analyses are based on this unique dataset.

In the robustness checks later, we need to identify the processing trade status of firms (that is, whether it is a processing trade firm or not) and their importing status (that is, whether the firm imports inputs directly or not). This requires information from another data source, which is China's Customs Data (2000-2006). To this end, we also merge the Customs Data with the NBS Data by using the same method as Yu (2014).

It is worth pointing out that Ge *et al.* (2011) and Yu (2014) use the merged Customs and NBS data in their studies, whereas we use it only for a robustness check. Specifically, they confine their analyses to manufacturing firms that also make direct imports, which we call direct importers. They omit a large number of manufacturing firms that do not make direct imports, which we call non-importers. However, non-importers may buy imported inputs from intermediaries and employ these inputs in their production. As pointed out by Goldberg *et al.* (2010), using the sample of direct importers may result in a bias. In the main analysis of our study, we use the whole NBS dataset. Therefore, our analysis will provide a more complete picture of how input tariff cut affects the innovation of firms.

Table 1 presents the summary statistics and definitions of the main variables used in this study. Overall, a Chinese manufacturing firm applied for 0.15 patents per year on average, and the patent applications increased significantly from the pre-WTO accession period to the post-WTO accession period. Input tariff and output tariff decreased significantly due to the WTO accession. Almost all firm-level performances and industrial characteristics were improved. The degree of industrial competition also increased after 2001.

<Table 1>

One potential concern is whether our key explanatory variable, the 2001 input tariff levels, is exogenous, to individual firms. This concern is generally legitimate, but it is alleviated by the observation on the actual liberalization process in China. As shown in Figure 2, both the mean tariff rate and the standard deviation remain quite constant in the 1998-2001 period. This feature implies that the stability of tariffs holds not only for industry average, but also for individual industries. Thus, the input tariffs in 2001 were largely determined by the previous round of liberalization in 1997. That

is, tariff rates in 2001 are *pre-determined* before our sample period and do not seem to be affected by innovation activities during the pre-WTO accession period. This finding can be confirmed by the data. Following Goldberg *et al.* (2010), we regress industrial innovation activities in the pre-WTO accession period on the tariff rates in 2001 and find that the tariff rates in 2001 are uncorrelated with the innovation activities (see Table 2). As shown in Table 2, other industrial performances are not correlated with the 2001 input tariff rates either. This independence result also holds for the actual input tariff cuts because of the WTO accession (instead of the initial tariff rates in 2001). This observation also implies that either the users of imported inputs did not engage in serious lobbying activities during 1998-2001, or the lobbying by the users of imported inputs was not effective.

In fact, it is commonly regarded that the timing of China's accession to WTO is an exogenous shock at least to individual firms. For this reason, a number of studies such as Fan *et al.* (2014) and Bloom *et al.* (2015) use it as an exogenous variable to proxy China's trade liberalization. We also take this approach.

<Table 2>

3 Empirical Analysis and Findings

3.1 Main Results

Table 3 presents the regression results based on our DID specification (1), with control variables introduced step by step. All estimations show that input tariff reduction leads to a decline in the innovation of firms. In column 1, with only firm fixed effect and year fixed effect being controlled for, we find a statistically significant and negative estimate for $InT01_i \cdot Post02_t$. The negative sign indicates that after China's WTO accession, firms in industries facing a larger cut in input tariffs (higher $InT01_i$) undertake less innovation. In column 2, we include some time-varying firm characteristics that may influence innovation activities, such as age, size, capital–labor ratio, export status, and equity share owned by foreign investors. Evidently, the negative effect of input tariff reduction on innovation is very robust to these additional controls. As for the effects of the control variables, we find that firms having a shorter history, larger employment, or higher capital-labor ratio have more innovations. Exporters also have more innovations than non-exporters, consistent with the finding in the literature (e.g., Baldwin and Gu, 2004). However, the effect of foreign ownership is

not statistically significant. As shown below, these findings are also robust after we introduce other control variables and use alternative measures of the key explanatory variable.

<Table 3>

China's WTO accession brings changes in both input and output tariffs. Output tariff change may affect the market competition in China and consequently influence the innovation incentives of firms. In column 3, we add a control for industrial output tariff $OutT_{it}$. We find that the estimate of $InT01_i \cdot Post02_t$ is still negative and statistically significant with a very similar magnitude. As for the effect of output tariff on innovation, we find that it is statistically insignificant, which holds even when we introduce additional control variables and use alternative measures of the key explanatory variable.[10] That is, input tariff liberalization has a stronger impact on firm innovation than output tariff liberalization. This comparison is similar to the findings in the literature which focuses on firm productivity. For example, Amiti and Konings (2007) disentangle the effect of input tariff reduction from that of output tariff reduction and find that the input tariff effect is at least twice as high as the output tariff effect in Indonesia.

If there are other policy reforms that were introduced around the time of the WTO accession and may affect our treatment and control groups differently, then the effects of those policy reforms will also be included in the DID estimates. In that case, the regression result from (1) will not be the pure effect of input tariff cuts. Indeed, two important reforms took place in the early 2000s: the SOE reform and the relaxation of FDI entry regulations. These are on-going reforms that had started in the 1980s and 1990s, respectively, and accelerated after the WTO accession. The SOE reform results in a large-scale privatization, close-down of small SOEs, and efficiency improvement in the surviving (large) SOEs. The new FDI regulations relax the entry requirement for foreign investors and reduce the range of industries restricted to foreign investment. These reforms may not have differentiated impacts on the treatment group and the control group. However, to control for any possible confounding effects from these two policy reforms, we include two additional control variables in our DID estimation: $SoeShare_i$ (measured by the ratio of the number of SOEs over the number of domestic firms) and FDI_i (measured by the logarithm of the number of foreign invested firms). The regression result [column (4)] shows that the negative effect of input tariff reduction on innovation is

[10] Bloom *et al.* (2015) find that trade liberalization that leads to more Chinese imports in Europe increases innovations of the European firms.

still present. Firms in industries with higher SOE shares tend to do less innovation, possibly because SOEs do less innovation on average, or the presence of SOEs in the market crowds out the innovation activities of private firms. However, the presence of foreign firms has no significant effect on the innovation activities of domestic firms.

Thus far, we have used the year 2001 input tariff rate, $InT01_i$, to represent the degree of tariff liberalization from China's WTO accession.[11] We have strong reasons for this measure instead of using the yearly input tariff rate as the key explanatory variable or using the actual input tariff reduction to interact with $Post02_t$. First, the schedule of tariff reductions upon WTO accession was released in 2002, and the schedule may be endogenous; hence, the phase-out process could be exploited by the firms (Guadalupe and Wulf, 2010). Second, the initial input tariff is pre-determined in China. For this reason, Amiti and Konings (2007) in their analyses also employ the initial tariff as the instrument for the actual tariff change. However, even though our choice of $InT01_i$ is well justified, we still want to check whether the results will be qualitatively different if those alternative measures are used. We first replace $InT01_i$ with the actual input tariff change, denoted as $DInT_i$. We define $DInT_i = InT_{i1998-2001} - InT_{i2002-2007}$, where $InT_{i1998-2001}$ is the average input tariff over the period 1998-2001, and $InT_{i2002-2007}$ is the average input tariff over the period 2002-2007. In column 5, we run the regression by replacing $InT01_i \cdot Post02_t$ in model (1) with $DInT_i \cdot Post02_t$. The effect of input tariff reduction is still statistically significant, negative, and even stronger than that using $InT01_i$. We then run the simple OLS regression with yearly input tariff level, denoted as InT_{it}, as the key regressor, i.e., replacing $InT01_i \cdot Post02_t$ in model (1) with InT_{it}. Column 6 shows the regression results. The coefficient of InT_{it} is positive and statistically significant, indicating that lower input tariff leads to significantly less innovation. Both results are qualitatively consistent with our DID estimations.

We have followed a common practice in the literature (e.g., Goldberg *et al.*, 2010) to calculate industry-level input tariff using Input-Output Tables. However, as pointed out earlier, such an approach is restrictive in the sense that the obtained input tariff is available only for industries classified at a highly aggregate level. To obtain input tariffs at a finer level of industry disaggregation, we need to find a way that does not rely on Input-Output Tables. The approach we take is to calculate the weighted average industry-level input tariff at the CIC 4-digit level, denoted as $InTA01_i$, by using

[11] Using the average tariffs over 1998–2001 or tariffs in 1998 generates similar results. The results are available upon request.

the import share constructed from the China's Customs Data as the weights, instead of using the cost share constructed from the Input-Output Table. We replace $InT01_i$ by $InTA01_i$ to run the regression with this new $InTA01_i$. The results are reported in column 7. The effect of input tariff reduction on innovation remains negative and statistically significant.

In summary, we find that input tariff cut reduces the innovation of firms. This finding is statistically significant and robust to various model specifications and input tariff measures. The impact is also economically significant. For example, with the estimated coefficient (-0.2847) in the specification with actual tariff cut as the key regressor (column 5), the average 4.64% input tariff cut due to China's WTO accession reduces the patent filings of firms by 0.0132. This decrease is quite significant because the average patent filings of the whole sample is just 0.1507. That is, the patent filings of firms drop by 8.76% as a result of the input tariff liberalization.

3.2 Validity of the DID Specifications

The reliability of our estimates, reported in Table 3, depends on the validity of our DID specifications. In this subsection, we conduct a series of validity checks**.** The new regression results are presented in Table 4, which confirms the validity of our specifications.

<Table 4>

Industry-specific time trend. In the DID estimation, we assume that, conditional on $\left(\mathbf{X}'_{fit}, \lambda_f, \lambda_t\right)$, innovation activities of the treatment and control groups follow the same time trend. This assumption allows us to use innovation activities of the control group as the counterfactual of the treatment group in the post-WTO accession period. However, the innovation trends in different industries (or different groups) could be different because they may be affected by some industry-specific confounding factors. To check whether some unobserved industry-specific factors would bias our estimates, we add an industry-specific linear time trend, $\lambda_i \cdot t$, to model (1). This addition enables us to control for all unobserved industry characteristics if they affect firm innovation in the form of a linear time trend. The regression result for the key explanatory variable is presented in column 1 of Table 4. The estimate is -0.1981, which is negative and statistically significant. Thus, our estimate is not driven by any unobserved industry characteristics.

Placebo test I: Pre-WTO accession period. Following Topalova (2010), we conduct our first placebo test to examine the effect of input tariffs on firm innovation in the pre-WTO accession period (1998–2001). The premise is that as tariffs did not change much during that period we should not expect any significant effect of input tariffs on innovation; if the result is the contrary, then it indicates existence of some underlying confounding industrial factors (other than the WTO accession) that drive innovation. Accordingly, we replace $InT01_i \cdot Post02_t$ by InT_{it} in (1) and run the regression for the sample in the pre-WTO accession period. The estimates are given in column 2 of Table 4. The effect of InT_{it} is not statistically significant. Hence, we can rule out the possibility that some underlying confounding factors drive innovation.

Placebo test II: Subsample of processing-trade firms. In our second placebo test, we run the regression model (1) by using the subsample of processing-trade firms. As processing-trade firms enjoy zero input tariff rate in the entire period, their innovation decisions should not be affected much by the input tariff liberalization from China's WTO accession, and the estimation using the sample of processing-trade firms should produce an insignificant liberalization effect. We use two criteria to define processing-trade firms. One includes all firms with the average ratio of processing exports over total exports larger than 90%, and the other consists of firms with the average ratio larger than 50%. The processing export ratio is identified based on the merged dataset between China's Customs Data and the NBS Data.

The regression results are presented in columns 3 and 4 for the 90% criterion and the 50% criterion, respectively. It is clear that the coefficient of $InT01_i \times Post02_t$ in both cases is highly insignificant, confirming the conjecture. This test suggests that manufacturing firms adjust their innovation activities in response to input tariff reduction after the WTO accession if, and only if, their imported inputs are really affected by tariff reduction.

Flexible estimation. In our main DID regression model, we use one time dummy variable, $Post02_t$, to separate the pre-WTO accession period and the post-WTO accession period. The estimate from the interaction term, $InT01_i \times Post02_t$, yields the average treatment effect, which compares the difference between the treatment group and the control group in their *average* differences between the pre-WTO and post-WTO accession periods. We now compare the difference between the treatment and control groups for *every* year in the entire period. Specifically, we use a flexible estimation specification which replaces the interaction term $\beta InT01_i \times Post02_t$ in model (1) with a series of

interaction terms between $InT01_i$ and the year dummies, that is, $\sum_{t=1999}^{2007} \beta_t InT01_i \times t$. We run this regression and report the results in column 5 of Table 4. The estimated coefficients are statistically insignificant for all the years before 2001, but become negative and statistically significant for every year from 2001 onwards and the magnitudes become larger and larger. These results clearly indicates the similarity between the two groups before the WTO accession, the innovation-reducing effect of input tariff cuts, and the increasing trend of the effect.

3.3 Robustness Checks

In this subsection, we further check the robustness of our results to address some other concerns. All results are presented in Table 5.

<Table 5>

Industrial competition. The degree of market competition is well known to affect innovation activities, as shown in the innovation literature. In the main model, we have taken into account changes in import competition because of China's output tariff reduction. We now further control for the overall industrial competition by including the Herfindahl–Hirschman Index (HHI) in the model. The new variable, HHI_{it}, is the HHI for industry i in year t. Column 1 of Table 5 shows that our result is robust to including the competition variable.

Export opportunity. While China undertook large trade liberalization during the period of 1998-2007, trade liberalization also happened in other countries. When foreign countries lower their tariffs on Chinese products, the market opportunity for Chinese exporters is enlarged, which may also induce them to adjust their innovation decisions. We handle this issue in two ways. First, we control for the export expansion opportunity by adding a term of industrial total exports, $InExp_{it}$. The regression results are reported in column 2 of Table 5. We find a positive and significant effect of industry export on a firm's innovation activity (estimated coefficient 0.0042). More importantly, the estimate of our key variable, $InT01_i \times Post02_t$, remains negative and statistically significant. Second, to isolate the export expansion effect, we run the regression using the subsample of non-exporting firms. The results are reported in column 3 of the table. It is clear that the main result also holds for this sub-group of firms.

Multi-product firms. Many firms produce multiple products that may span over different industries.[12] Thus, our dependent variable (i.e., a firm's total number of patent filings) may cover many industries that experience different degrees of input tariff cut. This will lead to an imprecise estimation of the impact of input tariff cut on firm innovation. To check whether our result is contaminated by this problem, we restrict our analysis to a subsample of firms that produce products all belonging to the same 3-digit industry.[13] We run the regression (1) based on this subsample of "single-industry" firms and find that the impact of input tariff reductions on innovation remains negative and statistically significant, as shown in column 4 of Table 5.

Surviving firms. We note from the summary statistics in Table 1 that there is a decrease in average age of firms. This observation implies a significant number of firms entering after 2001. From the data we also observe a significant number of firms exiting. If the new entrants and/or exiting firms have different innovation behaviors, our estimation results obtained earlier may just capture the selection effect, instead of the true effect of input tariff reductions. To check whether our estimates are driven by entry and exit, we focus on a subsample of surviving firms (i.e., firms in both the pre- and post-WTO accession periods). Results are reported in column 5 of Table 5. We still find negative impact of input tariff reductions and the magnitude becomes even bigger, implying that the selection from entry and exit does not drive our findings and, if it dose, it only biases our estimate downwards at the most.

Two-period estimation. The DID estimation and resulted statistical inference crucially depends on the accuracy of the standard errors. In the main analysis, we have followed Bertrand *et al.* (2004) to cluster the standard errors at the firm level. As a robustness check, we now use another approach, which is also suggested by Bertrand *et al.* (2004), to calculate the standard errors. In particular, we first collapse the panel structure into two periods (pre-WTO accession and post-WTO accession) and then use the White-robust standard errors. The regression results are presented in column 6 of Table 5. Evidently, the results are qualitatively similar to the ones obtained before.

[12] Note that each firm reports one industry which it belongs to in the NBS survey even if it is a multi-product firm spanning over many industries.

[13] We obtain product-level data from the NBS of China for the period 2000-2006, which contains the information about each product (defined at the 5-digit product level) produced by every firm. As the product-level data and the NBS data use the same firm identity, we can easily match these two datasets and thus identify firms producing all goods within only one 3-digit industry.

3.4 Heterogenous Impacts

Firms are heterogeneous in many dimensions, and so are innovations. We explore the possible heterogeneous impacts of input tariff reductions on innovations. Results are reported in Table 6.

<Table 6>

Types of Innovations. Our data have detailed information with regard to the types of innovations. In China, patents are classified into three categories by Patent Law, namely, invention, utility model, and design. 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. The requirements for obtaining each of the three patents are very different, with the invention application being the most difficult and the design application being the easiest. Thus, it is reasonable to ask whether the impacts of input tariff cuts on these innovations are also very different. Columns 1-3 present the empirical results obtained from regressions based on each of the three types of innovations. We find that input tariff cuts reduce all types of innovation significantly.

Capital intensity. Industries are different in many dimensions, which could potentially affect firms' responses to input tariff reductions. Capital-labor ratio, or simply called capital intensity, is a determinant of innovations, and it differs significantly across industries. To ascertain if the main result of our analysis is sensitive to industry differences in capital intensity, we rerun the regression by using a subsample of industries with high capital intensity and a subsample of industries with low capital intensity, respectively. To construct the two subsamples, we calculate the capital-labor ratio of each 4-digit CIC industry in the pre-WTO accession period (the simple average of the ratios in those years). The low capital-intensity industry group includes all industries with a capital intensity lower than the 25th percentile of the entire sample, and the high capital-intensity industry group includes all industries with a capital intensity higher than the 75th percentile of the entire sample. Column 4 of Table 6 reports the regression results from the low capital-intensity group while column 5 reports those from the high capital-intensity group. We find negative impacts of input tariff reduction on innovation in both groups. The impact is stronger for firms from the high capital-intensity industries than from the low capital-intensity industries. This comparison is consistent with the fact that firms with high capital-intensity do more innovations and are thus affected more.

Distance from technology frontier. Aghion *et al.* (2009) argue that the distance from the world's technology frontier is an important factor determining firm responses in innovation to market competition. Here we explore whether the input tariff reductions also lead to different responses by firms with different distances from the world's technology frontier.

We divide the sample into five quantiles based on the average total factor productivity (TFP) of the firms in the pre-WTO accession period.[14] Quantiles are constructed within each CIC 4-digit industry. We run regressions for the subsample of the first quantile firms (i.e., firms far away from the frontier) and the subsample of the fifth quantile firms (i.e., firms close to the frontier), respectively. Columns 6 and 7 report the results. We find that for low-productivity firms, the impact of input tariff reductions on innovation is insignificant, but for high-productivity firms, the impact is significantly negative. One possible reason for such a difference is that low-productivity firms do not use much imported intermediate input in their production or do not actively engage in innovation, and thus, their innovation activities are not sensitive to the change in input tariffs.

Ownership. With regard to ownership structure, three types of firms primarily exists in China: SOEs, domestic private firms, and foreign invested enterprises (FIEs). FIEs are all business entities established in China with part or all of foreign capital. They include both Sino-foreign joint ventures and wholly foreign-owned enterprises. It is interesting to know whether firms with different ownership structures have different responses to input tariff reduction. Columns 8-10 show the results for SOEs, domestic private firms, and FIEs, respectively. All types of firms reduce their innovations significantly in response to input tariff liberalization. The negative effect on SOEs is the weakest. Perhaps, the innovation incentives of SOEs are less responsive to the market and cost conditions. The effect on FIEs is the strongest, which may suggest that they depend more on imported intermediate inputs for production and innovations.

Direct importers and non-importers. We can classify firms into two groups, one group being direct importers, who import intermediate inputs directly by themselves, and the other group being non-importers. While direct importers are obviously affected directly by input tariff cuts, non-importers may also be affected indirectly because they may purchase imported inputs from the intermediaries. Amiti and Konings (2007) show that direct importers in Indonesia are affected by

[14] TFP is estimated using the Levinshon and Petrin (2003) method at the level of the two-digit CIC industry and with information of value added, employment, fixed assets, and intermediate inputs. All nominal variables are deflated using the deflators from Brandt et al. (2012).

tariff reductions more than non-importers. We now examine whether the difference obtained for Indonesian firms also exist for Chinese firms. We do so by running regressions using the sample of direct importers and that of non-importers, respectively. Columns 11 and 12 show the impact on direct importers and non-importers, respectively. We find that both types of firms reduce their innovations, and direct importers reduce more than non-importers.

4 Mechanism: Input Quality or Quantity?

We now check how the intermediate input imports of firms respond to the tariff cuts. Specifically, we investigate how input tariff cuts affect the value (exclusive of tariffs), quantity, and quality (or price, exclusive of tariffs) of the intermediate input imports.

The model of endogenous input and output quality choices proposed by Kugler and Verhoogen (2012) can be borrowed to provide insights on how firms respond to intermediate input tariff cut by adjusting their decisions. Let us focus on some key elements of their model without firm heterogeneity. The model assumes a fixed cost of production and a fixed cost of investment in output quality, f_q, which we can treat as innovation cost (innovation to raise product quality). $p_I(c)$ is the price of an intermediate input of quality c. For output quality, suppose that there exists substitution between input quality and investment in output quality, i.e., either quality investment or input quality can raise output quality. Firms need to choose c and f_q optimally. In response to an input tariff cut, firms may switch from importing low-quality inputs to high-quality inputs as $p_I(c)$ drops for the same input quality, or they may employ more imported inputs in their production. In the former case, firms can maintain the same output quality by reducing quality investment f_q. We will examine whether this is the response observed from Chinese data.

From China's Customs Data, we obtain detailed information about tariff and imports at the HS 6-digit level; thus, our regressions are conducted at this disaggregate level. To process the data before running the regressions, we first drop all processing imports. We then identify imports of intermediate inputs using the Classification by Broad Economic Categories (BEC) published by the United Nations Statistics Division. This classification requires us to convert product affiliations in all the years before 2002 to the HS2002 version with the concordance table from the United Nations Statistics Division.

Following Goldberg *et al.* (2010), we conduct the regression analyses (for import value, quantity

and price, respectively) based on the following model:

$$y_{ijt} = \alpha Tariff01_i \cdot Post02_t + \lambda_i + \lambda_t + \lambda_j \cdot t + \varepsilon_{ijt},$$

where y_{ijt} is, respectively, the logarithm of import value, quantity, or unit value of intermediate input i (at HS 6-digit level) of industry j (at HS 2-digit level) in year t; $Tariff01_i$ is the tariff of product i in year 2001; $Post02_t$ is the WTO accession dummy as defined previously; and ε_{ijt} is the robust error term. We control for product fixed effect (λ_i) and year fixed effect (λ_t) in all regressions. Because industries may have differentiated time trends, we further control for HS 2-digit industry-specific linear time trend (λ_j).

The regression results are reported in Table 7. For each dependent variable, we run the regressions for the whole sample, for the OECD country sample, and for the non-OECD country sample, respectively. The results are as follows.

As argued above, in response to input tariff cuts, firms may switch from importing low-quality inputs to high-quality inputs. If this is the case, then there will be implications for import quantity, price and value. Higher quality means higher price. This is confirmed by columns (1)-(3). From production's point of view, input quantity and quality are substitutes, and so we will expect import quantity to drop, which is again confirmed by columns (4)-(6). If price increases while quantity decreases, the change in value is ambiguous. Nevertheless, we find that imported value also decreases, as shown by columns (8)-(10).

An alternative way to proxy input quality is to look at the origin of the exporting country with OECD countries' exports representing higher quality. Although both quantity and value drop, the share of OECD increases in both quantity [column (7)] and value [column (11)], lending further support to the quality switch.

As intermediate inputs are classified into intermediate goods and capital goods in the BEC classification, we also check the two types of intermediates separately and the results are similar.

5 Conclusion

The impact of trade on innovation has long been a hot topic in both academic and policy circles. Trade in intermediate inputs has become increasingly more important. This paper investigates the

impact of intermediate input trade liberalization on firm innovation, which complements the emerging literature that investigates the impact of intermediate input trade liberalization on firm performance from different perspectives, for example, productivity, product scope, and product quality.

By exploiting the quasi-natural experiment of China's WTO accession in 2001 and the rich data on Chinese firms from 1998 to 2007, we find that input tariff reductions in China reduce the innovations of Chinese firms. This result is robust to a series of model specifications, and significant both statistically and economically.

The driving force underlying the negative effect of intermediate input imports on firm innovation is that high-quality input imports substitute for the internal innovation of firms. Intermediate input imports can be complements to internal innovation in the sense that high-quality inputs help lower the innovation cost. On the contrary, cheaper intermediate inputs from abroad can be substitutes for firm innovation because firms can buy instead of making them. Our empirical evidence shows that the input tariff cut leads firms to import less, but higher-quality, intermediate inputs, and the substitution effect dominates the complementarity effect.

Although the result is somewhat surprising, it is not incompatible with results obtained by other studies on the impact of intermediate input tariff reductions on other performances of Chinese firms, such as productivity (Yu, 2014) and export quality (Fan *et al.*, 2014; Bas and Vanessa, 2015). Introducing a general theoretical framework that can produce all these results and provide a clear mechanism is an attractive prospect. Such a model will also be helpful to predict whether our negative effect will present in some other countries. In addition, further empirical studies on the experiences of other countries about the impact of intermediate input liberalization on innovation are encouraged, such as Goldberg *et al.* (2011) on India.

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