What You Import Matters for Productivity Growth: Experience from Chinese Manufacturing Firms*

Jiawei Mo, Larry D. Qiu, Hongsong Zhang, and Xiaoyu Dong†

Abstract

This paper investigates the distinct effects of capital and intermediates imports on productivity growth at the firm level, and quantifies the importance of tariff structure in trade liberalization in developing countries. Using a large panel of Chinese manufacturing firms, we demonstrate that capital imports have a much larger productivity effect than intermediates imports. While both types of imports exert immediate effects on productivity, capital imports have dynamic productivity effects and induce more R&D investment. The mere change in tariff structure explains 18 percent of the productivity gains from the input tariff liberalization following China's accession to the WTO.

Keywords: productivity; imported inputs; capital goods; intermediate goods; R&D; tariff liberalization.

JEL Codes: F14, O10.

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†Jiawei Mo, School of Economics, Peking University, E-mail:jwmo@pku.edu.cn; Larry D. Qiu, Department of Economics, Lingnan University, E-mail:larryqiu@lu.edu.hk; Hongsong Zhang, Faculty of Business and Economics, University of Hong Kong, E-mail:hszhang@hku.hk; Xiaoyu Dong, Hong Kong Monetary Authority, E-mail:xydong@hku.hk.

1 Introduction

How international sourcing influences productivity remains an important question in development economics and international trade. On one hand, the development literature has shown that imported capital goods from developed economies improves productivity in less developed countries through international technology diffusion (Lee, 1995; Mazumdar, 2001; Keller, 2004). On the other hand, the international trade literature finds evidence that international sourcing in general—without distinguishing capital from intermediate goods—improves the productivity of importers due to more variety, better quality, and learning (Amiti and Konings, 2007; Halpern, Koren, and Szeidl, 2015). Identifying the channels of productivity gains from international sourcing is very important for trade/development policy decisions.

This paper investigates the distinct effects of capital and intermediates imports on productivity growth at the firm level, and quantifies the importance of tariff structure in trade liberalization in developing countries. Intermediate goods, such as materials, parts, and accessories, are usually one-off consumable in one accounting period. They typically affect firm productivity in the period when the firm uses them in production. By contrast, capital goods, such as equipment, machine tools, lathe, and industrial robots, can typically be used for multiple periods. As a result, capital goods can affect firm productivity for a longer time than intermediate goods. Importantly, capital imports serve as a good proxy for international technology diffusion since capital goods production is highly concentrated in a few R&D-intensive countries (Eaton and Kortum, 2001). In addition, capital goods imports may induce R&D investment if complementarity exists, which further enhances productivity in the long run.

We identify and quantify the distinct productivity effects of importing capital and intermediate goods through three channels: the *immediate productivity effect*, *dynamic productivity effect*, and *R&D-inducing effect*. The immediate productivity effect corresponds to the "quality and variety effects" of importing discussed in the literature.[1] The dynamic productivity effect focuses on the long-term impacts, echoing learning from importing or technology spillover effects. The R&D-inducing effect captures the potential impact of international sourcing on R&D investment, which further promotes firm productivity.

We first show that capital importers are larger, more productive, and invest more in R&D in China, compared with intermediate importers and firms that do not import. Capital import also triggers higher growth rate of sales, labor productivity, and R&D investment, compared with intermediate importers and non-importers. Motivated by these facts, we describe the distinct gains from importing capital and intermediate goods through the lens of a structural model, which describes firms' decisions on imports, investment, and R&D in a dynamic setting. The model also captures how importing capital and intermediate goods may influence the importers'

[1] See, for example, Kasahara and Rodrigue, 2008; Goldberg, Khandelwal, Pavcnik, and Topalova, 2009, 2010; Topalova and Khandelwal, 2011; Halpern,Koren, and Szeidl, 2015.

productivity differently through the aforementioned three channels. We quantify the empirical importance of these effects by estimating the model using the standard production estimation approach developed by Olley and Pakes (1996) and Levinsohn and Petrin (2003).

We apply our model to a large panel of Chinese manufacturing firms during 2000-2006. The empirical findings confirm that productivity gains arise from all three channels mentioned above. First, importing capital goods alone and importing intermediate goods alone have immediate productivity effects: they raise the importer's productivity within a year by 2.3% and 1.8%, respectively, compared with non-importing firms. When importing both, the productivity gain is even higher, by 1.5%, due to the complementarity of using imported capital and intermediate goods. Second, the dynamic productivity effect of importing capital goods is strong, which is represented by an 0.6% increase in productivity of the importers in the next period. By contrast, the dynamic productivity effect of intermediates imports is insignificant statistically and economically. Third, the R&D-inducing effect exists from capital imports but not from intermediates imports: the capital importers' probability of conducting R&D increases by 2.5%.

Our empirical analysis is guided by the structural model, which allows us to identify the causal effects of imports on productivity and R&D investment based on the timing assumption that is commonly used in the literature: import decisions are made one period ahead and, thus, they are uncorrelated with non-structural productivity shocks. Our results are robust when we relax this timing assumption and use an instrumental variable (IV) approach, in which we use the differential changes in import tariff rates of capital and intermediate goods at the four-digit industry level as the IVs for firms' import decisions. Our results are also robust to various alternative specifications of the model and different estimation methods.

Based on our empirical findings, we conduct quantitative exercises to show that international sourcing improves the average productivity of importing firms by 2.44% in China's manufacturing sector during 2000-2006, of which over 50% is contributed by capital imports. This large gain from capital imports is striking because capital imports account for only one-sixth of the total value of input imports. Consequently, one dollar of capital imports generates 13 dollar more in sales compared with one-dollar use of domestic capital inputs, whereas one dollar of intermediates imports yields 2.2 dollar more in sales compared with one-dollar use of domestic intermediate inputs. For capital imports, 25% of the productivity gains arise from the dynamic productivity effect and R&D-inducing effect.

We apply the model to China's accession to the WTO at the end of 2001 to quantify the impact of the input tariff liberalization (especially changes in tariff structure) on firm productivity. Following the WTO accession, China reduced the tariffs of capital imports more than those of intermediates imports, by approximately two percentage points. The differential productivity effects of capital and intermediate imports directly highlight the importance of tariff structure in liberalization, besides the changes in average tariff level. Simulation based on our structural model reveals that the tariff reduction increases the average productivity of the marginal importers by approximately 1.5% from 2002 to 2006,[2] of which 18% is contributed by the change in tariff structure.

The paper contributes to the development literature that examines the importance of international technology spillover via international trade. The literature focuses mainly on the imports of capital goods and is inconclusive. Using aggregate data, one set of studies find that capital imports are quantitatively important in explaining the differences of economic growth and productivity across countries (e.g. Coe and Helpman, 1995; Lee, 1995; Mazumdar, 2001; Eaton and Kortum, 2001; Mutreja, Ravikumar, and Sposi 2018),[3] while Keller (1998) documents a weak relationship between technology-embedded imports and productivity growth, casting doubts on the importance of imports as a channel of technology diffusion. Using firm-level data, Keller and Yeaple (2009) find that the spillover effects of import on firm TFP is insignificant in the United States; Hasan (2002) finds that the spillover effects of imported capital goods on firm's output is even smaller than that from domestic capital goods for Indian manufacturing firms. Our paper contributes to this literature by accounting for the distinct effects of capital and intermediates imports. It documents the strong positive effect of capital imports on productivity growth in the short and long run. It highlights the importance of tariff structure for productivity growth in developing countries when liberalizing input tariffs.

The paper also contributes to the international trade literature that examines the impact of international sourcing on productivity growth using firm-level data. The majority of the studies in this literature find a positive effect of international sourcing on productivity growth, through increased variety of imported inputs (e.g. Bas and Strauss-Kahn, 2014; Halpern, Koren, and Szeidl, 2015), reduced input prices (Grieco, Li, and Zhang, 2017), learning by importing (e.g. Kasahara and Rodrigue, 2013; Zhang, 2017; Grieco, Li, and Zhang, 2017). Amiti and Konings (2007) and Topalova and Khandelwal (2011) also demonstrate that trade liberalization can increase productivity more than from reduced output tariffs (competition effect). However, a number of studies find insignificant productivity gains from access to advanced foreign inputs in Columbia (Van Biesebroeck, 2003), Brazil (Muendler, 2004) and Germany (Vogel and Wagner, 2010), and show that the observed positive correlation between productivity and import is due to sorting. As a common feature, these studies do not distinguish capital and intermediates imports. We contribute to the literature by considering the distinct effects of capital and intermediates imports, and show that capital import is the more important source of productivity gains from international sourcing, especially in the long run.

[2]Marginal importers are defined as the group of firms that change their import decisions from not-import to import in response to a tariff change. They account for around 6.6% of total firms, or 50% of the importing firms, in our sample.

[3]A few papers focus on the relations between capital goods imports and skill-biased technology (Burstein, Cravino, and Vogel, 2013; Parro, 2013; Li, Li, and Ma, 2015; Koren and Csillag, 2017). Bas and Berthou (2012) study the determinants of firms' choices to import capital goods and find that firms with less financial constraints are more likely to import capital goods.

Our paper is also related to the literature on innovation, which is of vital importance for the productivity growth in developing countries. Three papers are most related. Bøler, Moxnes, and Ulltveit-Moe (2015) find that R&D tax credit in Norway in 2002 stimulated not only R&D investments but also intermediates imports. Bloom, Draca, and Van Reenen (2016) reveal that Chinese import competition in Europe leads to increased innovation within firms and employment reallocation between firms toward more technologically advanced firms. Liu and Qiu (2016) show that input tariff cuts in China result in less patent applications by Chinese firms, indicating a possible substitution between imported inputs and domestic R&D. By separating capital import from intermediates import, we document the strong effect of capital import on R&D investment, whereas the effect of intermediates import is insignificant.[4] This result suggests that what the firms import matters for R&D investment, again emphasizing the importance of tariff structure in stimulating R&D investment in developing countries.

The rest of the paper is organized as follows. Section 2 presents the data and stylized facts of capital and intermediate goods imports in China. Section 3 introduces the structural model and describes the estimation specifications. Section 4 presents the empirical results. Section 5 evaluates the relative contributions of capital and intermediate imports. Section 6 quantifies the role of tariff structure in trade liberalization. Section 7 concludes.

2 Data and Stylized Facts

2.1 Data

We use two micro-level datasets in China for empirical analysis. The first is the Annual Survey of Industrial Enterprises (ASIE) maintained by the National Bureau of Statistics of China (NBS) from 1998 to 2007, which covers all state-owned enterprises (SOEs), and non-SOEs whose annual sales are no less than RMB 5 million (around USD 0.72 million, depending on the actual exchange rates). The dataset includes more than 100 variables covering detailed information on firms' inputs, outputs, and other production-related information. We clean the data by dropping obviously abnormal observations according to the basic rules of the Generally Accepted Accounting Principles. In particular, we drop firms from our sample 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 are greater than total assets. We also drop firms with fewer than eight employees. In total, we drop 1.77% of the firms, most of which are firms with fewer than eight employees.

The second dataset is China's General Administration of Customs (GAC), which contains highly disaggregated transaction-level import and export information during 2000-2006. The

[4]In contrast, Hasan (2002) finds that capital imports dampen domestic R&D incentives.

information of each transaction includes the eight-digit product code of the traded goods, source or destination country, trade type (i.e., ordinary or processing trade), price, quantity, and value of the transaction. We aggregate the dataset to annual frequency to merge with the ASIE data.

The two datasets use different firm identifiers, but both include detailed firm-specific contact information (e.g., company name, zip code, contact person, telephone number, and registration address). We merge the two datasets using contact information. Eventually, 17% of the firms in our ASIE dataset are matched with the Customs data.[5] Table 1 reports the basic summary statistics based on our merged dataset. The data contain 431,039 individual firms and 1,414,173 observations, and 12.4% of the firms have engaged in direct import.

[Insert Table 1 around here]

Trade can be classified into ordinary and processing, and many Chinese firms engage in processing trade. In ordinary trade, firms purchase inputs either from domestic or foreign markets and fully control the production and sales decisions. In processing trade, at least a certain portion of the inputs is sourced abroad, and the outputs must be exported. The foreign sourced inputs can be purchased (processing trade with imported material) or provided by the foreign entity who purchases the outputs (processing trade with assembly). In the main analysis, we focus on ordinary trade. In Section 4.6, we evaluate the impact of processing imports and discuss its implication.

2.2 Product Classification

We classify imported inputs into capital and intermediate goods, using the Broad Economic Categories (BEC) developed by the United Nations Statistics Division. The BEC classification contains 19 basic categories of goods and services, which are grouped to three broad classes: intermediate goods, capital goods, and consumption goods. Table A1 in the Appendix provides the details of the classification. The classification is based on the nature of the goods and their end uses. Both intermediate and capital goods are used in the course of production, whereas consumption goods are utilized by individuals or communities to satisfy their needs. The distinction between intermediate and capital goods depends on whether these goods are completely used up in an accounting period. Capital goods are used repeatedly or continuously during production over certain accounting periods, whereas intermediate goods are used up in one accounting period.

The BEC product classification is based on BEC code, whereas the Chinese customs data are classified based on HS code. Given this difference, we match these two datasets using the concordance tables provided by the United Nations.[6] In particular, the concordance of HS96

[5] Our matching has a slightly lower matching rate than that of Feng, Li, and Swenson (2016) for two reasons. First, our matching is more conservative. Second, they match the data for different years, 2002-2006.

[6] https://unstats.un.org/unsd/trade/classifications/correspondence-tables.asp.

to BEC is used for years before 2002 and the concordance of HS02 to BEC is used for 2002 onward. Accordingly, intermediate goods are defined as products with the following BEC codes: 111, 121, 21, 22, 31, 322, 42, and 53. Capital goods are those with the following BEC codes: 41 and 521. Consumption goods are with the following BEC codes: 112, 122, 522, 61, 62, and 63. We also manually classify the products in the automobile industry. The correlation between the BEC classification and ours for this industry is higher than 0.8. The representative products in the automobile industry are displayed in Table A2 in the Appendix.

2.3 Stylized Facts

Fact 1. *The share of capital goods imports is smaller than that of intermediate goods imports.*

Figure 1 compares the import composition across countries based on the dataset of UN Comtrade. We choose the top 20 largest importing countries/regions in 2016 and sort them by the share of capital goods imports. The share of capital goods in total imports is between 10% and 24% in these countries/regions. The share of intermediate goods imports is substantially larger than that of capital goods imports.

[Insert Figure 1 around here]

Table 2 compares the import shares of capital and intermediate goods based on our data from 2000 to 2006. For ordinary trade, intermediate and capital goods contribute 82.4% and 15.6% to the total value of imports, respectively. For processing trade, the corresponding figures are 82.4% and 13.9%. Consumption goods only account for a very small share, that is, 2% in ordinary trade and 3.7% in processing trade. Seeing that consumption goods import is small and does not directly affect firm production, we exclude consumption goods import from our discussion below so that we can focus on the comparison between capital and intermediate goods imports.

The lower panel of Table 2 reports the share of Chinese firms engaging in different types of trade. After excluding consumption goods import from our discussion, we classify all firms into four categories based on their import information in the entire sample period: (i) firms that ever imported capital goods but never imported intermediate goods, (ii) firms that ever imported intermediate goods but never imported capital goods, (iii) firms that ever imported both intermediate and capital goods, and (iv) firms that never imported capital or intermediate goods in the sample period. Table 2 shows that as for firms that ever engaged in ordinary trade imports in the sample (categories i-iii), 9.8% of them import capital goods only, 48.4% import intermediate goods only, and 41.8% import both capital and intermediate goods. The percentage of processing trade firms that import capital goods only is small, approximately 0.4%.

[Insert Table 2 around here]

Fact 2. *Firms that ever import capital goods are more productive (labor productivity), larger, and more likely to invest in R&D than firms that import intermediate goods only.*

Table 3 reports the key performance of each type of firms. Firms ever importing capital goods have better performance than those importing intermediate goods only. The former has higher value added per worker, larger size (in terms of output, capital stock and employment), and higher R&D participation rate (i.e., share of firms doing R&D) than the latter.

[Insert Table 3 around here]

Fact 3. *Compared with importing intermediate goods, importing capital goods triggers more R&D participation in the future and faster growth in firm productivity and size.*

Figure 2 compares the dynamic performance of firms that ever import capital goods with those importing intermediate goods only, in terms of over-time changes in value-added per worker (VAPW), value added (lnVA), capital stock (lnK), labor (lnL), and R&D participation. This figure focuses on firms engaging in ordinary trade. To remove industry differences, all values are demeaned by the industry means yearly. As a result, a positive value of a firm implies that the firm's value is higher than the average value of all firms in the same industry. On the horizontal axis, we normalize the year when the firm first starts importing capital or intermediate goods in our data period as year one. The kth year before and after the first-time import is denoted as time $1 - k$ and $1 + k$, respectively.[7]

[Insert Figure 2 around here]

Four observations are noticed from Figure 2. First, sorting is strong. Before the first time of importing, the capital-import group has better performance in every measure than the intermediate-import-only group. Second, import effect is clear. The immediate effect of import on performance is indicated by the jump from period 0 to period 1, which is clearly the case in all sub-figures and for both groups of firms. Third, the impact of starting importing capital is larger than that of starting importing intermediates. The former generates relatively higher growth rate of value added per worker, firm size (as measured by value added, capital, and labor), and R&D participation than the latter. Finally, long-term differential effect is evident as the gap between the capital-import group and the intermediate-import-only group widens over time after period one.

[7] To compare the performance before and after import, we exclude firms with capital or intermediate goods imports in the first year of the sample period.

3 Model and Estimation

3.1 Model

We construct a model to analyze firms' production and outsourcing decisions. The model provides a basis for estimating the production function and effects of imports.

Production Function. We assume Cobb-Douglas production function. Specifically, firm j uses labor (L_{jt}), intermediate input (M_{jt}), and capital (K_{jt}) at time t to produce a single output (Q_{jt}) as follows:

$$Q_{jt} = exp(\omega_{jt} + \alpha_k d^k_{jt} + \alpha_m d^m_{jt} + \alpha_{km} d^k_{jt} d^m_{jt} + \zeta_{jt}) L^{\beta_l}_{jt} M^{\beta_m}_{jt} K^{\beta_k}_{jt}.$$

In the above production function, β_l, β_m, and β_k are the output elasticities of each corresponding input. ω_{jt} is the structural productivity that is persistent over time and observed by the firm (but not researchers), whereas ζ_{jt} is the non-structural idiosyncratic productivity shocks, which are i.i.d. and unobserved by both the firm and researchers. d^k_{jt} and d^m_{jt} are two dummy variables capturing the immediate effect of using imported capital and intermediate goods as input, respectively, on productivity. The two dummies are defined as follows: $d^k_{jt} = 1$ if firm j imports capital goods at time t, and $d^k_{jt} = 0$ otherwise; similarly, $d^m_{jt} = 1$ if firm j imports intermediate goods at time t, and $d^m_{jt} = 0$ otherwise.

We have three remarks on d^k_{jt} and d^m_{jt}. First, like the domestically sourced capital and intermediate goods, the imported capital and intermediate goods are used during production as they are part of the K_{jt} and M_{jt} in the production function. Therefore, the mere usage of the imported capital and intermediate goods as input of production is captured by their inclusion in K_{jt} and M_{jt}. Second, in addition to the usage as input, the two import dummy variables in the production function capture the possibility that using the imported capital and intermediate goods may bring productivity gains in the same period. We call this the *immediate productivity effect.* This assumption is in line with the observations (by Kasahara and Rodrigue, 2008; Goldberg, Khandelwal, Pavcink, and Topalova, 2009, 2010; Halpern, Koren, and Szeidl, 2015) that imported inputs may improve firm performance immediately through increased quality, additional varieties of available inputs, and lowered input prices. However, these studies do not distinguish capital and intermediate goods. By contrast, we allow the two types of imports to have differential effects, as captured by coefficients α_k and α_m. In the robustness check, we extend the model by allowing the immediate productivity effect to depend on the value of the imports rather than the act of importing or not. Third, we allow the two types of import to have certain complementarity or substitution effect, as captured by α_{km}.

We write the production function in logarithm form as

$$q_{jt} = \omega_{jt} + \alpha_k d^k_{jt} + \alpha_m d^m_{jt} + \alpha_{km} d^k_{jt} d^m_{jt} + \beta_l l_{jt} + \beta_m m_{jt} + \beta_k k_{jt} + \zeta_{jt}, \tag{1}$$

where the lower-case variables represent the logarithm of the corresponding upper case variables, i.e., $x_{jt} \equiv log(X_{jt})$ for $X_{jt} \in \{Q_{jt}, L_{jt}, M_{jt}, K_{jt}\}$. As we only have output value but not quantity in our dataset, the productivity measure is revenue based. We calculate q_{jt} using the firm's revenue deflated by industry output price index.

Productivity Evolution. We assume that the structural productivity follows the first-order Markov process with a shift, that is,

$$\omega_{jt} = \rho_0 + \rho\omega_{jt-1} + \gamma_k d^k_{jt-1} + \gamma_m d^m_{jt-1} + \gamma_{km} d^k_{jt-1} d^m_{jt-1} + \lambda d^{rd}_{jt-1} + X'_{jt-1}\Theta + \xi_{jt}. \tag{2}$$

In the above productivity evolution process, ω_{jt-1} is the lagged productivity and ξ_{jt} the productivity shock to the Markov process, which is i.i.d drawn from a normal distribution with mean zero standard deviation σ_ξ: $\xi_{jt} \sim N(0, \sigma^2_\xi)$. X_{jt-1} is a set of control variables.

The lagged import dummy variables, d^k_{jt-1} and d^m_{jt-1}, in (2) capture the possible *dynamic productivity effect* in which past (last period) importing experience affects the firm's productivity today. The dynamic effect exists because through importing, the firm may obtain advanced knowledge about the production due to its exposure to foreign knowledge and technologies embedded in the imports or its receipt of technical support and on-site training from the foreign suppliers for using the imported goods. These knowledge gains are long lasting and can exert an impact on the firm's productivity beyond the importing period.[8] Such a dynamic effect is also emphasized by Kasahara and Rodrigue (2008), Zhang (2017), and Keller (2004), but they term it as learning by importing or technology spillover effect and do not distinguish capital from intermediate goods.[9]

We follow Aw, Roberts, and Xu (2008) to include the lagged R&D variable to productivity evolution: d^{rd}_{jt-1} is a dummy variable, which is equal to unity if the firm does R&D at time $t-1$, and zero otherwise. The justification of including this variable is that a firm's import may affect its R&D activity, carrying out the R&D activity takes time, and R&D investment may influence the firm's productivity. In the baseline model, d^{rd}_{jt-1} is a discrete variable recording firms' R&D participation. We also examine the case in which the quantity of R&D investment is used instead.

Because a firm's R&D investment and importing decisions are both endogenous, the productivity evolution (2) is also endogenous.

[8]The dynamic productivity effect may also arise from the higher quality of imported inputs, compared with domestic inputs.

[9]Given that our panel data is short, we focus on the one-period lag effect. The analysis can be extended to allow for high-order lags to capture the dynamic effect completely.

Firm Decisions. Firms face monopolistic competition in the same industry. Each firm maximizes its expected discounted value of lifetime profits by making decisions on production, capital investment, R&D investment, and import. The timing of the information flow and decisions is as follows.

1. *State.* At the beginning of period t, each firm j observes its state variables, which include its own capital stock k_{jt}, productivity ω_{jt}, current import status d^k_{jt} and d^m_{jt}, export status, denoted as e_{jt}, and other state variables, denoted as z_{jt}. $e_{jt} = 1$ if the firm exports in period t and $e_{jt} = 0$ otherwise. These state variables are summarized in $s_{jt} = (k_{jt}, \omega_{jt}, d^k_{jt}, d^m_{jt}, e_{jt}, z_{jt})$. Apart from s_{jt}, firm j observes the fixed costs of R&D investment (ξ^{rd}_{jt}), capital investment (ξ^i_{jt}), importing capital goods (ξ^k_{jt}), and importing intermediate goods (ξ^m_{jt}). These fixed costs are assumed to be i.i.d. drawn from different distributions over time and across firms.

2. *Production decisions.* Observing state s_{jt}, firm j makes its production decision by choosing the amount of intermediate input (m_{jt}) and labor (l_{jt}). The capital input is determined by the investment decisions in the earlier periods, to be described below. The production decision (m_{jt}, l_{jt}) is static in the sense that it only affects the current period's profits because their services are used up within one period. Denote the optimal profit as $\pi(s_{jt})$.

If $d^m_{jt} = 0$, then all the intermediate inputs (m_{jt}) are sourced from the domestic market only. If $d^m_{jt} = 1$, then firm j sources the intermediate inputs from the foreign market and maybe the domestic market as well. An implicit assumption in our production function (1) is that domestic and imported intermediate inputs are homogenous with regard to their direct contribution to production. As the costs of domestic and international sourcing can differ, we simplify this part of the model by assuming that each firm has made its optimal decision on domestic and international sourcing of the intermediate inputs to reach the quantity m_{jt}.

3. *Import, R&D, and investment decisions.* Observing s_{jt} and (ξ^{rd}_{jt}, ξ^k_{jt}, ξ^m_{jt}, ξ^i_{jt}), firm j decides whether to import capital goods (d^k_{jt+1}), import intermediate goods (d^m_{jt+1}), participate in R&D investment (d^{rd}_{jt}), and make capital investment (i_{jt}) by paying a fixed cost for each activity if the firm decides to do it. If the firm pays the costs for capital import (or intermediate import), it can have the right to import at time $t + 1$. If the firm pays the R&D costs, it may gain higher productivity in the next period. Similarly, if the firm invest in capital stock (i_{jt}), it will increase the next period capital stock. These decisions are dynamic in the sense that they exert a long-term impact on firm profits.

To make capital investment, the firm can source capital domestically and internationally. If $d^k_{jt+1} = 0$, then all capital is sourced domestically at $t + 1$. If $d^k_{jt+1} = 1$, then the firm sources capital from the foreign market and maybe the domestic market as well at $t + 1$. Similar to the case of intermediate inputs, we do not model the source-based capital investment decisions separately. Instead, we consider the total amount of capital investment made by the firm (I_{jt}), assuming that the firm has chosen the optimal composition of domestic and foreign capitals.

The firm's dynamic decisions on import and R&D can be expressed in the following recursive form:

$$\begin{aligned} V(s_{jt}, \xi^k_{jt}, \xi^m_{jt}, \xi^{rd}_{jt}, \xi^i_{jt}) &= \pi(s_{jt}) + \max_{d^k_{jt+1}, d^m_{jt+1}, d^{rd}_{jt}, i_{jt}} E[V(s_{jt+1}, \xi^k_{jt+1}, \xi^m_{jt+1}, \xi^{rd}_{jt+1}, \xi^i_{jt+1}) \\ &\quad - d^k_{jt+1}\xi^k_{jt} - d^m_{jt+1}\xi^m_{jt} - d^{rd}_{jt}\xi^{rd}_{jt} - C(i_{jt}, \xi^i_{jt})] \\ &\quad \text{subject to Equation (2),} \end{aligned} \tag{3}$$

where $V(\cdot)$ is the present value of the firm and $C(i_{jt}, \xi^i_{jt})$ is the total costs of capital investment. The expectation is taken over the future shocks to fixed costs $(\xi^k_{jt+1}, \xi^m_{jt+1}, \xi^{rd}_{jt+1}, \xi^i_{jt+1})$ and productivity (ξ_{jt+1}). We denote the optimal decisions on the firm's imports, R&D, and capital investment as follows:

$$\begin{aligned} d^k_{jt+1} &= d^k(s_{jt}, \xi^k_{jt}, \xi^m_{jt}, \xi^{rd}_{jt}, \xi^i_{jt}), \\ d^m_{jt+1} &= d^m(s_{jt}, \xi^k_{jt}, \xi^m_{jt}, \xi^{rd}_{jt}, \xi^i_{jt}), \\ d^{rd}_{jt} &= d^{rd}(s_{jt}, \xi^k_{jt}, \xi^m_{jt}, \xi^{rd}_{jt}, \xi^i_{jt}). \\ i_{jt} &= i(s_{jt}, \xi^k_{jt}, \xi^m_{jt}, \xi^{rd}_{jt}, \xi^i_{jt}). \end{aligned} \tag{4}$$

The dynamic decisions, (3) and (4), indicate the possibility of sorting on the importing and investment decisions as these decisions depend on the firm's state in productivity, size, import, and R&D history and the realized cost shocks to import and R&D investment. Although productivity gains from importing capital and intermediate may exist, the existence of fixed costs of importing and R&D investment may prevent certain firms from realizing the benefits from importing and making R&D investment.

In (4), if importing experience (d^k_{jt} or d^m_{jt}) exerts a positive effect on the R&D decision (d^{rd}_{jt}) for the next period, then we can say import of capital or intermediate goods induces R&D investment, which is the *R&D-inducing effect*.

The above model provides a basis for the estimation strategy to be discussed in the next subsection.

3.2 Estimation Method

We estimate the gains from different import types by jointly estimating the production function and productivity evolution, namely Equations (1) and (2). The usual simultaneity problem arising from the unobserved productivity in the production function also exists in our model. We solve the identification problem using the standard approach developed in Olley and Pakes (1996) and Levinsohn and Petrin (2003). Our model introduces two new terms in the production function, d^k_{jt} and d^m_{jt}, which capture the immediate productivity effect of imports in the production function. Given our timing assumption that the decisions of whether to import capital and intermediate goods are made one period ahead by paying a fixed cost, d_{jt}^k and d_{jt}^m are uncorrelated with the idiosyncratic productivity shocks in the production function. Thus, in the baseline model, we can assume that d_{jt}^k and d_{jt}^m are exogenous to the idiosyncratic productivity shocks. In Section 4.4, we show that our results are robust when relaxing this assumption and using reductions of import tariffs on capital and intermediate goods as instrumental variables for d_{jt}^k and d_{jt}^m.

Following Olley and Pakes (1996), we use a two-stage approach to estimate the production function and productivity evolution simultaneously. In the first stage, we separate the idiosyncratic productivity shocks ζ_{jt} from the structural productivity ω_{jt} in the production function. We use labor usage as the proxy for structural productivity under the assumption that labor demand is a monotonic function of productivity conditional on other observed state variables, $l_{jt} = l(\omega_{jt}, k_{jt}, d_{jt}^k, d_{jt}^m, e_{jt}, z_{jt})$, and, thus, we can invert the labor demand function to solve for $\omega_{jt} = \omega(l_{jt}, k_{jt}, d_{jt}^k, d_{jt}^m, e_{jt}, z_{jt})$. Substituting this productivity function into the production function (1), we obtain:

$$q_{jt} = \beta_m m_{jt} + \phi(l_{jt}, k_{jt}, d_{jt}^k, d_{jt}^m, e_{jt}, z_{jt}) + \zeta_{jt}, \tag{5}$$

where $\phi(\cdot) = \omega_{jt} + \alpha_k d_{jt}^k + \alpha_m d_{jt}^m + \alpha_{km} d_{jt}^k d_{jt}^m + \beta_l l_{jt} + \beta_k k_{jt}$. In the empirical application, we proxy the function $\phi(\cdot)$ by a full set of third order polynomial terms of l_{jt}, k_{jt}, d_{jt}^k, d_{jt}^m, e_{jt}, and the interactions of these terms. Following Brandt, Biesebroeck, Wang, and Zhang (2017), we also control for industry fixed effect and a series of dummies for ownership, year, and province to capture potential firm differences in these dimensions. Given the polynomial approximation, Equation (5) can be estimated using linear least square model.

After carrying out the first-stage estimation, we obtain the estimates of q_{jt} and β_m, denoted as $\hat{q}_{jt}$ and $\hat{\beta}_m$, respectively. This also gives the estimate of $\phi(\cdot)$ denoted as $\hat{\phi}_{jt} = \hat{q}_{jt} - \hat{\beta}_m m_{jt}$. Note that $\hat{\phi}_{jt}$ does not include the idiosyncratic productivity shocks in the production function. We solve the structural productivity ω_{jt} from the definition of $\phi(\cdot)$ as a function of observed variables and parameters:

$$\omega_{jt} = \hat{\phi}_{jt} - \left(\alpha_k d_{jt}^k + \alpha_m d_{jt}^m + \alpha_{km} d_{jt}^k d_{jt}^m + \beta_l l_{jt} + \beta_k k_{jt}\right).$$

Replacing ω_{jt} in the production function by the productivity evolution (2) and substituting the resulting ω_{jt-1} by the above function, we obtain the second-stage estimation equation as follows:

$$
\begin{aligned}
q_{jt} - \hat{\beta}_m m_{jt} \;\; = \;\; & \alpha_k d^k_{jt} + \alpha_m d^m_{jt} + \alpha_{km} d^k_{jt} d^m_{jt} + \beta_l l_{jt} + \beta_k k_{jt} \\
& + \rho_0 + \rho \left[\hat{\phi}_{jt-1} - \left(\alpha_k d^k_{jt-1} + \alpha_m d^m_{jt-1} + \alpha_{km} d^k_{jt-1} d^m_{jt-1} + \beta_l l_{jt-1} + \beta_k k_{jt-1} \right) \right] \\
& + \gamma_k d^k_{jt-1} + \gamma_m d^m_{jt-1} + \gamma_{km} d^k_{jt-1} d^m_{jt-1} + \lambda d^{r\&d}_{jt-1} + X'_{jt-1}\Theta + \xi_{jt} + \zeta_{jt}. \qquad (6)
\end{aligned}
$$

The error term $\xi_{jt} + \zeta_{jt}$ combines the i.i.d. idiosyncratic shock to productivity in the production function and that in the productivity evolution. By assumption, $\xi_{jt} + \zeta_{jt}$ is uncorrelated with all the variables on the right-hand side of (6), except l_{jt} which depend on ζ_{jt}. We use the lag terms l_{jt-1} as instrumental variables for l_{jt} in the estimation. Equation (6) can be estimated using generalized method of moments (GMM).

In the above estimation procedure, identification of the direct effects of import (both immediate and dynamic effects) relies on the timing assumption of the model. As the import status in period t is determined one period ahead, d^k_{jt} and d^m_{jt} are uncorrelated with the shocks in period t, $\xi_{jt} + \zeta_{jt}$. Such a timing assumption is commonly made in the production estimation literature (e.g., Olley and Pakes, 1996; Kasahara and Rodrigue, 2008; Aw, Roberts, and Xu, 2011; Kasahara and Lapham, 2013). In Section 4.4, we provide an alternative identification strategy based on instrumental variable, and our results are robust.

4 Estimation Results

We estimate the model using our dataset described in Section 2. Our objective is to quantify the distinct productivity effects of capital and intermediate imports and discover the channels through which such effects are generated. The main estimation results are reported in Table 4. In all estimations, we control for industry fixed effect to capture the cross-industry difference in productivity and demand. We also control for a series of dummies for ownership, year, and province to capture potential firm differences in these dimensions. In all regressions in Table 4, we exclude pure processing firms, that is, firms engaging in processing trade only.

4.1 Immediate Productivity Effect

The immediate productivity effect is captured by α_k and α_m, the coefficients of d^k_{jt} and d^m_{jt}, respectively, in the production function (1). The baseline results shown in column (1) of Table 4 indicate that both α_k and α_m are positive and statistically significant. Both capital and intermediate goods imports have positive effects on the productivity of the importers. The immediate productivity effect of capital import is larger than that of intermediate import. Importing capital immediately increases the productivity of the importers by 2.3%, as opposed to 1.8% for importing intermediates. The difference is statistically significant.

[Insert Table 4 around here]

This immediate productivity effect corresponds to the "variety" and "quality" effects of intermediate goods import discussed in the literature (e.g., Amiti and Konings, 2007; Topalova and Khandelwal, 2011; Kasahara and Rodrigue, 2008; Halpern, Koren, and Szeidl, 2015). The common understanding is that importing renders access to more varieties of intermediate inputs, which generally have higher quality compared to domestic inputs. Despite the claim of such an effect from intermediate goods import, the evidence is provided on the basis of total input imports. We separate the two types of imports and show that both imported capital and intermediate goods have such an effect and that the effect from imported capital goods is stronger.

Using imported capital and intermediates has substantial complementarity. This is implied by the positive and significant coefficient of the interaction term of the capital and intermediate import dummies. In the baseline model, importing capital and intermediates simultaneously generates additional productivity benefits by 1.5%. This represents two-thirds additional productivity gains relative to capital import only or roughly the same magnitude of the productivity gain from intermediate import only. The complementarity may arise from the possibility that the imported capital equipment may run better with the intermediates imported from abroad, and vice versa.

In sum, the main result from our baseline estimation is that both capital and intermediates imports have positive immediate productivity effect, and capital import has a larger effect than intermediate import. This result is robust when using investment (instead of labor) as an alternative proxy for productivity in estimating production function following Olley and Pakes (1996) which will be discussed later in Section 4.4.

The result is also robust when we add the share of each type of import in column (2) in Table 4. The share of capital import, denoted as $Share\ of\ import\ k$, is defined as the value of capital import divided by the capital size of the firm. The share of intermediates import, denoted as $Share\ of\ import\ m$, is defined as the value of intermediates import normalized by the total usage of domestic and imported intermediates by the firm. After controlling for the size of import, the result is qualitatively unchanged. Moreover, column 2 of Table 4 shows that a larger share of imports of capital or intermediates results in a larger increase in productivity, with an elasticity of 0.112 and 0.132, respectively. Conditional on importing, the mean values of $Share\ of\ import\ k$ and $Share\ of\ import\ m$ are 0.057 and 0.07, respectively. Thus, the relative size of importing capital and intermediates contributes to 0.64% ($= 0.057 * 0.112\%$) and 0.92% ($= 0.07 * 0.132\%$), respectively, to average firms. The total immediate productivity effect of capital importing (1.4+0.64=2.04%) remains larger than that of intermediate importing (0.8+0.92=1.72%), consistent with the baseline results in column (1). The magnitudes are also close to the baseline results.

4.2 Dynamic Productivity Effect

As discussed in Section 3, the dynamic effects of capital and intermediate imports are captured by γ_k and γ_m, which are the coefficients of the lagged importing status in the productivity evolution in (2). The positive and significant γ_k suggests that importing capital can have a dynamic effect on future (next period) productivity. In the baseline model in column (1), $\gamma_k = 0.006$, and, thus, importing capital will improve next-period's productivity by 0.6%.

Because the imported capital is counted as part of the importer's total capital stock that is used in production, the fact that the imported capital is used for multiple periods is already accounted for in the capital stock variable in the production function. As a result, the estimated dynamic productivity effect of capital import is not due to the nature of imported capital being used for multiple periods. Instead, it represents the additional gains from using imported capital relative to its domestic counterpart, corresponding to the finding of learning by importing and technology spillover effect in the literature (Kasahara and Lapham, 2013; Vogel and Wagner, 2010; Keller, 2004). The dynamic effect can arise from multiple channels. For example, capital importers need to interact with foreign suppliers to discuss the necessary techniques for the efficient use of the imported capital before and at the stage of making purchase. At the stage of installation and usage, capital importers also need technique support, training, and maintenance support from foreign suppliers, through which they gain more exposure to foreign advanced knowledge. These experiences can benefit the importers in the long run.

Such a dynamic effect, however, is absent for intermediate import. The coefficient of the lagged intermediate import in the productivity evolution is statistically insignificant and close to zero in the baseline model in column (1). This outcome is not surprising as importing intermediates does not require the kinds of contacts with foreign suppliers discussed above for capital import.

In contrast with the complementarity between capital and intermediate imports observed for the immediate productivity effect, we find no significant complementarity between capital and intermediate imports for the dynamic effect.

The results on the dynamic effects are robust after controlling for the shares of capital and intermediate imports as reported in column (2) in Table 4.

4.3 R&D-Inducing Effect

We now turn to examining whether the imported capital and intermediate goods may induce the firms to participate in R&D investment. Based on a simple event study depicted in Figure

2, we observe that importing capital and intermediate goods causes a structural change in R&D participation of the importers. To analyze this issue, we estimate a linear version of firms' R&D decision functions as implied by our dynamic model as follows:

$$d_{jt}^{rd} = \lambda_1 d_{jt-1}^{rd} + \lambda_k d_{jt-1}^{k} + \lambda_m d_{jt-1}^{m} + \lambda_{km} d_{jt-1}^{k} d_{jt-1}^{m} + \lambda_\omega \omega_{jt-1} + \lambda_e e_{jt-1} + \lambda_K lnK_{jt-1} + \lambda_Z Z_{jt} + FE + \epsilon_{jt}^{rd}, \quad (7)$$

where d_{jt}^{rd} is a dummy of R&D investment at time t. The lagged term d_{jt-1}^{rd} may have an impact on current R&D decision. The main parameters of interest include λ_k, λ_m, and λ_{km}, which capture the impact of import on R&D decision. We control for the productivity level (ω_{jt-1}) and export participation (e_{jt-1}) because firms of different productivity levels and export status may have different incentives to invest in R&D.[10] We also control for firm size (lnK_{jt-1}); the fixed effects (FE) including year, province, industry, and ownership; and others included in Z_{jt}.[11]

The results are reported in Table 5. In the baseline result in column (1), we find that being a capital importer one year ahead increases the probability of investing in R&D by 2.5%. As the average R&D probability is 12% for all firms, importing capital increases the chance for a firm to invest in R&D by 21% (=2.5/12). This complementarity result is robust when we add the import share in the estimation in column (2). The existence of R&D-inducing effect may be because some of the imported capital, such as equipment and machinery, may be directly used for R&D purpose or because the known-how learned from capital importing may spill over to R&D activity.

[Insert Table 5 around here]

By contrast, the effect of intermediate import on R&D is very small and statistically insignificant (column (1)). Moreover, importing both capital and intermediates simultaneously does not have any additional (or complementarity) effect on R&D participation in all specifications.

We also find clear sorting of firms into R&D activities: firms that are larger, more productive, and exporters are more likely to invest in R&D.

Given that R&D investment has positive impact on productivity, as shown in Table 4, the induced R&D from capital goods import brings additional productivity gains to the importers.

4.4 Robustness Checks

This section presents robustness checks to our estimation results when using a different control function for productivity and using instrumental variables for trade decisions.

Investment as Alternative Proxy for Productivity. Following Olley and Pakes (1996),

[10] Productivity (ω_{jt-1}) is estimated based on the baseline model in column (1) in Table 4.

[11] Ownership is classified as state owned, collectively owned, private, Hong Kong-Macao-Taiwan, foreign owned, the other.

we can estimate the model using investment, instead of labor in our baseline model, as a proxy for productivity. Our data include individual firms' long-term investment on yearly basis, and we use them as the proxy for productivity. With this as the only change, we conduct the same baseline estimation as before. As shown in columns (1) and (2) in Table 6, all of our main results are robust to this alternative estimation procedure.

Moreover, because the long-term investment reported in the data contains a large share of zeros, we construct a measure of firm gross investment to mitigate the many-zero problem. Specifically, the gross investment in each year is defined as the difference between the end-of-year fixed asset and beginning-of-year fixed asset, plus the yearly depreciation. Using this definition, only 2% of the observations have zero investment. Our results are robust when using the constructed gross investment as control function for productivity, as shown in columns (3) and (4) in Table 6.

[Insert Table 6 around here]

Instrumental Variable Estimation. The timing assumption plays an important role in our main estimation: the import decisions are made one period ahead of the production decision, and, thus, the import decisions are uncorrelated with the non-structural productivity shocks, which validates our identification strategy. In this section, we show that our results are robust when relaxing this assumption and using an IV approach. We use the differential changes of import tariff rates for capital and intermediate goods as IVs for firm import decisions.

China's accession to the WTO in 2001 resulted in substantial reductions of tariffs on imports. We calculate the tariff changes from 2000 to 2006 using the disaggregated product-line tariff rates at the eight-digit Harmonized System (HS) level in the World Integrated Trade Solution (WITS) from the World Bank. Using the HS code, we match the tariff rate with the Chinese customs data at the transaction level that also reports HS8 code. Specifically, based on the HS8 tariff rates, we calculate the four-digit industry-level average tariff rates for capital goods and those for intermediate goods using import value as the weights.

Figure 3 shows the annual average import tariff rates during 2000-2006 in China. The tariff rates for both capital and intermediate imports dropped substantially after China's accession to the WTO. The tariff rates, however, are reduced disproportionately, with a much larger reduction for capital imports. Before 2001, capital imports faced a higher tariff rate (13.9%) than intermediate imports (12.8%). In 2006, the situation was reversed, with a lower tariff rate for capital imports (4.1%) than that for intermediate imports (4.4%). Overall, the capital tariff dropped by 9.75 percentage points and intermediate tariff dropped by 8.36 percentage points from 2000 to 2006.

[Insert Figure 3 around here]

The differential changes of tariff rates for capital and intermediate goods form valid IVs for individual firms' decisions on capital and intermediate imports. First, tariff reductions affect the import decisions of individual firms. Second, the industry-level tariff rates and the firm-level productivity are unlikely to be correlated. Hence, the exclusion condition is likely to be satisfied. We use the industry-average changes in tariff rates for capital and intermediate goods from the initial year 2000 as the independent IVs for the import decisions of individual firms. Specifically, the IVs are $\triangle\tau_t^k$ and $\triangle\tau_t^m$, which are defined as the tariff changes from 2000 to year t for capital and intermediate goods, respectively. In Appendix, we show that the changes in industry average tariff rates have substantial impact on firms' import decisions and that the exclusion conditions are satisfied.

We estimate the model using GMM, with the changes in industry average tariff rates for capital and intermediate goods ($\triangle\tau_t^k$ and $\triangle\tau_t^m$), and one-period-ahead import status of capital and intermediate goods ($d_{j,t-1}^k$ and $d_{j,t-1}^m$) as the four IVs for firms' import decisions.[12] The second stage follows similarly as our baseline estimation. The results are reported in Table 7. All the main results are similar to our baseline results as reported in Table 4. The findings remain robust even when we use different proxies for productivity (i.e., labor in column (1), long-term investment in column (2), or gross investment in column (3)). In particular, both capital and intermediate imports have a positive and significant immediate productivity effect. Capital and intermediate importing are complementary in promoting immediate productivity. The dynamic effect is strong and significant for capital importing (2.5%), but it is insignificant statistically and economically for intermediate importing.

[Insert Table 7 around here]

4.5 Heterogeneous Effects of Capital Imports

This section investigates the differential effects of importing capital goods in different industries. Compared to those in labor intensive industries, firms in capital intensive industries may benefit more from capital imports because they are more involved in utilizing foreign capital goods, which provides more chances for them to learn.

We categorize 2-digit industries into two groups: capital and labor intensive industries. We define a capital (labor) intensive industry if the industry's capital-to-labor ratio is greater than or equal to (smaller than) the median of the capital-to-labor ratio in all industries, in the initial year (2000). We then estimate the productivity effects from imports separately in these two groups of subsamples.

Table 8 reports the effects of import on firm productivity in capital intensive (column 1) and labor intensive (column 2) industries. The immediate productivity effect from importing capital (intermediate) goods in capital intensive industries is 0.5 (0.2) percentages points larger than

[12] The IV regression is performed in the first stage of estimation in Equation (5). As we proxy the function $\phi(\cdot)$ by a full set of third order polynomial terms of l_{jt}, k_{jt}, d_{jt}^k, d_{jt}^m, e_{jt}, and the interactions of these terms, all the polynomial terms having d_{jt}^k and d_{jt}^m are instrumented by the four IVs we use.

that in labor intensive industries. Importantly, the dynamic productivity effect from capital imports in capital intensive industries is 0.77 percentage points larger than its counterpart (0.012 vs. 0.0043), and is twice as large as that in the baseline results in Table 4 (0.006). The dynamic productivity effect from intermediate imports is close to zero in both columns. Our results suggest that firms in capital intensive industries gain more from importing capital goods in the long run, compared to those in labor intensive industries.

[Insert Table 8 around here]

4.6 Processing Trade

In this subsection, we demonstrate that processing trade has productivity effects different from ordinary trade. As shown in Table 2, processing trade accounts for more import than ordinary trade in China, but the distribution between capital and intermediate goods import are very similar for these two types of trade. Processing-trade firms differ from ordinary-trade firms in many aspects. For example, the former has lower self-launched new products and spend less on worker training than the latter. Whether the impacts of imports on productivity are also different between these two groups is interesting to explore.

We estimate our model using a subsample of the data obtained by excluding firms that only conduct ordinary trade from the full sample. Table 9 reports the estimation results.[13] Consistent with the baseline results from ordinary trade, capital import in processing trade has a larger immediate effect on productivity than intermediate import (3.5% versus 0.7%). However, for processing trade, capital importing does not bring about significant dynamic effect. As shown in Table 9, the coefficients on the lag of processing capital import is insignificant for all specifications, implying that the dynamic effect is insignificant. Moreover, although R&D continues to exert a positive effect on productivity, processing capital import does not lead to more R&D investment, as shown in Table 10, suggesting that the R&D-inducing effect is insignificant. For processing intermediates import, the dynamic effect is small and negative for both the dynamic productivity and R&D-inducing effects.

[Insert Tables 9 and 10 around here]

5 Contribution of Different Types of Imports

In this section, we quantify the contributions of capital and intermediate imports to firms' productivity and sales. We also evaluate the relative importance of the three channels as sources of productivity gains, i.e., immediate productivity, dynamic productivity, and R&D-inducing effects.

[13] Processing firms may also import via ordinary trade. To distinguish the effects of ordinary trade, we control for the ordinary imports in Tables 9 and 10.

Contribution to Firm Productivity. Our analysis is based on the estimation results in column (2) of Table 4, which takes into account the effects of import participation and import size. First, the immediate productivity effect of importing capital and/or intermediate goods is defined as the weighted average of the corresponding productivity gains from 2000 to 2006 as follows:

$$\triangle\omega^h_{immediate} = \sum_{j,t} (\alpha_h d^h_{jt} + \alpha^s_h s^h_{jt}) w_{jt}, \quad h \in \{k, m, km\},$$

where $w_{jt} = R_{jt} / \left(\sum_{j,t} R_{jt}\right)$ is the share of revenue (R_{jt}) of firm j at time t. d^h_{jt} and s^h_{jt} are the import status and value share of importing $h \in \{k, m, km\}$ as defined in section 4.1, respectively. The parameter α_h is the immediate productivity effect of importing $h \in \{k, m, km\}$ as defined in Equation (1), and α^s_h is the estimated immediate productivity effect of importing share in the extended regression as reported in column (2) of Table 4. The total productivity gains from the immediate effect is $\triangle\omega_{immediate} = \sum_{h\in\{k,m,km\}} \triangle\omega^h_{immediate}$.

Second, the productivity gains from the dynamic effect of importing h are calculated as follows:

$$\triangle\omega^h_{dynamic} = \sum_{j,t} (\gamma_h d^h_{jt-1} + \gamma^s_h s^h_{jt-1}) w_{jt},$$

where γ_h and γ^s_h are the elasticities of the dynamic effect corresponding to import participation and import share, respectively. The total productivity gains from the dynamic effect in all types of goods are $\triangle\omega_{dynamic} = \sum_{h\in\{k,m,km\}} \triangle\omega^h_{dynamic}$.

Third, the productivity gains from R&D-inducing effect for importing type $h \in \{k, m, km\}$ is calculated as follows:

$$\triangle\omega^h_{rd} = \sum_{j,t} \gamma_{rd} \, (\lambda_h d^h_{jt-1} + \lambda^s_h s^h_{jt-1}) w_{jt},$$

where γ_{rd} is the effect of (lag) R&D dummy on the productivity evolution process as reported in Table 4. λ_h and λ^s_h are the effects of import participation and import share on firms' R&D decision, as captured by the coefficients of import dummy, d^h_{jt-1}, and import value share, s^h_{jt-1}, in column 2 in Table 5. The total productivity gains from the R&D-inducing effect are $\triangle\omega_{rd} = \sum_{h\in\{k,m,km\}} \triangle\omega^h_{rd}$. Let us call this induced-R&D productivity effect.

Finally, the total productivity contribution of each type of import $h \in \{k, m, km\}$ is

$$\triangle\omega^h = \triangle\omega^h_{immediate} + \triangle\omega^h_{dynamic} + \triangle\omega^h_{rd}.$$

Table 11 reports the decomposition results. First, the results confirm that import in general contributes to the productivity growth. In the data, importing (either capital or intermediate goods) increases the importer's productivity in the next period by 2.44%.

Second, capital import contributes to over half of the total productivity gains from import, although it accounts for only one-sixth of intermediates import in value. Among the 2.44% total productivity gains from import in the next period, capital import accounts for over one half (1.25%). The other half is mainly contributed by intermediate import, together with the effect from complementarity.

Third, both the immediate and dynamic effects matter. If we consider the one-year productivity effect, the immediate effect explains 86% (2.1% out of 2.44%) of the total productivity gains. This large productivity gains arise from direct usage of the imported capital and intermediate inputs during production.

Fourth, the dynamic effect, which accounts for 14% of total productivity gains, almost completely comes from the dynamic effect by importing capital goods. The induced-R&D productivity effect, although positive and significant, is very small in magnitude compared with the dynamic effect. This outcome is because we evaluate R&D-inducing effect focusing on the extensive margin, that is, the inducement of firm to participate in R&D investment. Import may also induce existing R&D firms to increase their R&D investment. This effect is not included in our analysis.

[Insert Table 11 around here]

Contribution to Firm Sales. We now evaluate the impact of capital and intermediate imports on firm sales. Specifically, to understand the importance of input imports, we ask how much more revenue can be created by importing one dollar of capital or intermediate goods, compared with using domestic inputs. We address this question by calculating the effect of import on revenue due to the productivity gains from importing, which is defined as the difference between the observed revenue in the data and counterfactual revenue when firms are not allowed to import and foreign inputs are simply replaced by the same amount of domestic inputs. Because we don't consider firms' optimal input responses when they change importing status for simplicity, our results can be considered as the lower bound of the effects on sales.

To implement the above idea, we take the first-order approximation of the revenue impact of import, which is given by $\triangle\omega_{jt}R_{jt}$ for firm j at time t, where $\triangle\omega_{jt}$ is the productivity change from importing and R_{jt} is the revenue-based gross output observed in the data. Then, the total gains in revenue are $\sum_{jt}\triangle\omega_{jt}R_{jt}$. The ratio $\sum_{jt}\triangle\omega_{jt}R_{jt}/\sum_{jt}V_{jt}$ defines the gains in revenue from per dollar of the import, where V_{jt} is the total value of the import by firm j at time t.

Based on the above definitions, the revenue gains due to the immediate productivity effect of importing $h \in \{k, m, km\}$ per dollar can be calculated as follows:

$$\triangle R^h_{immediate} = \frac{\sum_{jt}\ (\alpha_h d^h_{jt} + \alpha^s_h s^h_{jt})R_{jt}}{\sum_{jt} V^h_{jt}}.$$

Similarly, the revenue effects from per-dollar importing due to the dynamic and R&D-inducing

effects are, respectively,

$$\begin{aligned}\triangle R^h_{dynamic} &= \frac{\sum_{jt}\ (\gamma_h d^h_{jt} + \gamma^s_h s^h_{jt}) R_{jt+1}}{\sum_{jt} V^h_{jt}},\\ \triangle R^h_{rd} &= \frac{\sum_{jt}\gamma_{rd}\ (\kappa_h d^h_{jt} + \kappa^s_h s^h_{jt}) R_{jt+1}}{\sum_{jt} V^h_{jt}}.\end{aligned}$$

The results are reported in Table 12. On average, importing one dollar of inputs (capital and intermediate goods combined) increases firm's sales by an additional 3.98 dollar, compared with using domestic inputs. Among this gain in revenue, 3.34 dollars are realized immediately in the importing period, 0.63 dollar is realized in the next period from the dynamic effect, and a very small amount is due to the R&D-inducing effect.

The revenue effect of capital import is much larger for that of intermediate import. Importing one dollar of capital goods brings an additional 13.01 dollars of revenue to the firm, compared with using domestic capital. In the period of capital importing, one dollar of capital import improves revenue by 9.28 dollars. On top of this, in the next period, an additional revenue gain of 3.7 dollars is due to the dynamic effect and 0.03 dollar of revenue gain arises from the R&D-inducing effect. By contrast, one dollar of intermediate import leads to only 2.2 dollars of additional revenue growth (relative to using domestic intermediate inputs), which is less than one-sixth of the revenue effect of capital import. Among revenue effect of intermediate import, nearly 98% is due to the immediate productivity effect.

[Insert Table 12 around here]

The above analysis implies that the sizable gains in productivity and revenue from international sourcing should generate huge incentives for firms to import, especially for capital goods. However, the relatively low share of firms that import (approximately 12%) indicates the existence of large frictions in international sourcing. This observation from Chinese data is consistent with the literature that estimates large sunk and fixed costs of importing using different data and methods (Kasahara and Lapham, 2013; Zhang, 2017; Grieco, Li, and Zhang, 2017).

6 Productivity Gains from Tariff Liberalization

China's accession to the WTO in 2001 resulted in substantial reductions of tariffs on imports. The average tariff rates for all imports reduced by 8.61 percentage points from 2000 to 2006 in our dataset. However, as shown in Figure 3 in Section 4.4, the tariff rates for capital goods and intermediates goods were reduced disproportionately, with a much larger reduction for capital imports. Overall, the capital tariff dropped by 9.75 percentage points and intermediates tariff dropped by 8.36 percentage points from 2000 to 2006. In this paper, we use the *average tariff* *reduction* to represent the decline of average tariff rates for all imports, and *changes in tariff structure* to represent the relative reduction of tariff rates for capital and intermediate goods. In this section, we conduct two sets of counterfactual simulations to quantify the productivity gains from tariff liberalization after China's WTO accession via the average tariff reduction and changes in tariff structure.

Tariff Liberalization and Importing Decisions. To quantify the productivity effect of tariff reduction by changing firms' sourcing decisions, we estimate a linear version of firms' dynamic decisions on importing capital and intermediates, similar to the R&D decision function in Equation (7), as implied by the dynamic model. Specifically, we estimate the following discrete capital and intermediates importing decision functions,

$$\begin{aligned} d_{jt}^{k} &= d^{k}(\Delta\tau_{jt}^{k}, \Delta\tau_{jt}^{m}, d_{jt-1}^{k}, d_{jt-1}^{m}, \omega_{jt-1}, e_{jt-1}, k_{jt-1}) + \varepsilon_{jt}^{k}, \\ d_{jt}^{m} &= d^{m}(\Delta\tau_{jt}^{k}, \Delta\tau_{jt}^{m}, d_{jt-1}^{k}, d_{jt-1}^{m}, \omega_{jt-1}, e_{jt-1}, k_{jt-1}) + \varepsilon_{jt}^{m}, \end{aligned}$$

where $\{\varepsilon_{jt}^{k}, \varepsilon_{jt}^{m}\}$ are i.i.d error terms with zero mean, which capture any unobserved factors influencing firms' import decisions. $\{\varepsilon_{jt}^{k}\}$ and $\{\varepsilon_{jt}^{m}\}$, however, may be correlated. $\Delta\tau_{jt}^{k}$ and $\Delta\tau_{jt}^{m}$ are the changes in tariff rates for capital and intermediate goods from the initial year (2001) to year t, defined as $\Delta\tau_{jt}^{h} = \tau_{jt}^{h} - \tau_{j,2001}^{h}$, where $h \in \{k, m\}$. They may affect firms import decisions after the WTO accession and we allow this possibility as an extension, as implied in the IV estimation in Section 4.4.

The estimation results are reported in Table 13. First, tariff reduction for capital and intermediates goods promotes imports of both goods. We also find sizable persistence of import decisions over time. Importing capital today improves the probability of importing capital next period by 45%, and importing intermediates today increases the probability of importing intermediates next period by 56%. Meanwhile, there is substantial complementarity between capital and intermediate importing: importing intermediates (capital) today increases the probability of importing capital (intermediates) next period by 15% (17% for capital). We also find that firms that are larger, more productive, and exporting are more likely to import capital and intermediate goods than firms that are smaller, less productive, and not exporting. The import decision functions will be used to quantify the gains from tariff liberalization in the rest of this section.

[Insert Table 13 around here]

Total Gains from Tariff Liberalization. Given the productivity evolution and firms' endogenous decisions on R&D and import, we can simulate the productivity path for each firm in response to changes in tariff rates after China's accession to the WTO. Specifically, we first simulate the productivity of each firm in each year by fixing the tariff rates for capital and intermediate imports at the level of 2001, assuming that firms endogenously update their R&D

and import decisions corresponding to this tariff level. The productivity difference between this case and that observed in the data defines the total productivity gains from tariff liberalization. However, there are factors outside of our model that impact the actual productivity from the observed data. To have a fair comparison, we do not use the actual productivity but simulate the productivity of each year after the WTO entry by setting the tariff rates at the level as observed in the data. This is the predicted productivity after the WTO entry. The difference of the simulated productivity in the above two counterfactual simulations is defined as the total productivity gains from tariff reduction associated with China's accession to the WTO.

Average Tariff Reduction Versus Tariff Structure. The differential productivity effects of capital and intermediate importing bear clear policy implications. Given the degree of tariff liberalization, the choice of tariff structure (i.e., the tariff distribution between capital and intermediate imports) can also affect the aggregate productivity gains and, as a result, welfare in the economy. To analyze this issue, we conduct the second counterfactual exercise in which we quantify the relative contribution of the changes in tariff structure and average tariff rate. We first simulate the productivity for each year in a hypothetical scenario in which the tariff rates of capital and intermediate imports drop by the same percentage points, which are assumed equal to the weighted average of the tariff changes in both capital and intermediate goods in the corresponding year. This counterfactual keeps the tariff structure unchanged. By comparing this simulated productivity in each year under the (hypothetical) uniform tariff reduction with simulated productivity obtained when fixing the tariffs at the level of 2001, we then obtain the productivity gains up to each year and purely from tariff reductions without a change in tariff structure. Finally, by comparing the productivity of each year under the actual tariff reductions from the WTO accession with the simulated productivity under above hypothetical situation for the corresponding year, we obtain the productivity gains from a change in tariff structure.[14]

We focus on the group of firms that ever changed their capital or intermediates importing status from not-import to import at least once after the WTO tariff shock. We define these firms as marginal firms. These firms are most likely to be affected by the changes in tariff rates, because the productivity gains from extensive margin is much more important than that from intensive margin, as shown in Table 4. The marginal firms account for 6.6% of total firms, or 50% of the importing firms, in 2001 in our sample. We calculate the revenue-weighted average productivity in each counterfactual and the contribution of tariff changes on aggregate productivity accordingly.

Figure 4 shows the total gains, gains from average tariff reduction, and gains from changes in tariff structure over time from 2001 to 2006. Until 2006, WTO tariff reduction increases the average productivity of the marginal firms by roughly 1.5%. The reduction in tariff levels

[14]The detailed process of our counterfactual simulation is provided in the Appendix.

explains most of the productivity gains, by approximately 82%, and the tariff structure change explains the rest 18%. This finding emphasizes the importance of the choice of tariff structure to maximize the gains from tariff liberalization.

[Insert Figure 4 around here]

Relative Contribution: Capital Tariff Versus Intermediates Tariff. We now evaluate the relative contribution of import tariff cut on capital goods and that on intermediate goods. To this end, we simulate the productivity in two scenarios. The first is when there is only tariff cut on capital imports and the second is when there is only tariff cut on intermediate imports, with both cuts at the actual levels of the WTO accession. Productivity gains from reduction of capital tariffs is calculated as the difference between the average productivity of the marginal firms under only reduction of capital tariffs and that under no tariff change. Productivity gains from reduction of intermediate tariffs are calculated as the difference between the average productivity under only reduction of intermediates tariffs and that under no tariff change.

The simulation results are depicted in Figure 5. Around 62% of the total productivity gains from 2001 to 2006 due to the tariff reductions comes from tariff reductions on capital goods, although capital import accounts for only 15.6% of the total imports. In contrast, while 82.4% of the total imports are intermediate goods, the intermediate goods tariff cut contributes to only 31% of the productivity gains from 2001 to 2006.[15] The disproportionately larger gains from capital tariff reduction, relative to its import share, are due to the larger productivity effect of capital import and the larger reduction of import tariff rate on capital goods, relative to that on intermediate goods.

[Insert Figure 5 around here]

7 Concluding Remarks

International sourcing of inputs has become more important in global trade than ever. However, how international sourcing influences productivity remains an important question in development economics and international trade. This paper investigates the distinct effects of capital import and intermediates import on productivity growth at the firm level, and quantifies the role of tariff structure on productivity growth in a developing country after input tariff liberalization. Using a panel of Chinese manufacturing firms from 2000 to 2006, we demonstrate that capital goods import is the more important channel of productivity gains from international sourcing. It accounts for over 50% of the total productivity gains from international sourcing, although capital import accounts for only one-sixth of total input imports in value. Moreover, capital import has significant dynamic productivity effects and it stimulates more R&D investment,

[15]The rest 7% of the productivity gains comes from the complementarity between capital and intermediate tariff reductions.

accounting for about 25% of the productivity gains from capital import. These effects are insignificant for intermediates import. These results highlight the importance of separating capital import from intermediates import when evaluating the impact of international sourcing and trade policy on productivity growth at the firm level and at the aggregate level.

Our findings point to the importance of tariff structure in tariff liberalization. In the case of China's accession to the WTO in 2001, while the tariff reductions result in Chinese firms' productivity improvement, the changes of the tariff structure between capital and intermediate imports can explain around 18% of the productivity gains for those firms whose import decisions are affected by the tariff cuts.

Our firm-level evidence bears clear implications on theoretical models of firms' import decisions. Such a model needs to explicitly differentiate the effects of capital and intermediate importing. Further studies endeavoring to fully solve firms' dynamic decisions on capital and intermediate import are also encouraged to completely evaluate the gains from tariff liberalization in the short, medium, and long run.

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Appendix

A1 Product Classifications

[Insert Tables A1 and A2 here]

A2 Validity of Instrumental Variables

We use the change of industry-level average tariff rates (Δt_k and Δt_m) as instrumental variables (IVs) for the import decisions of individual firms. The first-stage results are reported in Table A3. We also include the lagged capital and intermediate imports as IVs in the estimation. Both capital and intermediate imports are sensitive to the reduction of capital and intermediates tariffs. One percentage increase of the reduction in capital (intermediate) tariff leads to 0.121 (0.086) percent increase of the probability of importing capital goods, and 0.173 (0.064) percent increase of the probability of importing intermediate goods.

[Insert Table A3 around here]

The exclusion condition check is reported in Table A4. After controlling for capital and intermediates imports, the effects of capital and intermediates tariff changes on both productivity and gross output are insignificant.

[Insert Table A4 around here]

A3 Counterfactual Simulation

First, we estimate the following decision equations for d^k_{jt}, d^m_{jt}, $d^{r\&d}_{jt}$, and ω_{jt} based on our sample.

(1) $d^k_{jt} = \hat{d^k}(\Delta t^k_{jt,2001}, \Delta t^m_{jt,2001}, d^k_{jt-1}, d^m_{jt-1}, \omega_{jt-1}, z_{jt-1}) + \varepsilon^k_{jt}$;

(2) $d^m_{jt} = \hat{d^m}(\Delta t^k_{jt,2001}, \Delta t^m_{jt,2001}, d^k_{jt-1}, d^m_{jt-1}, \omega_{jt-1}, z_{jt-1}) + \varepsilon^m_{jt}$;

(3) $d^{r\&d}_{jt} = \hat{d^{r\&d}}(d^k_{jt-1}, d^m_{jt-1}, d^{r\&d}_{jt-1}, \omega_{jt-1}, z_{jt-1}) + \varepsilon^{r\&d}_{jt}$;

(4) $\omega_{jt} = \hat{\omega}(\omega_{jt-1}, d^k_{jt-1}, d^m_{jt-1}, d^{r\&d}_{jt-1}) + \varepsilon^{\omega}_{jt}$,

where the change of tariff is defined as tariff changes since 2001, that is, $\Delta t^h_{jt,2001} = t^h_{j,t} - t^h_{j,2001}$, $h \in \{k, m\}$. Control variables, z_{jt-1}, include export status, log of capital size and year trend. $\{\varepsilon^k_{jt}, \varepsilon^m_{jt}, \varepsilon^{r\&d}_{jt}, \varepsilon^{\omega}_{jt}\}$ are assumed to be i.i.d with zero mean. Table A5 reports the estimation for the first three equations. The estimation of the fourth equation follows the results in column (1) in Table 4.

[Insert Table A5 around here]

Second, we calculate the simulated $\{\widetilde{d^k_{jt}}, \widetilde{d^m_{jt}}, \widetilde{d^{r\&d}_{jt}}, \widetilde{\omega}_{jt}\}$ based on five scenarios:

(1) The hypothetical tariff changes equal the real changes: $\Delta\widetilde{t^k_{jt,2001}} = \Delta t^k_{jt,2001}$ and $\Delta\widetilde{t^m_{jt,2001}} = \Delta t^m_{jt,2001}$.

(2) No tariff reduction for both types of tariff in each year t since 2001: $\Delta\widetilde{t}^{k}_{jt,2001} = \Delta\widetilde{t}^{m}_{jt,2001} = 0$.

(3) Only tariff reduction for capital tariff: $\Delta\widetilde{t}^{k}_{jt,2001} = \Delta t^{k}_{jt,2001}$ and $\Delta\widetilde{t}^{m}_{jt,2001} = 0$.

(4) Only tariff reduction for intermediate tariff: $\Delta\widetilde{t}^{k}_{jt,2001} = 0$ and $\Delta\widetilde{t}^{m}_{jt,2001} = \Delta t^{m}_{jt,2001}$.

(5) Both tariff reduction equal the same weighted average tariff to remove the structure differences: $\Delta\widetilde{t}^{k}_{jt,2001} = \Delta\widetilde{t}^{m}_{jt,2000} = \Delta t_{jt,2001}$.

With different hypothetical tariff changes, we calculate the simulated $\{\widetilde{d}^{k}_{jt,2001}, \widetilde{d}^{m}_{jt,2001}, \widetilde{d}^{r\&d}_{jt,2001}, \widetilde{\omega}_{jt,2001}\}$ according to the following process:

(1) We fix our sample of firms in 2001. Thus, we do not consider new firms entering after 2001, and we assume all firms in 2001 can survive to 2006.

(2) Generate random number p^{k}_{jt}, p^{m}_{jt}, $p^{r\&d}_{jt}$ for all firms in all years. The random numbers are generated from uniform distribution with support $(0, 1)$. Generate random shock $\widetilde{\varepsilon}^{\omega}_{jt}$ to productivity with normal distribution of zero mean and 0.361 standard deviation, which equals the estimated standard deviation of $\varepsilon^{\omega}_{jt}$.

(3) In the first period, $n = 1$ (year=2001), let $\widetilde{d}^{j}_{j,1} = d^{j}_{j,1}$ and $\widetilde{\omega}_{j,1} = \omega_{j,1}$, where $j = \{k, m, r\&d\}$.

(4) When $n > 1$, calculate $\widetilde{d}^{k}_{j,n} = \hat{d}^{k}(\Delta\widetilde{t}^{k}_{j,n,2001}, \Delta\widetilde{t}^{m}_{j,n,2001}, \widetilde{d}^{k}_{j,n-1}, \widetilde{d}^{m}_{j,n-1}, \widetilde{\omega}_{j,n-1})$. If $\widetilde{d}^{k}_{j,n} > p^{k}_{j,n}$, then replace $\widetilde{d}^{k}_{j,n} = 1$. Otherwise, replace $\widetilde{d}^{k}_{j,n} = 0$. Similarly, we have $\widetilde{d}^{m}_{j,n}$ and $\widetilde{d}^{r\&d}_{j,n}$.

(5) Calculate $\widetilde{\omega}_{j,n} = \hat{\omega}(\widetilde{\omega}_{j,n-1}, \widetilde{d}^{k}_{j,n-1}, \widetilde{d}^{m}_{j,n-1}, \widetilde{d}^{r\&d}_{j,n-1})$.

(6) In period $n + 1$, follow the above steps (3)-(4) until the last observation of each i is fulfilled.

Finally, repeat the previous process 100 times by generating different random numbers for $\{p^{k}_{jt}, p^{m}_{jt}, p^{r\&d}_{jt}\}$.

There were 147,298 firms in 2001, among which 9108 firms imported either capital or intermediate goods in 2001 through ordinary trade. In our simulation, 9713 firms ever changed their capital or intermediates importing status from not-import to import at least once after the WTO tariff shock. We focus on the productivity gains of these marginal importers.

By comparing the average productivity for these marginal importers under different scenarios, we calculate the contributions of different components of tariff reduction. The difference between average productivity under real tariff and no tariff reduction (scenarios 1 and 2) is regarded as total productivity gains from tariff reduction. The difference between average productivity under the same tariff and no tariff reduction (scenarios 5 and 2) is regarded as productivity gains from tariff trend. The gap between total gains and gains from tariff trend is the gains from tariff structure. Figure 4 shows total gains, gains from tariff trend, and gains from tariff structure over time. Total gains from tariff reduction are around 1.5% in 2006. Gains from tariff structure accounts for around 18% of the total gains from 2002 to 2006.

We are also interested in the single effect of capital and intermediate tariff. Productivity gains from capital tariff reduction is calculated as the difference between average productivity under only capital tariff and no tariff reduction (scenarios 3 and 2). Similar calculation is performed for the gains from intermediate tariff reduction. Figure 5 compares the gains from capital and intermediate tariff reduction. Around 67% of productivity gains come from capital tariff reduction.

Table 1: Basic Summary Statistics

Number of firms	431,039	
Total observations	1,414,173	
Share of importing firms (%)	12.4	
Share of importing observations (%)	11.1	
Firm variables	Mean	S.D.
Gross output (million RMB)	71.2	593.5
Value added (million RMB)	18.7	160.3
Capital stock (million RMB)	24.8	271.3
Labor (number of employees)	258	918.7
Intermediate inputs (million RMB)	52.4	464.5
R&D participation rate	0.12	0.32

Note: Our dataset covers manufacturing firms from 2000 to 2007. The average duration of firms is 3.28 years (1414173/431.39 = 3.28). Importing firms are defined as firms ever imported capital goods, intermediate goods or consumption goods through either ordinary or processing trade (duty-free). Importing firms did not always import every year during the sample period, resulting in a smaller share of importing observations than the share of importing firms. All values are deflated by respective price index using the input and output price index developed by Brandt, Van Biesebroeck, Wang, and Zhang (2017).

Table 2: Import Share of Capital and Intermediate Goods in China from 2000 to 2006 (%)

Value share of transactions	Ordinary	Processing
Capital goods	15.6	13.9
Intermediate goods	82.4	82.4
Others	2	3.7
Total share	100	100
Total value (trillion RMB)	274.1	690.5
Share of firms that import	Ordinary firms	Processing firms
Capital goods only	9.8	0.4
Intermediate goods only	48.4	56.1
Both	41.8	43.5
Total share	100	100
Total number of firms	14,544	37,979

Note: The calculation is based on firm-level manufacturing dataset matched with customs dataset in China from 2000 to 2006. Others refer to imported consumption goods. Ordinary firms refer to the firms import via ordinary trade, and processing firms are the firms import via processing trade (duty-free) or via both processing and ordinary trade. The average share of import through processing trade for processing firms is 59%.

Table 3: Characteristics of Capital and Intermediate Importers in China, 2000–2006

Firm type	Value added per worker	Gross output	Capital stock	Labor	Intermediate inputs	Foreign ownership (%)	R&D participation (%)
	VAPW	ln*Y*	ln*K*	ln*L*	ln*M*	Foreign_share	R&D
Capital only	81.30	10.67	9.23	5.38	10.33	0.17	0.29
	(229.1)	(1.24)	(1.61)	(1.12)	(1.30)	(0.32)	(0.45)
	[7,119]	[7,103]	[7,111]	[7,125]	[7,104]	[7,106]	[6,767]
Intermediate only	72.17	10.35	8.72	5.27	9.99	0.52	0.13
	(280.2)	(1.18)	(1.57)	(1.07)	(1.25)	(0.44)	(0.34)
	[120,594]	[120,369]	[120,268]	[120,875]	[120,486]	[120,415]	[116,626]
Both	122.90	11.21	9.86	5.73	10.83	0.61	0.27
	(576.7)	(1.52)	(1.80)	(1.28)	(1.58)	(0.43)	(0.44)
	[110,940]	[110,757]	[110,712]	[111,115]	[110,782]	[110,720]	[107,885]
Non-importers	78.46	9.71	8.08	4.60	9.34	0.08	0.10
	(185.7)	(1.26)	(1.63)	(1.05)	(1.32)	(0.25)	(0.30)
	[1,167,806]	[1,154,913]	[1,162,348]	[1,175,000]	[1,157,600]	[1,159,630]	[1,115,039]
All firms	81.44	9.89	8.28	4.75	9.52	0.16	0.12
	(249.00)	(1.35)	(1.72)	(1.12)	(1.40)	(0.34)	(0.32)
	[1,406,459]	[1,393,142]	[1,400,439]	[1,414,115]	[1,395,972]	[1,397,871]	[1,346,317]

Note: "Capital only" refers to firms that only import capital goods. "Intermediate only" refers to firms that only import intermediate goods. "Both" refers to firms that import both capital and intermediate goods. "Non-importers" refer to firms that never import capital or intermediate goods in the sample. Each cell reports the mean, standard deviation in ( ) and number of observations in [ ], respectively. VAPW is in thousand RMB, all other value terms are in log of thousand RMB, and labor is in log of the number of employment.

Table 4: Effects of Capital and Intermediate Imports on Productivity

Dependent variable: Log gross output	(1)	(2)
Labor (log *L*)	0.069***	0.069***
	(0.0006)	(0.0006)
Intermediate inputs (log *M*)	0.860***	0.861***
	(0.0003)	(0.0003)
Capital (log *K*)	0.018***	0.018***
	(0.0004)	(0.0004)
Import k	0.023***	0.014***
	(0.0007)	(0.0008)
Import m	0.018***	0.008***
	(0.0003)	(0.0003)
Import k * Import m	0.015***	0.003***
	(0.0008)	(0.0008)
Share of import k		0.112***
		(0.004)
Share of import m		0.132***
		(0.003)
Share of import k * Share of import m		0.018
		(0.019)
Productivity evolution ρ	0.986***	0.985***
	(0.0005)	(0.0005)
Import k (lag)	0.006***	0.006***
	(0.0009)	(0.0010)
Import m (lag)	-0.0003	-0.0001
	(0.0003)	(0.0003)
Import k (lag) * Import m (lag)	0.0002	0.0002
	(0.0010)	(0.0011)
Share of import k (lag)		0.013***
		(0.005)
Share of import m (lag)		0.005**
		(0.002)
Share of import k (lag) * Share of import m (lag)		-0.006
		(0.019)
R&D participation (lag)	0.0025***	0.0025***
	(0.0001)	(0.0001)
Observations	860,799	858,233

Note: Labor (log) is adopted as proxy for productivity. Firms that imported only through processing trade are excluded. All regressions control for firm ownership (state, private, and foreign ownership). Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 5: Effects of Capital and Intermediate Imports on R&D Participation

Dependent variable: R&D participation	(1)	(2)
R&D participation (lag)	0.620***	0.620***
	(0.002)	(0.002)
Import k (lag)	0.025***	0.023***
	(0.005)	(0.005)
Import m (lag)	0.002	0.003*
	(0.002)	(0.002)
Import k (lag) * Import m (lag)	-0.006	-0.006
	(0.006)	(0.006)
Share of import k (lag)		0.050***
		(0.018)
Share of import m (lag)		-0.020**
		(0.009)
Share of import k (lag) * Share of import m (lag)		0.023
		(0.072)
lnTFP (lag)	0.020***	0.020***
	(0.001)	(0.001)
Export participation (lag)	0.014***	0.014***
	(0.001)	(0.001)
Log capital (lag)	0.014***	0.014***
	(0.000)	(0.000)
Fixed Effects	Yes	Yes
Observations	854188	852526
Adjusted R-squared	0.465	0.465

Note: Fixed effects include year, province, industry, and ownership (state owned, collectively owned, private, Hong Kong-Macao-Taiwan, foreign owned, and other). Firms that import only through processing trade are excluded. Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 6: Effects of Imports on Productivity (Proxy: Investment)

Dependent variable: Log gross output	(1)	(2)	(3)	(4)
	Long-term investment		Gross investment	
Labor (log L)	0.071***	0.071***	0.066***	0.066***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Intermediate (log M)	0.859***	0.861***	0.868***	0.869***
	(0.0003)	(0.0003)	(0.0004)	(0.0004)
Capital (log K)	0.029***	0.028***	0.028***	0.028***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)
Import k	0.022***	0.014***	0.018***	0.012***
	(0.0007)	(0.0008)	(0.0008)	(0.0008)
Import m	0.019***	0.008***	0.016***	0.006***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Import k * Import m	0.016***	0.004***	0.021***	0.008***
	(0.0008)	(0.0008)	(0.0009)	(0.0009)
Share of import k		0.104***		0.093***
		(0.0051)		(0.0054)
Share of import m		0.118***		0.139***
		(0.0028)		(0.0031)
Share of import k * Share of import m		0.071**		0.044
		(0.032)		(0.038)
Productivity evolution ρ	0.984***	0.984***	0.955***	0.955***
	(0.0005)	(0.0005)	(0.0006)	(0.0006)
Import k (lag)	0.0058***	0.0057***	0.0055***	0.0053***
	(0.0008)	(0.0009)	(0.0009)	(0.0010)
Import m (lag)	-0.00002	0.00004	0.0005*	0.0006**
	(0.0002)	(0.0002)	(0.0003)	(0.0003)
Import k (lag) * Import m (lag)	-0.0001	-0.0001	0.0016	0.0012
	(0.0009)	(0.0010)	(0.0010)	(0.0011)
Share of import k (lag)		0.012***		0.018***
		(0.0040)		(0.0041)
Share of import m (lag)		0.0002		0.0024
		(0.0015)		(0.0016)
Share of import k * Share of import m (lag)		-0.005		-0.024
		(0.0235)		(0.0229)
R&D participation (lag)	0.0024***	0.0024***	0.0030***	0.0029***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	860,383	857,819	656,411	654,433

Note: Firms that import only through processing trade are excluded. All regressions control for the firm ownership (state, private, and foreign ownership). Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 7: Effects of Capital and Intermediate Imports on Productivity (IV Approach)

Dependent variable: Log gross output	(1) Labor	(2) Long-term investment	(3) Gross investment
Labor (log *L*)	0.066***	0.070***	0.068***
	(0.022)	(0.0005)	(0.0005)
Intermediate inputs (log *M*)	0.864***	0.869***	0.867***
	(0.0004)	(0.0004)	(0.0004)
Capital (log *K*)	0.029***	0.026***	0.027***
	(0.0027)	(0.0001)	(0.0001)
Import k	0.020***	0.045***	0.076***
	(0.0077)	(0.0012)	(0.0008)
Import m	0.010***	0.019***	0.019***
	(0.004)	(0.0004)	(0.0003)
Import k * Import m	0.017***	0.023***	-0.011***
	(0.0072)	(0.0014)	(0.0009)
Productivity evolution ρ	0.802***	0.975***	0.950***
	(0.050)	(0.0005)	(0.0005)
Import k (lag)	0.025***	0.005***	0.003***
	(0.011)	(0.0011)	(0.0011)
Import m (lag)	0.0055	-0.0001	0.0004
	(0.0061)	(0.0003)	(0.0003)
Import k (lag) * Import m (lag)	-0.020*	0.0015	0.004***
	(0.011)	(0.0012)	(0.0012)
R&D participation (lag)	0.037***	0.0023***	0.003***
	(0.005)	(0.0001)	(0.0002)
Observations	858,446	860,383	656,411

Note: We employ the changes of capital and intermediate tariff since 2000 and the lagged capital and intermediate imports as instrumental variables for capital and intermediate imports in the first stage estimation. For the last two columns, we also include the lag of foreign share as the instrumental variable. Firms that import only through processing trade are excluded. All regressions control for the firm ownership (state, private, and foreign ownership). * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 8: Heterogeneous Effects of Capital Imports on Productivity

Dependent variable: Log gross output	(1) Capital intensive	(2) Labor intensive
Labor (log *L*)	0.057***	0.079***
	(0.0009)	(0.0008)
Intermediate inputs (log *M*)	0.860***	0.860***
	(0.0003)	(0.0003)
Capital (log *K*)	0.017***	0.022***
	(0.0006)	(0.0005)
Import k	0.026***	0.021***
	(0.0013)	(0.0008)
Import m	0.020***	0.018***
	(0.0005)	(0.0003)
Import k * Import m	0.013***	0.016***
	(0.0014)	(0.0009)
Productivity evolution ρ	0.984***	0.982***
	(0.0007)	(0.0008)
Import k (lag)	0.012***	0.0043***
	(0.0017)	(0.0011)
Import m (lag)	0.0016***	-0.0006*
	(0.0004)	(0.0003)
Import k (lag) * Import m (lag)	-0.0018	-0.0009
	(0.0018)	(0.0012)
R&D participation (lag)	0.0038***	0.0009***
	(0.0002)	(0.0002)
Observations	433,698	427,101

Note: Capital (labor) intensive industries are defined as the industries with a capital-to-labor ratio greater than or equal to (smaller than) the median of the capital-to-labor ratio in all industries in the initial year (2000). Labor (log) is adopted as proxy for productivity. Firms that imported only through processing trade are excluded. All regressions control for firm ownership (state, private, and foreign ownership). Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 9: Effects of Processing Imports on Productivity

Dependent variable: Log gross output	(1) Proxy: Labor	(2) Long-term investment	(3) Gross investment
Labor (log *L*)	0.070***	0.072***	0.067***
	(0.0006)	(0.0004)	(0.0005)
Intermediate (log *M*)	0.858***	0.858***	0.867***
	(0.0003)	(0.0003)	(0.0004)
Capital (log *K*)	0.018***	0.028***	0.027***
	(0.0004)	(0.0001)	(0.0002)
Processing import k	0.035***	0.035***	0.014***
	(0.0024)	(0.0027)	(0.0032)
Processing import m	0.007***	0.009***	0.008***
	(0.0003)	(0.0003)	(0.0004)
Processing import k * Processing import m	-0.019***	-0.016***	0.004
	(0.0024)	(0.0028)	(0.0032)
Ordinary import participation	0.004***	0.004***	0.004***
	(0.0003)	(0.0003)	(0.0004)
Productivity evolution ρ	0.987***	0.986***	0.957***
	(0.0005)	(0.0005)	(0.0006)
Processing import k (lag)	-0.0016	0.0001	-0.003
	(0.0026)	(0.0023)	(0.0028)
Processing import m (lag)	-0.006***	-0.005***	-0.006***
	(0.0002)	(0.0002)	(0.0002)
Processing import k (lag) * processing import m (lag)	0.005*	0.002	0.006**
	(0.0027)	(0.0024)	(0.0028)
Ordinary import participation (lag)	0.007***	0.007***	0.008***
	(0.0003)	(0.0002)	(0.0003)
R&D participation (lag)	0.002***	0.002***	0.003***
	(0.0001)	(0.0001)	(0.0002)
Observations	848,222	847,852	645,184

Note: Firms that import only through ordinary trade are excluded. All regressions control the firm ownership (state, private, and foreign ownership). * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 10: Effects of Processing Imports on R&D Participation

Dependent variable: R&D participation	(1)	(2)
R&D participation (lag)	0.614***	0.613***
	(0.002)	(0.002)
Processing import k (lag)	-0.003	-0.001
	(0.003)	(0.003)
Processing import m (lag)	-0.024***	-0.007***
	(0.001)	(0.002)
Share of processing import k (lag)		0.026*
		(0.013)
Share of processing import m (lag)		-0.066***
		(0.003)
Ordinary import k (lag)	0.025***	0.024***
	(0.003)	(0.003)
Ordinary import m (lag)	0.013***	0.014***
	(0.002)	(0.002)
Share of ordinary import k (lag)		0.041**
		(0.021)
Share of ordinary import m (lag)		-0.012
		(0.011)
lnTFP (lag)	0.018***	0.019***
	(0.001)	(0.001)
Export participation (lag)	0.012***	0.012***
	(0.001)	(0.001)
Log capital (lag)	0.013***	0.013***
	(0.000)	(0.000)
Fixed Effects	Yes	Yes
Observations	841902	832505
Adjusted R-squared	0.449	0.449

Note: Fixed effects include year, province, industry and ownership (state owned, collectively owned, private, Hong Kong-Macao-Taiwan, foreign owned, and other). Firms that import only through ordinary trade are excluded. Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 11: Decomposition of Productivity Gains from Import (in percentage)

	Capital import	Intermediate import	Complementarity (+) / Substitution (-)	Total gains
Immediate effect	0.94	1.04	0.12	2.10
Dynamic effect	0.31	0.02	0.006	0.34
Induced-R&D effect	0.003	0.0002	-0.0006	0.002
Total gains	1.25	1.06	0.13	2.44

Note: Firms that import only through processing trade are excluded. Calculation is based on specifications in column (2) of Table 4 and column (3) of Table 5.

Table 12: Revenue Gains from Per Dollar Import (USD in current price)

	Import	Import k	Import m	Complementarity (+) / Substitution (-)
Immediate effect	3.34	9.28	2.16	0.23
Dynamic effect	0.63	3.70	0.04	0.01
Induced-R&D effect	0.005	0.03	0.0004	-0.001
Total	3.98	13.01	2.20	0.24

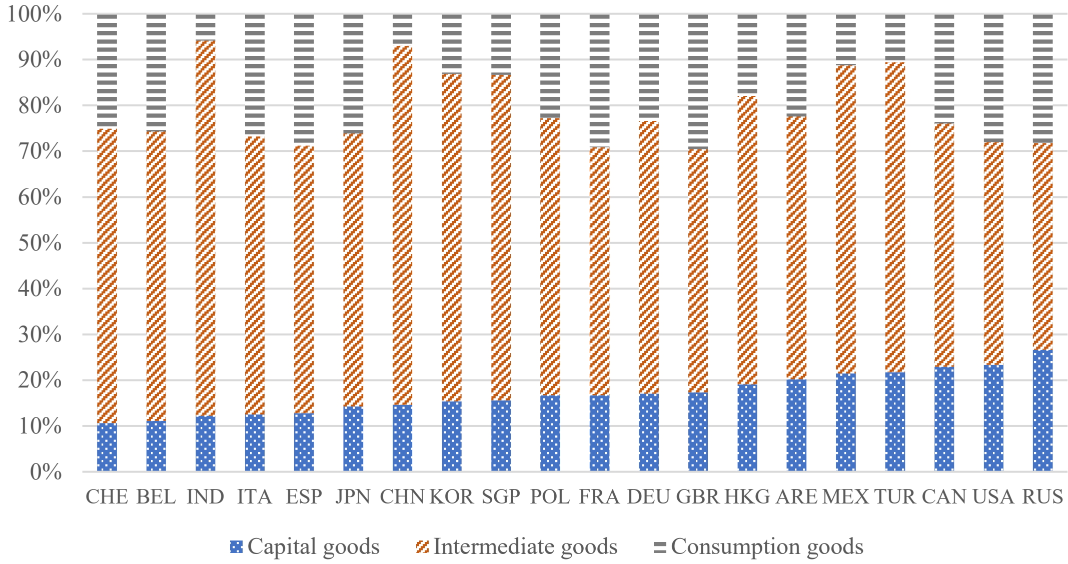
Note: Firms that import only through processing trade are excluded. Calculation is based on specification in column (2) of Table 4 and column (3) of Table 5.

Table 13: Tariff Liberalization and Import Decisions

	(1) Capital import	(2) Intermediate import
Change of capital tariff since 2001	-0.091^{***}	-0.143^{***}
	(0.006)	(0.007)
Change of intermediate tariff since 2001	-0.103^{***}	-0.062^{***}
	(0.006)	(0.007)
Capital import (lag)	0.446^{***}	0.169^{***}
	(0.003)	(0.003)
Intermediate import (lag)	0.146^{***}	0.558^{***}
	(0.002)	(0.002)
lnTFP (lag)	0.010^{***}	0.013^{***}
	(0.000)	(0.001)
Export participation (lag)	0.020^{***}	0.060^{***}
	(0.000)	(0.001)
Log capital (lag)	0.007^{***}	0.009^{***}
	(0.000)	(0.000)
Observations	952,623	952,623
R-squared	0.375	0.473

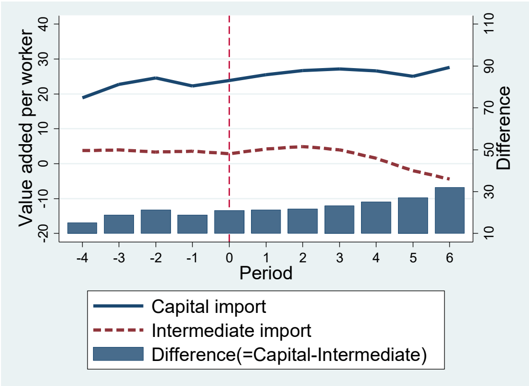
Note: We also control for year trend in all regressions. Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Figure 1: Import Structure across Countries/Regions, 2016

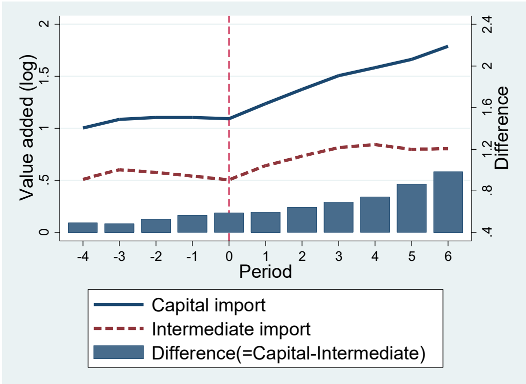


Source: UN Comtrade.

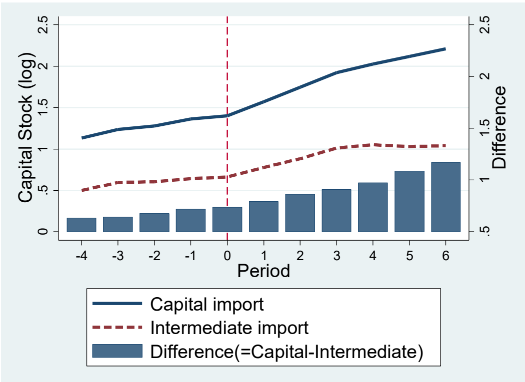
Figure 2: Dynamic Comparison



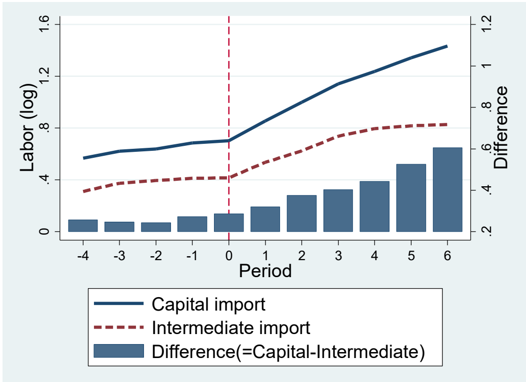
(a) VAPW



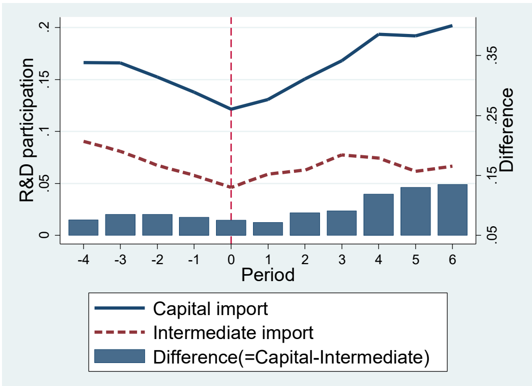
(b) lnVA



(c) lnK



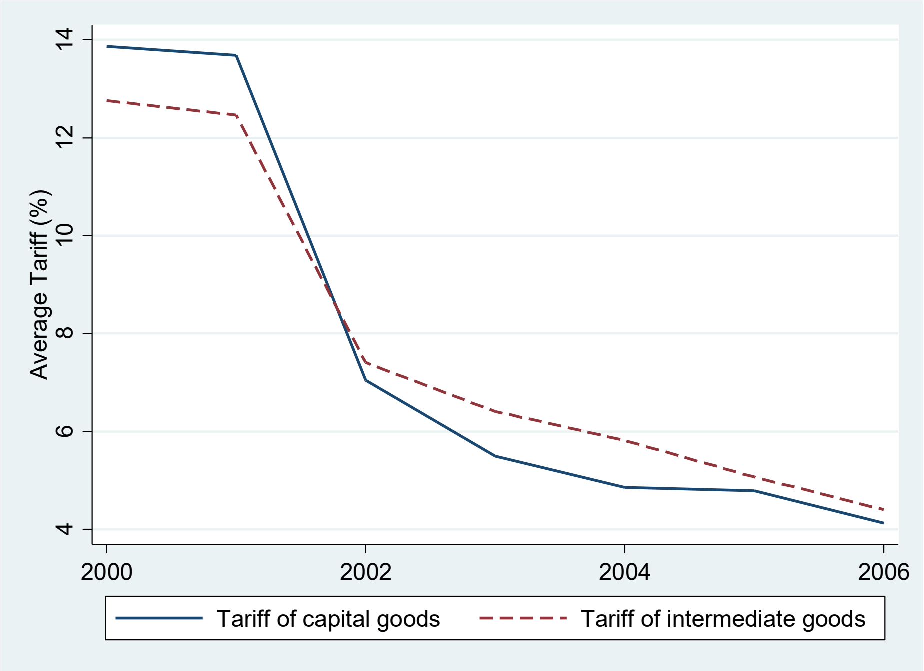
(d) lnL



(e) R&D participation

Note: Year one is the year when a firm first imports capital or intermediate goods through ordinary trade. The *k*th year before and after the first-time import is denoted as period 1-*k* and 1+*k* respectively. The dash line represents the mean of the firms importing intermediate goods only, whereas the solid line represents the firms that have capital goods in the entire period. The mean is the average value demeaned from the industry.

Figure 3: Average Import Tariff Rates by Product Category



Note: The average tariff rates are calculated using import value of corresponding products as the weights.

Figure 4: Productivity Gains from Tariff Reduction: Average Tariff Reduction versus Tariff Structure

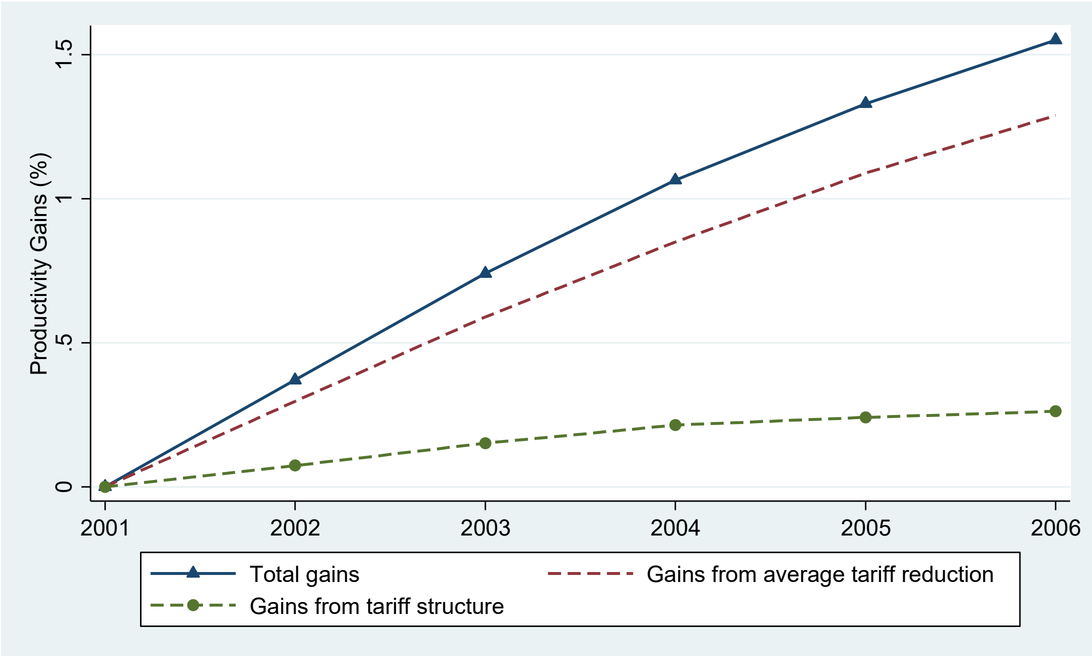
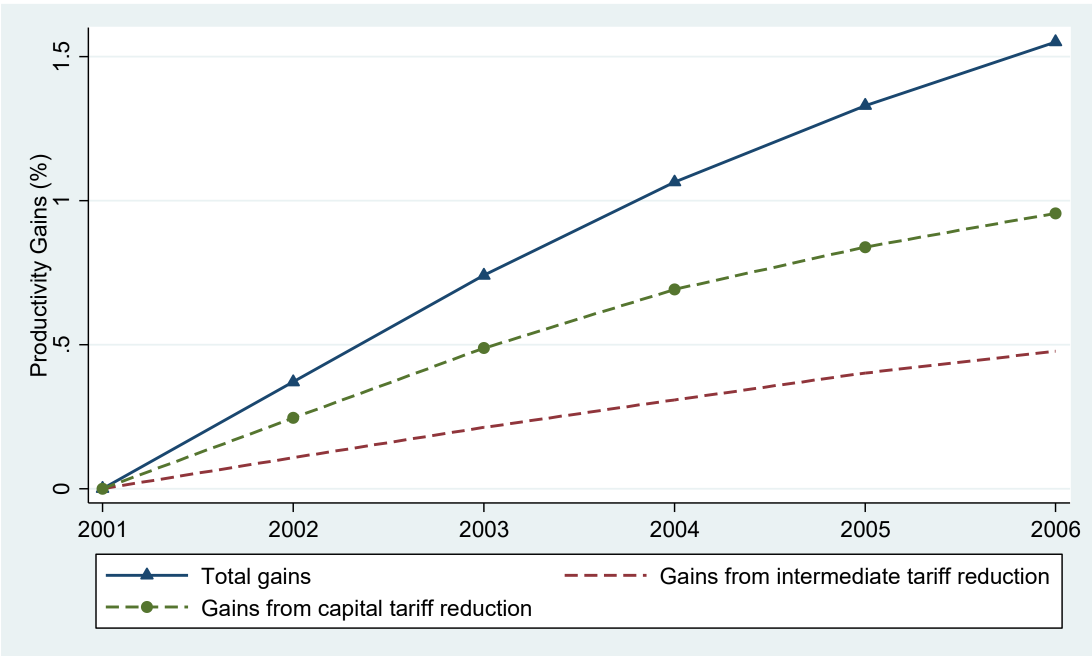


Figure 5: Productivity Gains from Tariff Reduction: Capital versus Intermediate Tariff



Tables in Appendix

Table A1: BEC Classification

Classification of goods by BEC	Unique categories	Basic classes in SNA
1 Food and beverages		
11 Primary		
111 Mainly for industry	1	Intermediate
112 Mainly for household consumption	2	Consumption
12 Processed		
121 Mainly for industry	3	Intermediate
122 Mainly for household consumption	4	Consumption
2 Industrial supplies not elsewhere specified		
21 Primary	5	Intermediate
22 Processed	6	Intermediate
3 Fuels and lubricants		
31 Primary	7	Intermediate
32 Processed		
321 Motor spirit	8	*Not classified*
322 Other	9	Intermediate
4 Capital goods (except transport equipment), and parts and accessories thereof		
41 Capital goods (except transport equipment)	10	Capital
42 Parts and accessories	11	Intermediate
5 Transport equipment and parts and accessories thereof		
51 Passenger moto vehiles	12	*Not classified*
52 Other		
521 Industrial	13	Capital
522 Non-industrial	14	Consumption
53 Parts and accessories	15	Intermediate
6 Consumer goods not elsewhere specified		
61 Durables	16	Consumption
62 Semi-durable	17	Consumption
63 Non-durable	18	Consumption
7 Goods not elsewhere specified	19	*Not classified*

Source: United Nations.

Table A2: Examples of Product Classification

Product code	Authors	BEC	BEC category	Product name
820559	K	K	41	Hand tools, incl. glaziers' diamonds, of base metal, n.e.s.
840410	K	K	41	Auxiliary plant for use with boilers of heading 8402 or 8403, e.g., economizers, superheaters, soot removers and gas recoverers
845420	K	K	41	External refining equipment
845931	K	K	41	NC boring and milling machine
846249	K	K	41	Other punching or slotting machines
851750	K	K	41	Other optical communication equipment
901210	K	K	41	Microscopes (excluding optical microscopes); Diffraction device
902720	K	K	41	Gas chromatograph
220720	M	M	22	Denatured ethyl alcohol and other spirits of any strength
250410	M	M	21	Natural graphite in powder or in flakes
250700	M	M	21	Kaolin and other kaolinic clays, whether or not calcined
270400	M	M	322	Coke and semi-coke of coal, lignite, or peat, whether or not agglomerated; retort carbon
271114	M	M	322	Ethylene, propylene, butylene and butadiene, liquefied (excl. ethylene of a purity of >= 95% and propylene, butylene and butadiene of a purity of >= 90%)
284110	M	M	22	Peroxyborates "perborates"
294200	M	M	22	Separate chemically defined organic compounds, n.e.s.
340391	M	M	322	Textile lubricant preparations and preparations of a kind used for the oil or grease treatment of leather, fur skin, or other material not containing petroleum or bituminous mineral oil
610230	C	C	62	Women's or girls' overcoats, car coats, capes, cloaks, anoraks, incl. ski jackets, windcheaters, wind-jackets and similar articles of man-made fibers
610342	C	C	62	Men's or boys' trousers, bib and brace overalls, breeches, and shorts of cotton, knitted or crocheted (excl. swimwear and underpants)
610349	C	C	62	Men's or boys' trousers, bib and brace overalls, breeches, and shorts of textile materials, knitted or crocheted
610444	C	C	62	Women's or girls' dresses of artificial fibers, knitted or crocheted (excl. petticoats)
610453	C	C	62	Women's or girls' skirts and divided skirts of synthetic fibers, knitted or crocheted (excl. petticoats)
611610	C	C	63	Gloves, mittens and mitts, impregnated, coated or covered with plastics or rubber, knitted or crocheted

Note: "K": Capital goods; "M": Intermediate goods; "C": Consumption goods.

Table A3: First Stage Checks of IV Regressions

	(1) Capital import	(2) Intermediate import
Change of capital tariff since 2000	-0.121***	-0.173***
	(0.006)	(0.007)
Change of intermediate tariff since 2000	-0.086***	-0.064***
	(0.006)	(0.007)
Capital import (lag)	0.445***	0.167***
	(0.003)	(0.003)
Intermediate import (lag)	0.143***	0.550***
	(0.002)	(0.002)
Export status (lag)	0.024***	0.071***
	(0.0005)	(0.0007)
Capital (log *K*, lag)	0.008***	0.010***
	(0.0001)	(0.0001)
Controls	Yes	Yes
Observations	921,193	921,193
R-squared	0.374	0.474

Note: Control variables include year trend, lags of capital (log), and export status. Firms that import only through processing trade are excluded. Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A4: Exclusion Condition Checks of IV Regressions

	(1)	(2)
	Log TFP	Log gross output
Change of capital tariff since 2000	-0.240	-0.231
	(0.157)	(0.163)
Change of intermediate tariff since 2000	-0.089	-0.068
	(0.127)	(0.122)
Capital import (lag)	0.064***	0.040***
	(0.003)	(0.003)
Intermediate import (lag)	0.053***	0.027***
	(0.003)	(0.004)
Capital (log *K*)		0.034***
		(0.001)
Labor (log *L*)		0.076***
		(0.003)
Intermediate input (log *M*)		0.871***
		(0.003)
Constant	1.027***	0.797***
	(0.022)	(0.031)
Fixed effects	Yes	Yes
Observations	913,732	913,732
R-squared	0.141	0.941

Note: Firms that import only through processing trade are excluded. Fixed effects of province, year, industry, and ownership are included in all regressions. Standard errors in parentheses are clustered in four-digit industry code. * p < .10, ** p < .05, *** p < .01.

Table A5: Import Decisions in Simulation

	(1) Capital import	(2) Inter. import	(3) R&D participation
Change of capital tariff since 2001	-0.091***	-0.143***	
	(0.006)	(0.007)	
Change of intermediate tariff since 2001	-0.103***	-0.062***	
	(0.006)	(0.007)	
Capital import (lag)	0.446***	0.169***	0.034***
	(0.003)	(0.003)	(0.002)
Inter. import (lag)	0.146***	0.558***	0.002*
	(0.002)	(0.002)	(0.001)
R&D participation (lag)			0.639***
			(0.001)
lnTFP (lag)	0.010***	0.013***	0.017***
	(0.000)	(0.001)	(0.001)
Export participation (lag)	0.020***	0.060***	0.006***
	(0.000)	(0.001)	(0.001)
Log capital (lag)	0.007***	0.009***	0.015***
	(0.000)	(0.000)	(0.000)
Observations	952,623	952,623	891,463
R-squared	0.375	0.473	0.452

Note: We also control for year trend in all specifications. Standard errors in parentheses. * p < .10, ** p < .05, *** p < .01.