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

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

May 2021

Abstract

This paper investigates the distinct effects of capital and intermediates imports on firms' productivity growth, 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 import has a substantially larger productivity effect than intermediates import. On the one hand, while both types of imports exert immediate effects on productivity, only capital import has dynamic productivity effects. On the other hand, we identify significant R&D-capital synergy effect and R&D-inducing effect from capital import, but there is no clear evidence of these effects from intermediates import. Regarding the effects of China's input tariff liberalization following its WTO accession, the change in tariff structure explains 18 percent of the productivity gains.

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

JEL Codes: F14, O10.

*We benefitted from discussions with Costas Arkolakis, Shengyu Li, Mark Roberts, Hylke Vandenbussche, Yifan Zhang, and presentations at the Eighth Annual Conference of China Trade Research Group (2017), the 13th Australasian Trade Workshop (2018), the Asia Pacific Trade Seminars (2018) and Beijing Forum (2019). We also thank the editor and two anonymous referees for their insightful comments. This work received financial support from the General Research Fund (#17502018) and the URC/CRCG–Conference Support for Teaching Staff (# 201807170336) at The University of Hong Kong, and research start-up fund from Peking University.

†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 the one hand, the 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 literature finds evidence that international sourcing in general—without distinguishing capital from intermediate goods—improves the productivity of importers due to more varieties, better quality, and learning (Amiti and Konings, 2007; Halpern, Koren, and Szeidl, 2015). Identifying the channels through which international sourcing affects productivity growth is very important for governments in developing countries to design their trade and development policies.

Based on the data of Chinese manufacturing firms, this paper investigates the distinct effects of capital and intermediates imports on productivity growth at the micro level, and quantifies the importance of tariff structure in trade liberalization. By definition, intermediate goods, such as materials, parts, and accessories, are usually one-off consumable in one accounting period whereas capital goods, such as equipment, machine tools, lathe, and industrial robots, can typically be used for multiple periods. In addition to the difference in time horizon, capital goods import is often regarded as a channel for international technology diffusion since capital goods production is highly concentrated in a few R&D-intensive countries (Eaton and Kortum, 2001). As a result, capital goods import may generate an augmented immediate productivity effect via an import-R&D synergy effect when the importer is also conducting R&D investment, or induce more R&D investment which further enhances productivity growth in the long run. The objective of this paper is to investigate the distinct productivity effects of capital and intermediates imports in the short and long run, and the role played by R&D investment in this process.

Our data from Chinese manufacturing industries show a number of interesting stylized facts: capital importers are larger, more productive, and invest more in R&D, compared with intermediates importers and firms that do not import. Capital importers also have higher growth rates of sales, labor productivity, and R&D investment. To explain these stylized facts, we first build a structural model, which describes firms' decisions on imports, investment, and R&D in a dynamic setting. The model allows input import to influence the importers' productivity through several channels. We then quantify the empirical importance of the productivity effects from capital and intermediates imports, by estimating the model using the standard production estimation approach developed by Olley and Pakes (1996) and Levinsohn and Petrin (2003).

We apply the model to a large panel of Chinese manufacturing firms during 2000-2006. The empirical findings demonstrate that capital import generates larger productivity gains compared with intermediates import, and that the two types of import generate productivity premiums through different channels. First, both capital and intermediates imports have strong immediate productivity effects. Importing capital goods alone and importing intermediate goods alone raises the importer's productivity by 1.8% within a year, respectively; importing both further augments the productivity gains by 1.5%, thereby implying a complementarity of using imported capital and intermediate goods. This result echoes the quality-and-variety effect of input imports as emphasized in the literature, although the literature does not distinguish capital import from intermediates import.[1] In addition, we also identify a new channel through which capital import generates immediate productivity effect: If the importer also makes R&D investment while importing capital, there exists 1% additional productivity gain, which we refer to as the *R&D-capital synergy effect*. However, there is no clear evidence for a synergy effect between R&D and intermediates import.

Second, capital import has strong dynamic effects on firm productivity through three channels. First, there exists learning by importing or technology spillover as documented in the literature, but this literature does not distinguish capital import from intermediates import.[2] Second, as not all the imported capital has been used up in one period, the remaining capital still generates the quality-and-variety effect in the subsequent periods. Because we are not able to separate the aforementioned two effects, we combine them and refer to as the *direct dynamic effect*. Our empirical analysis shows that the direct dynamic effect of capital import increases the importer's productivity one year later by 0.45%. Third, we identify an additional channel in the dynamic effect: capital import increases the firms' probability of conducting R&D by 2.3 percentage points (or 19%). The increased R&D further raises the importer's productivity dynamically. We refer to this effect as the *R&D-inducing effect*. In contrast, our study shows that the direct dynamic and R&D-inducing effects from intermediates import are insignificant economically and statistically.

As our empirical analysis is guided by a structural model, we can 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 un-correlated 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 a number of alternative specifications of the model and other estimation methods, such as those proposed by Ackerberg, Caves, and Frazer (2015) and Gandhi, Navarro, and Rivers (2020).

We also examine the heterogeneous effects of capital import on firm productivity by exploring

[1]Examples include Kasahara and Rodrigue (2008), Goldberg, Khandelwal, Pavcnik, and Topalova (2009, 2010), Topalova and Khandelwal (2011), and Halpern, Koren, and Szeidl (2015).

[2]The literature does not distinguish capital import from intermediates import. For learning by importing, see Kasahara and Rodrigue (2008), Zhang (2017), and Grieco, Li, and Zhang (2017). For technology spillover, see Lee (1995), Mazumdar (2001), and Keller (2004).

source country heterogeneity. We find stronger R&D-capital synergy and dynamic productivity effects of capital import when capital goods are from high-income countries, compared to those from low-income countries. This finding provides indirect evidence for the aforementioned channels through which capital import generates productivity gains.

Based on our empirical results, we conduct quantitative exercises to show that international sourcing improves the average productivity of importing firms by 2.43% in China's manufacturing sector during 2000-2006, of which 52% is contributed by capital import. This large share of gains from capital import is striking because capital import accounts for only one-sixth of the total value of input imports. Importantly, about 43% of the productivity gains from capital import come from the R&D-capital synergy and dynamic productivity effects, while almost all of the productivity gains from intermediates import are from the quality-and-variety effect. Converting productivity gains to sales, we find that one dollar of capital imports generates 12.3 dollar more in sales compared with one-dollar use of domestic capital inputs, whereas one dollar of intermediates imports yields 1.98 dollar more in sales compared with one-dollar use of domestic intermediate inputs.

We apply the model to quantify the impact of China's input tariff liberalization (especially changes in tariff structure) on firm productivity following the country's accession to the WTO at the end of 2001. After 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 intermediates imports directly highlight the importance of tariff structure in liberalization. Simulation based on our structural model demonstrates that the tariff reduction increases the average productivity of marginal importers by approximately 1.5% from 2002 to 2006, of which 18% is contributed by the change in tariff structure.[3]

Our 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 the findings are 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).[4] 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

[3]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 7.6% of total firms, or 54% of the importing firms, in 2001 in our sample.

[4]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.

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 import on productivity growth in the short and long run, especially for importers with R&D investment. It highlights the importance of tariff structure for productivity growth in developing countries when liberalizing input tariffs.

Our 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, 2008; 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 other 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. One common feature among all these studies is that they do not distinguish capital and intermediates imports. We contribute to the literature by considering the distinct effects of capital and intermediates imports and identifying R&D-capital synergy, direct dynamic, and R&D-inducing effects as additional channels on how imports affect productivity. We show that capital import is the more important source of productivity gains from international sourcing, especially in the long run.

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 find the strong R&D-capital synergy and R&D-inducing effects of capital import, whereas these effects of intermediates import are insignificant.[5] Our finding suggests that what the firms import matters for R&D investment and emphasizes 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

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

of capital and intermediates 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 intermediates 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). This dataset includes more than 100 variables covering detailed information on firms' inputs, outputs, and other production-related information. We clean the data by dropping 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 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 this 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.[6] Table 1 reports the basic summary statistics based on our merged dataset. The data contain 431,039 individual firms and 1,414,173 observations. 12.4% of the firms have engaged in direct import. In the empirical analysis, our sample includes both importers and non-importers.

[Insert Table 1 around here]

[6]Our matching performance is highly comparable to that in the relevant papers using the same datasets. For example, in their matched data, Yu (2015) reported 56,459 importing firms from 2000 to 2006 and Wang and Yu (2012) reported 161,336 importing observations from 2002 to 2006. In our matched data, we have 53,553 importing firms and 192,573 importing observations during the respective time periods.

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.

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.[7] In particular, the concordance of HS96 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

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

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 imports 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 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.[8]

[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 rates 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.

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 and Immediate Productivity Effect of Import. 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:[9]

$$Q_{jt} = \exp\left(\omega_{jt} + \sum_{p\in\{k,m,km\}} \left(\alpha_p d_{jt}^p + \alpha_{rd,p} d_{jt}^{rd} d_{jt}^p\right) + \alpha_{rd} d_{jt}^{rd} + \zeta_{jt}\right) L_{jt}^{\beta_l} M_{jt}^{\beta_m} K_{jt}^{\beta_k}.$$

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

[8]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.

[9]Although the performance of multi-product firms is an important topic to investigate, we resist the temptation to include it in this paper because the information provided in the NBS firm survey data is not sufficient to address the issue. Empirically, we assume that a firm produces a single product in a single industry, as defined by their reported SIC4 industry code in the data. Doing so saves us from dealing with production of multiple products and allows us to focus on the import side.

(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^p_{jt} is a dummy variable capturing the immediate effect of using imported p goods as input on firm productivity, and $p \in \{k, m, km\}$ stands for capital goods (k), intermediate goods (m), and both (km), respectively. $d^p_{jt} = 1$ if firm j imports p goods at time t, and $d^p_{jt} = 0$ otherwise. Note that $d^{km}_{jt} = d^k_{jt} d^m_{jt}$. The R&D dummy d^{rd}_{jt} equals 1 if the firm does R&D at time t, and zero otherwise. The summation term captures the immediate effects of imports, which may arise from the traditional quality-and-variety effect through $\alpha_p d^p_{jt}$ and the import-R&D synergy effect through $\alpha_{rd,p} d^{rd}_{jt} d^p_{jt}$. For ease of reference, we call the non-R&D related effect (for example, the quality-and-variety effect here) as direct effect.

We have three remarks on capital and intermediates import. 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 inputs 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. 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

$$q_{jt} = \omega_{jt} + \sum_{p \in \{k,m,km\}} \left(\alpha_p d^p_{jt} + \alpha_{rd,p} d^{rd}_{jt} d^p_{jt} \right) + \alpha_{rd} d^{rd}_{jt} + \beta_l l_{jt} + \beta_m m_{jt} + \beta_k k_{jt} + \zeta_{jt}, \tag{1}$$

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.[10]

Productivity Evolution and Dynamic Productivity Effect of Import. We assume

[10] By using deflated revenue data to estimate the production, we are making an assumption that the firms face homogenous output prices as typically done in the literature. We understand that in practice output prices may be heterogeneous, and we can only estimate the revenue-based productivity (and associated coefficients).

that the structural productivity follows the first-order Markov process with a shift.[11] That is,

$$\omega_{jt} = \rho_0 + \rho\omega_{jt-1} + \sum_{p\in\{k,m,km\}} \gamma_p d^p_{jt-1} + \gamma_{rd} d^{rd}_{jt-1} + Z'_{jt-1}\Theta + \xi_{jt}, \tag{2}$$

where 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: $\xi_{jt} \sim N(0, \sigma^2_\xi)$. Z_{jt-1} is a set of control variables, including the dummies of firm ownership (state, private, and foreign ownership).

The dynamic productivity effect of imports summarizes the direct dynamic effect and the R&D-inducing effect, as captured by $\sum_{p\in\{k,m,km\}} \gamma_p d^p_{jt-1} + \gamma_{rd} d^{rd}_{jt-1}$. The first term, $\sum_{p\in\{k,m,km\}} \gamma_p d^p_{jt-1}$, represents the direct dynamic effect of import—the direct effect of past (last period) importing experience on the firm's current productivity. Such a direct dynamic effect is typically termed as learning by importing (or technology spillover effect) in the literature (Kasahara and Rodrigue, 2008; Zhang, 2017; and Keller, 2004), which does not distinguish capital imports from intermediate imports. Such an 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. It may also arise from the importers' receipt of technical support and on-site training from the foreign suppliers when using the imported goods. These knowledge gains are long lasting and can exert an impact on the firm's productivity beyond the importing period. The direct dynamic productivity effect of import may also arise from the quality-and-variety effect carried by the imported capital goods.

The second term, $\gamma_{rd} d^{rd}_{jt-1}$, measures how endogenous R&D investment may have an impact on firms' future productivity, following the insight of Aw, Roberts, and Xu (2008). The lagged effect captures the fact that it takes time to carry out R&D investment and for R&D outcome to have an impact on productivity. If imports increase firms' endogenous choice of R&D investment, then imports can generate an R&D-inducing productivity effect if $\gamma_{rd} > 0$, which is true as documented in the literature and verified in our paper.

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.

[11] There are two remarks. First, we focus on only one-period lag effect in the productivity evolution process. This is because the average year duration of firms is only around 3.5 years in our panel data. Introducing more lags leads to a large loss of observations. But the analysis could be extended to allow for high-order lags to capture the dynamic effect completely if the data is long enough. Second, in the robustness check we also estimated an extended version of the model which allows (lagged) imports and R&D to have an interaction effect. We found that this interaction effect is always insignificant economically and statistically. All other estimates are very similar too. So in the main specification we assume there is no synergy effect between R&D and imports in the productivity evolution process.

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}, past R&D experience dummy d^{rd}_{jt-1}, 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 $s_{jt} = (k_{jt}, \omega_{jt}, d^k_{jt}, d^m_{jt}, d^{rd}_{jt-1}, e_{jt}, z_{jt})$. Apart from s_{jt}, firm j observes the fixed costs of capital investment (ξ^i_{jt}), R&D investment ($\xi^{rd}_{jt}(d^{rd}_{jt-1})$), importing capital goods ($\xi^k_{jt}(d^k_{jt})$), and importing intermediate goods ($\xi^m_{jt}(d^m_{jt})$).[12] The fixed costs of capital import and intermediates imports are history dependent, which captures the fact that new importers need to pay higher costs to start importing, while continuing importers just need to may lower fixed costs. The similar idea applies to the history-dependent R&D fixed costs. These fixed costs are assumed to be i.i.d. drawn from different distributions over time and across firms, which depend on the firms' import and R&D experience.[13] To simplify notation, we will drop the "history" in the fixed costs of import and R&D whenever it does not cause a confusion in the rest of the paper. This will do no harm for our empirical purpose because we have controlled for the history of R&D and imports in the state variable s_{jt}.

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 intermediates 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

[12]The assumption that import decisions entail per-period firm-specific fixed costs follows Bøler, Moxnes, and Ulltveit-Moe (2015), Halpern, Koren, and Szeidl (2015), and Gopinath and Neiman (2014).

[13]When firms start importing for the first year, they may pay higher costs in expectation due to the sunk entry cost, which means that the lagged import status will have an impact on the firms' import decisions. However, this will not affect the decision functions of import and R&D, which has controlled for the lagged import status in its state. Thanks the referees for pointing out this.

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:

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

where $V(\cdot)$ is the present value of the firm, $C(I_{jt}, \xi^i_{jt})$ is the total costs of capital investment, and δ is the depreciation rate of capital stock. 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 ($\xi_{jt+1}$). Recall that $s_{jt} = (k_{jt}, \omega_{jt}, d^k_{jt}, d^m_{jt}, d^{rd}_{jt-1}, e_{jt}, z_{jt})$, including firm's individual status and predetermined choice variables. 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 intermediates 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}), 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 standard production function, d_{jt}^k and d_{jt}^m, 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 4.3, 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. Our results are also robust to the estimation methods proposed by Ackerberg, Caves, and Frazer (2015) and Gandhi, Navarro, and Rivers (2020).

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 $\omega_{jt} = \omega(l_{jt}, k_{jt}, d_{jt}^k, d_{jt}^m, e_{jt}, z_{jt})$.[14] Substituting this productivity function into the production function (1), we obtain:

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

where $\phi(\cdot) = \omega_{jt} + \sum_{p\in\{k,m,km\}} \left(\alpha_p d_{jt}^p + \alpha_{rd,p} d_{jt}^p d_{jt}^{rd}\right) + \alpha_{rd} d_{jt}^{rd} + \beta_l l_{jt} + \beta_k k_{jt}$. 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, d_{jt}^{rd}, 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.

[14] We do not have d_{jt-1}^{rd} in the labor demand function because the effect of lagged R&D has been captured by the productivity ω_{jt}.

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:

$$\begin{aligned}\omega_{jt} =& \hat{\phi}_{jt} - \left(\sum_{p \in \{k,m,km\}} \left(\alpha_p d_{jt}^p + \alpha_{rd,p} d_{jt}^{rd} d_{jt}^p \right) + \alpha_{rd} d_{jt}^{rd} + \beta_l l_{jt} + \beta_k k_{jt} \right) \\ \triangleq & \hat{\phi}_{jt} - \varphi(d_{jt}^k, d_{jt}^m, d_{jt}^{rd}, l_{jt}, k_{jt}).\end{aligned}$$

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

$$\begin{aligned}\hat{\phi}_{jt} &= \varphi(d_{jt}^k, d_{jt}^m, d_{jt}^{rd}, l_{jt}, k_{jt}) + \rho_0 + \rho \left[\hat{\phi}_{jt-1} - \varphi(d_{jt-1}^k, d_{jt-1}^m, d_{jt-1}^{rd}, l_{jt-1}, k_{jt-1}) \right] \\ &+ \sum_{p \in \{k,m,km\}} \gamma_p d_{jt-1}^p + \gamma_{rd} d_{jt-1}^{rd} + Z'_{jt-1} \Theta + \xi_{jt}. \end{aligned} \quad (6)$$

By assumption, ξ_{jt} is uncorrelated with all the variables on the right-hand side of (6), except l_{jt} which depend on ξ_{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 (i.e., the non-R&D related effects) relies on the timing assumption of the model. As the import status in period t is determined one period ahead, d_{jt}^k and d_{jt}^m are uncorrelated with the shocks in period t, ξ_{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 4.3, we provide an alternative identification strategy based on instrumental variable, and our results are robust.

4 Estimation Results

We estimate the model using the data described in Section 2. The objective is to quantify the distinct productivity effects of capital and intermediates imports and identify the channels through which such effects are generated. The main estimation results are reported in Table 4. The first column reports the results of a simplified version of our model without considering the synergy effect between R&D and imports as a baseline result. The second column reports results from our full model, corresponding to the specifications in Equations (1) and (2). The last column further controls the value share of each type of import as an additional check.

In all estimations, we control for industry fixed effect to capture the cross-industry difference in productivity and demand. We also add a series of dummies for ownership, year, and province to control for 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.

[Insert Table 4 around here]

4.1 Immediate Productivity Effect

The direct immediate productivity effects of capital and intermediates imports are captured by α_k and α_m in Equation (1), the coefficients of d_{jt}^k and d_{jt}^m, respectively. The baseline results in the first column of Table 4 indicate that both α_k and α_m are positive and statistically significant, thereby suggesting a positive direct immediate productivity effect of capital and intermediates imports. However, capital import has a slightly larger direct immediate effect than intermediates import. Importing capital immediately increases the productivity of the importers by 2.2%, as opposed to 1.9% for importing intermediates. The difference is statistically significant.

Using imported capital and intermediates has substantial complementarity. This is shown by the positive and significant coefficient of the interaction term of capital and intermediates import dummies. In the baseline models in column (1) of Table 4, importing capital and intermediates simultaneously generates additional productivity benefits by 1.5%. This represents almost the same magnitude of the productivity gains from importing only capital or intermediates. The complementarity may arise from the possibility that imported capital equipment may run better with imported intermediates from abroad, and vice versa.

Synergy between Import and R&D. To examine all the mechanisms that leads to the immediate effects, the full model extends the baseline model by adding the interaction effect of imports and R&D. The additional interaction term captures the potential synergy effect between imports and R&D investment. As shown in column (2) of Table 4, capital import and R&D have a strong synergy effect. A firm that is importing capital and participating in R&D investment simultaneously enjoys additional productivity benefits by 1%. This R&D-capital synergy effect represents more than half of the direct immediate effect from capital import only and a quarter of the productivity gain from R&D participation only. This result suggests that R&D-capital synergy effect is an important mechanism through which capital import has the immediate productivity effect. In contrast, intermediates import has no significant synergy effect with R&D.

After controlling for the R&D-capital synergy effect in the full model, R&D and capital themselves still maintain a positive effect on firm productivity. Participating in R&D investment increases the current output by 3.9%; capital import generates direct immediate effect of 1.75%.

The above results suggest that the differential immediate productivity effects of capital and intermediates imports, as observed in column (1) of Table 4, is mainly driven by the additional R&D-capital synergy effect, as observed in column (2). The R&D-capital synergy effect may arise from the technology spillover effect of imported capital goods because capital goods production is highly concentrated in a few R&D-intensive countries (Eaton and Kortum, 2001). In section 4.4, we show that this R&D-capital synergy effect is stronger when firms source capital from relatively high-income countries.

The baseline results are robust when we add the share of each type of import in column (3) in Table 4. The share of capital imports, 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 imports, 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, all main results remain qualitatively very similar. Moreover, we find that a larger share of imports of capital or intermediates results in a larger increase in productivity, with an elasticity of 0.11 and 0.13, 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 0.63% ($= 0.11 * 5.7\%$) and 0.91% ($= 0.13 * 7\%$), respectively, to average firms. The total immediate productivity effect of capital importing (0.9+0.63=1.53%) is close to that of intermediates importing (0.7+0.91=1.61%), consistent with the baseline results in column (2). The magnitudes are also close to the baseline results.

4.2 Dynamic Productivity Effect

Capital and intermediates imports may generate a dynamic productivity effect through two channels: the direct dynamic productivity effect and the R&D-inducing effect. As discussed before, the direct dynamic effect arises from learning by importing and technology spillover as defined in the literature, or the dynamic quality-and-variety effect carried by capital import. The R&D-inducing effect arises from the complementarity with R&D investment.

Direct Dynamic Productivity Effects. The direct dynamic productivity effects of capital and intermediates imports are captured by γ_k and γ_m, the coefficients of the lagged importing status in the productivity evolution in Equation (2) in Section 3. The positive and significant γ_k in Table 4 suggests that importing capital can have a dynamic effect on future (next period) productivity. In both specifications in columns (1) and (2), we find a quantitatively similar dynamic effect of capital import.[15] Quantitatively it suggests that importing capital can improve the importer's productivity one year later by 0.45-0.50%. The dynamic effect of importing capital can be accumulated over time through the productivity evolution process.

[15]In a robustness check, we find that introducing the interactive effect between (lagged) import and R&D participation in the productivity evolution does not affect the dynamic effect of capital import. The interaction term is also insignificant economically and statistically. Results are reported in Table A3 in the Appendix.

For example, if a firm keeps importing capital goods consecutively for five years, the cumulative productivity effects amount to 2.20-2.46%.[16]

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 direct dynamic 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). Such 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. While these effects are well understood in the literature that lumps capital and intermediates together, our findings suggest that unlike imported intermediates, imported capital can further bring the static quality-and-variety effect to the future periods because of the repeated usage of the capital.

Such a direct dynamic effect, however, is absent for intermediates import. The coefficient of the lagged intermediates import in the productivity evolution is statistically insignificant and close to zero in all estimations in Table 4. This outcome is not surprising as importing intermediates does not require the kinds of contacts with foreign suppliers discussed above for capital import and all imported intermediates have been used up in the importing period.

The above results on the direct dynamic effects are robust after controlling for the shares of capital and intermediates imports as reported in column (3) in Table 4.[17]

R&D-inducing Effect. The potential complementarity between imports and R&D may serve as another mechanism through which imports may enhance firms' productivity dynamically. To explore this mechanism, we estimate how importing capital and intermediate goods affects firms' R&D decisions as implied by firms' dynamic decisions in Equation (4) in the structural model above. We estimate a linear approximation of firms' R&D decision functions as follows:[18]

$$d_{jt}^{rd} = \lambda_1 d_{jt-1}^{rd} + \sum_{p \in \{k,m,km\}} \lambda_p d_{jt}^{p} + \lambda_\omega \omega_{jt} + \lambda_e e_{jt} + \lambda_K lnK_{jt} + FE + \epsilon_{jt}^{rd}, \tag{7}$$

[16]The cumulative productivity effect is calculated by $\hat{\gamma}_k \sum_{t=0}^{t=4} \hat{\rho}^t$.

[17]We report the transition probabilities of import status in Table A8 in the Appendix.

[18]We also test an alternative timing assumption in which R&D dummy is determined one period ahead in the same way as capital and intermediates import decisions. That is, $d_{jt+1}^{rd} = d^{rd}(s_{jt}, \xi_{jt}^{k}, \xi_{jt}^{m}, \xi_{jt}^{rd}, \xi_{jt}^{i})$. Based on this alternative timing, we find consistent results, as reported in Table A4 in the Appendix.

The lagged term d^{rd}_{jt-1} may have an impact on current R&D decision due to the existence of sunk start up costs of doing R&D. We follow Bøler, Moxnes, and Ulltveit-Moe (2015) to include the contemporaneous impact of import on R&D decision, as captured by λ_k, λ_m, and λ_{km}. If importing does increase R&D ($\lambda_p > 0$), then it can further enhance firm productivity in the long run through R&D inducing effect, given that R&D has an positive effect on productivity as estimated before. We control for the productivity level (ω_{jt}) and export participation (e_{jt}) because firms of different productivity levels and export status may have different incentives to invest in R&D. We also control for firm size (lnK_{jt}); the fixed effects (FE) including year, province, industry, and ownership.[19]

The results are reported in Table 5. In all specifications, we find that firms that are larger, more productive, and exporters are more likely to invest in R&D. More importantly, as shown in the baseline result in column (1), we find that being a capital importer increases the probability of contemporaneous R&D investment by 2.3 percentage points. As the average R&D probability is 12% for all firms, importing capital increases the chance for a firm to invest in R&D in current period by 19.2% (=2.3/12). 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. This finding is consistent with the event study depicted in Figure 2, where we observe that importing capital and intermediate goods causes a structural change in R&D participation of the importers. Given that R&D investment has immediate and dynamic effects on productivity, as shown in Table 4, the induced R&D from capital goods import brings additional productivity gains to the importers, which we call as *R&D-inducing effect*.

[Insert Table 5 around here]

By contrast, the effect of intermediates import on R&D is small (0.003) and statistically insignificant, as shown in column (1) of Table 5. Moreover, importing both capital and intermediates simultaneously does not have a significant effect on R&D participation.

Overall, the results show that capital import has a dynamic effect on the importers' productivity, through the mechanisms of both the direct dynamic effect and R&D-inducing effect. In contrast, the dynamic effect is insignificant for intermediates import.

4.3 Robustness Checks

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

[19] Productivity (ω_{jt}) is estimated based on the baseline model in column (2) in Table 4. Ownership is classified as state owned, collectively owned, private, Hong Kong-Macao-Taiwan, foreign owned, the other.

Investment as Alternative Proxy for Productivity. Following Olley and Pakes (1996), we 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 column (1) in Table 6, all of our main results are robust to this alternative estimation procedure.

[Insert Table 6 around here]

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 column (2) in Table 6.

Different Estimation Methods. According to Ackerberg, Caves, and Frazer (2015, hereinafter ACF), we may not identify the elasticity of intermediate inputs, β_m, in the first stage and an alternative procedure is to estimate all input elasticities in the second stage. However, the ACF method may not be applied to the gross output production function as pointed out by Gandhi, Navarro, and Rivers (2020, hereinafter GNR) and may generate a spurious minimum in the estimation (Kim, Luo, and Su, 2019). Exploiting the information of the first-order condition with respect to intermediate inputs, GNR (2020) propose an alternative approach to estimating gross output production function. To check the robustness of our main findings, we apply both the GNR and ACF methods to estimate Equations (1) and (2).[20] The results are reported in Table 7.

[Insert Table 7 around here]

While the estimated elasticities of labor, intermediate inputs, and capital stock are different using different estimation methods, our main results are generally robust to each method. First, both capital and intermediates imports have positive and significant direct immediate effects. Second, there is a substantial synergy effect between capital import and R&D participation. Last, the dynamic productivity effect exists from capital import but not from intermediates import.

When we compare our estimated elasticities with those reported by Yu (2015) who uses the same dataset, we find that our estimated elasticities are highly comparable to his estimations. Results are reported in Table A9 in the Appendix.

[20]The estimations of GNR and ACF are sensitive to the extreme values of the share of intermediate inputs (i.e., intermediate input divided by gross output). To address this issue, we winsorize the share of intermediate inputs at 1% and 99% for all estimations in Table 7. Note that when applying the GNR's method, we use a complete polynomial of degree three for (m_{jt}, l_{jt}, k_{jt}, d^k_{jt}, d^m_{jt}, d^{rd}_{jt}) in the first stage and for (l_{jt}, k_{jt}, d^k_{jt}, d^m_{jt}, d^{rd}_{jt}) in the second stage.

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 six-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 HS code. Specifically, based on the HS6 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 intermediates 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 intermediates imports (12.8%). In 2006, the situation was reversed, with a lower tariff rate for capital import (4.1%) than that for intermediates imports (4.4%). Overall, the capital tariff dropped by 9.75 percentage points and intermediates tariff dropped by 8.36 percentage points from 2000 to 2006.

[Insert Figure 3 around here]

The differential changes of industry-level tariff rates for capital and intermediate goods form valid IVs for individual firms' decisions on capital and intermediates 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 the Appendix A2, 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 $\triangle\tau_t^m$), one-period-ahead import status of capital and intermediate goods ($d_{j,t-1}^k$ and $d_{j,t-1}^m$), and one-period-ahead R&D participation ($d_{j,t-1}^{rd}$) as the five IVs for firms' import and R&D decisions.[21] The second stage follows similarly as our

[21] 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, d_{jt}^{rd}, e_{jt}, and the interactions of these

baseline estimation. The results are reported in Table 8. All the main results are similar to our baseline results as reported in Table 4. In particular, both capital and intermediate imports have positive and significant direct immediate productivity effects. Capital and intermediates imports are complementary in promoting immediate productivity. There is a substantial synergy effect between capital import and R&D participation in the production function (4.9%). The direct dynamic effect is strong and significant for capital import (0.6%), but it is insignificant statistically and economically for intermediates import.[22]

[Insert Table 8 around here]

Controlling for Export Status. There might be potential interactive effects between export and import. For example, a positive demand shock in export market may drive an exporter to import more intermediate or capital goods, which may bias our estimation. To mitigate this problem, we control for the export status in the firms' import and R&D decisions in Equations (4) . Recall that the state variables s_{jt} include export status e_{jt}. We also instrument import status with tariff changes to alleviate the impact of export-market demand shocks. Moreover, our results are robust when including current and lagged export status in the production function and productivity evolution by which we control for the effect of export (see Table A11 in the Appendix).

4.4 Heterogeneous Effects of Capital Import

This section explores the heterogeneous effects of capital and intermediates imports from different source countries to provide further evidence on the mechanisms through which capital and intermediates imports influence firm productivity.

Source Country Heterogeneity. The development level of the source countries may influence the quality and technology of the goods produced by those countries, which in turn affects the productivity gains from importing their capital and intermediates. Under those mechanisms of import highlighted earlier, we hypothesize that firms sourcing from high-income countries may benefit more than those sourcing from low-income countries.

We use GDP per capita (constant price in 2010) to capture the income level of source countries. The data are from the World Bank WDI database. We define high- (low-) income countries as the countries whose the GDP per capita in 2000 was greater than (smaller than or equal to) 10,000 USD. Among the matched 187 countries (or regions), there are 60 high-income

terms, all the polynomial terms having d^k_{jt}, d^m_{jt}, and d^{rd}_{jt} are instrumented by the five IVs we use. Given the high sensitivity to gross output in the first-stage IV regression, we winsorize the gross output at 1% and 99%.

[22] We have two additional robustness checks using the input tariff. First, we estimate firms' R&D decision function in Equation (7) using the changes in industry average tariff rates and one-period-ahead import status as the IVs for firms' import decisions. We find consistent results which are reported in Table A7 in the Appendix. Second, we also estimate a reduced-form model following Amiti and Konings (2007). Consistent with our main findings, firm productivity is more sensitive to capital input tariff than that to intermediate input tariff. Results are reported in Table A10 in the Appendix.

countries and 127 low-income countries. We use $d_{jt}^{ph} = 1$ to denote that firm j at period t imports p goods from a country of type h, where $p \in \{k, m, km\}$, $h \in \{H, L\}$, and H and L stand for high- and low-income countries, respectively. Otherwise, $d_{jt}^{ph} = 0$. If a firm imports p from both high- and low-income countries, then we have $d_{jt}^{pH} = d_{jt}^{pL} = 1$. Despite the fact that capital goods production is highly concentrated in high-income countries, there are also 9.5% (23.1%) of observations with capital (intermediates) imports from low-income countries in our sample, which provides the basis for our identification of source country heterogeneity.

To estimate the heterogeneous effects of imports from different types of the source countries, we extend the production and productivity evolution in Equations (1) and (2)as follows:

$$\begin{aligned} q_{jt} =& \omega_{jt} + \sum_{h}^{\{H,L\}} \sum_{p}^{\{k,m,km\}} (\alpha_{ph} d_{jt}^{ph} + \alpha_{rd,ph} d_{jt}^{rd} d_{jt}^{ph}) + \alpha_{rd} d_{jt}^{rd} + \beta_l l_{jt} + \beta_m m_{jt} + \beta_k k_{jt} + \zeta_{jt}, \\ \omega_{jt} =& \rho_0 + \rho \omega_{jt-1} + \sum_{h}^{\{H,L\}} \sum_{p}^{\{k,m,km\}} \gamma_{ph} d_{jt-1}^{ph} + \gamma_{rd} d_{jt-1}^{rd} + Z'_{jt-1} \Theta + \xi_{jt}. \end{aligned}$$

Table 9 reports the estimation results. First, we find that capital import exerts a larger immediate effect than intermediates import when sourcing from high-income countries, but the comparison is reverse for sourcing from low-income countries. Second, the R&D-capital synergy effect mainly comes from sourcing from high-income countries. Third, the direct dynamic effect is obtained mainly from capital import from high-income countries. All these findings lend indirect support to the mechanisms we have identified before.[23]

[Insert Table 9 around here]

5 Contribution of Different Types of Imports

This section evaluates the contribution of capital and intermediates imports to firms' productivity and sales. We also quantify the importance of the immediate effect and dynamic productivity effects, as well as the role of R&D in the process.

Contribution to Firm Productivity. Our calculation is based on the estimation results in column (3) of Table 4, which takes into account the effects of import participation and import size. To quantify the relative contribution of different channels, we define the contribution of import to productivity through the immediate and dynamic productivity effects separately. Specifically, the immediate productivity effect of import $p \in \{k, m, km\}$ is defined as the

[23]Note that the R&D-capital synergy and dynamic effects from high-income capital import are slightly smaller than our baseline results. This result may exist due to data limitation: there exist import transactions that we cannot identify their sourcing countries or we have no income data of those sourcing countries.

weighted average of the corresponding productivity gains from 2000 to 2006 as follows:

$$\triangle\omega^p_{immediate} = \sum_{j,t} \ (\alpha_p d^p_{jt} + \alpha^s_p s^p_{jt} + \alpha_{rd,p} d^{rd}_{jt} d^p_{jt}) w_{jt}, \quad p \in \{k, m, km\},$$

where the weight $w_{jt} = R_{jt} / \left(\sum_{j,t} R_{jt} \right)$ is firm j's revenue share in the industry at time t. The notations in this section are consistent with the definition in the model section 3, and s^p_{jt} and parameters with a superscript s denotes the value share of importing p and its corresponding parameters as defined in section 4.1, respectively. Note that $s^{km}_{jt} = s^k_{jt} s^m_{jt}$. The total productivity gains from the immediate effect is $\triangle\omega_{immediate} = \sum_{p\in\{k,m,km\}} \triangle\omega^p_{immediate}$.

To evaluate the importance of R&D-import synergy effect as a mechanism, we isolate it from the immediate productivity effect. Specifically, the contribution of R&D-import synergy effect for importing $p \in \{k, m, km\}$ is calculated as follows:

$$\triangle\omega^p_{rd\_synergy} = \sum_{j,t} \alpha_{rd,p} d^{rd}_{jt} d^p_{jt} w_{jt},$$

The total productivity gains from the R&D synergy effect in all types of imports are defined as $\triangle\omega_{rd\_synergy} = \sum_{p\in\{k,m,km\}} \triangle\omega^p_{rd\_synergy}$.

The dynamic productivity effect of importing p is calculated similarly. It contains the direct dynamic productivity effect and the R&D-inducing effect.

$$\triangle\omega^p_{dynamic} = \sum_{j,t} \ (\gamma_p d^p_{jt-1} + \gamma^s_p s^p_{jt-1}) w_{jt} + \triangle\omega^p_{rd\_induce},$$

where the first term refers to the direct dynamic productivity effect. The second term, $\triangle\omega^p_{rd\_induce}$, represents the R&D-inducing effect for importing type $p \in \{k, m, km\}$, which by definition can be calculated as follows:

$$\begin{aligned}\triangle\omega^p_{rd\_induce} = \sum_{j,t} \{ & (\alpha_{rd} + \alpha_{rd,k} d^k_{jt} + \alpha_{rd,m} d^m_{jt} + \alpha_{rd,km} d^k_{jt} d^m_{jt})(\lambda_p d^p_{jt} + \lambda^s_p s^p_{jt}) \\ & + \gamma_{rd}(\lambda_p d^p_{jt-1} + \lambda^s_p s^p_{jt-1}) \} w_{jt},\end{aligned}$$

where λ measures the impact of imports on firms' R&D decisions as defined in Equation (7). The total productivity gains from the dynamic effect in all types of goods are $\triangle\omega_{dynamic} = \sum_{p\in\{k,m,km\}} \triangle\omega^p_{dynamic}$. The contribution of R&D-inducing effect is similarly defined as $\triangle\omega_{rd\_induce} = \sum_{p\in\{k,m,km\}} \triangle\omega^p_{rd\_induce}$. Let us call this induced-R&D productivity effect.

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

$$\triangle\omega^p = \triangle\omega^p_{immediate} + \triangle\omega^p_{dynamic}.$$

Table 10 reports the decomposition results. The standard errors are obtained using the bootstrap with 200 replications of our main estimation in column 3 of Table 4. 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 2.43 percentage points. Among the total productivity gains, capital import contributes to 52% (1.26 percentage points), although it accounts for only one-sixth of intermediates import in value. The rest is mainly contributed by intermediates import, together with a small effect from complementarity between these two types of imports.

Both the immediate and dynamic productivity effects matter quantitatively. The immediate productivity effects explain 86% of the total one-year productivity gains from import; the dynamic productivity effects explain the remaining 14%. The dynamic productivity effects completely come from capital import, while that from intermediates import are insignificant economically and statistically.

Finally, the results confirm that R&D plays an important role in explaining the large productivity gains from capital import compared with intermediates import. The R&D synergy effect accounts for 25.7% of the immediate effect of capital import. The induced R&D effect explains 17.1% of the dynamic productivity effect of capital import. In contrast, neither of these two effects are significant for intermediates import. This result complements the finding in Bøler, Moxnes, and Ulltveit-Moe (2015), who find that R&D tax credit in Norway in 2002 stimulated not only R&D investments but also intermediates import.

Overall, about 43% (=(0.25+0.29)/1.26) of the productivity gains from capital imports come from the R&D-capital synergy and dynamic productivity effects, while almost all of the productivity gains from intermediates imports are from the direct immediate productivity effect.

[Insert Table 10 around here]

Contribution to Firm Sales. We now evaluate the impact of capital and intermediates 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 import, 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 import 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 impact of imports on revenue, 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 $p \in \{k, m, km\}$ per dollar can be calculated as follows:

$$\triangle R^p_{immediate} = \frac{\sum_{jt} \ (\alpha_p d^p_{jt} + \alpha_{rd,p} d^{rd}_{jt} d^p_{jt} + \alpha^s_p s^p_{jt}) R_{jt}}{\sum_{jt} V^p_{jt}}.$$

Similarly, the revenue effects from per-dollar import due to the dynamic, R&D synergy, and R&D-inducing effects are, respectively,

$$\begin{aligned}
\triangle R^p_{dynamic} =& \frac{\sum_{jt} \ (\gamma_p d^p_{jt} + \gamma^s_p s^p_{jt}) R_{jt+1}}{\sum_{jt} V^p_{jt}} + \triangle R^p_{rd_induce}, \\
\triangle R^p_{rd_synergy} =& \frac{\sum_{jt} \alpha_{rd,p} d^{rd}_{jt} d^p_{jt} R_{jt}}{\sum_{jt} V^p_{jt}}, \\
\triangle R^p_{rd_induce} =& \frac{1}{\sum_{jt} V^p_{jt}} \{ \sum_{j,t} [(\alpha_{rd} + \alpha_{rd,k} d^k_{jt} + \alpha_{rd,m} d^m_{jt} + \alpha_{rd,km} d^k_{jt} d^m_{jt})(\lambda_p d^p_{jt} + \lambda^s_p s^p_{jt}) R_{jt} \\
& + \gamma_{rd} (\lambda_p d^p_{jt} + \lambda^s_p s^p_{jt}) R_{jt+1}]\}.
\end{aligned}$$

The total revenue gains of each type of import $p \in \{k, m, km\}$ is

$$\triangle R^p = \triangle R^p_{immediate} + \triangle R^p_{dynamic}.$$

The results are reported in Table 11. On average, importing one dollar of inputs (capital and intermediate goods combined) increases firm's sales by an additional 3.77 dollar, compared with using domestic inputs. Among this gain in revenue, 3.19 dollars are realized immediately in the importing period and 0.58 dollar is realized in the next period from the dynamic effect.

The revenue effect of capital import is much larger for that of intermediates import. Importing one dollar of capital goods brings an additional 12.3 dollars of revenue to the firm, compared with using domestic capital. In the period of capital import, one dollar of capital import improves revenue by 9.12 dollars. On top of this, in the next period, an additional revenue gain of 3.18 dollars is due to the dynamic effect. By contrast, one dollar of intermediates import leads to only 1.98 dollars of additional revenue growth (relative to using domestic intermediates inputs), which is less than one-sixth of the revenue effect of capital import. Among revenue effect of intermediates import, almost all is due to the direct immediate productivity effect. While the R&D synergy and induced-R&D effects contributes substantially to the productivity gains from capital import, they are insignificant statistically and economically for intermediates import.

[Insert Table 11 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 import 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 reduction in import tariffs. 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 4.3, the tariff rates for capital goods and intermediate goods were reduced disproportionately, with a much larger reduction for capital import. 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. This section quantifies the productivity gains from tariff liberalization after China's WTO accession via the average tariff reduction and changes in tariff structure by conducting two sets of counterfactual simulations.

Tariff Liberalization and Import Decisions. To quantify the productivity effect of tariff reduction, we first need to understand how tariff reduction affects firms' sourcing decisions. To this end, 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.[24] Specifically, we estimate the following discrete capital and intermediates import 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 $\Delta\tau_{jt}^p = \tau_{jt}^p - \tau_{j,2001}^p$, where $p \in \{k, m\}$. They may affect firms import decisions

[24] In the simulation, we abstract away capital evolution and take capital stock as fixed. This limits firms' freedom to make adjustment after the tariff changes in the counterfactual. However, because our focus of the counterfactual is to evaluate the relative importance of tariff structure in the total gains from tariff liberalization, which is calculated based on the three counterfactuals that all treat capital as fixed in the same way, the impact on the counterfactual result is of second order.

after the WTO accession and we allow this possibility as an extension, as implied in the IV estimation in Section 4.3.[25]

The estimation results are reported in Table 12. First, tariff reduction for capital and intermediate goods promotes imports of both goods, as suggested by the negative coefficients on the tariffs in the first two rows. Import decisions over time are also persistent. Importing capital today improves the probability of importing capital next period by 44.6%, and importing intermediates today increases the probability of importing intermediates next period by 55.8%. Meanwhile, there is substantial complementarity between capital and intermediates imports: importing intermediates (capital) today increases the probability of importing capital (intermediates) next period by 14.6% (16.8%). 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. These results are consistent with our baseline results in Section 4.2 and Table 5. The import decision functions will be used to quantify the gains from tariff liberalization in the rest of this section.

[Insert Table 12 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 intermediates 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. Note that our simulation is based on the observed set of firms in 2001 and assume that these firms survive from 2001 to 2006.

Average Tariff Reduction Versus Tariff Structure. The differential productivity effects of capital and intermediates imports bear clear policy implications. Given the degree of tariff liberalization, the choice of tariff structure 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

[25] Note that we in fact only use data of 2001-2006 when estimating the dynamic import decisions here because the data in 2000 are used to construct the lag variables.

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 intermediates 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 that are purely driven by 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.[26]

We focus on the group of firms that ever changed their capital or intermediates import 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 7.6% of total firms, or 54.3% 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 1.51%. This effect is accompanied by an increase in the share of firms that import capital, that import materials, and that participate in R&D by 1.12, 1.45, and 0.06 percentage points, respectively.[27] The reduction in tariff levels explains most of the productivity gains, by approximately 81.6%, and the changes in tariff structure explain the remaining 18.4%. 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 intermediates imports,

[26] The detailed process of our counterfactual simulation is provided in the Appendix A3.

[27] These numbers are calculated as the difference in the shares of corresponding firms in total firms under two scenarios: one under the actual tariff reduction and the other with fix tariffs at the level of 2001. These effects should be treated as the lower bounds of the effect of the WTO tariff reduction on import and R&D participation, because we assume that other firms outside the sub-sample of marginal firms are not affected by the tariff reduction. Given the fact that the sub-sample of marginal firms consists of all firms in the data that actually changed their importing status of capital or intermediates at least once after the WTO tariff shock, this assumption is reasonable.

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 intermediates 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 reported in Figure 5. Around 63% 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 32% of the productivity gains from 2001 to 2006.[28] 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]

Policy Implications for Low-Income Countries. Based on China's experience, our study bears clear policy implications for other low-income countries. First, while the literature has found that input tariff liberalization generates productivity growth for low-income countries, our paper adds that the structure of tariff liberalization is also important because what a country imports matters: manufacturing firms benefit more from capital import than from intermediates import. That is, we need trade policies to encourage more capital imports in the low-income countries. However, we observe that the tariff reduction of capital goods is generally smaller than that of intermediate goods in many low-income countries. For example, the reductions of import-value-weighted average tariff rates for capital and intermediate goods were around 3.60 and 4.05 percentage points, respectively, in the low-income countries (excluding China) from 2000 to 2006, whereas the corresponding numbers were 7.20 and 6.84 percentage points in China.[29] Therefore, in addition to the reduction of average tariff rate, low-income countries should focus more on the improvement of their tariff structures.

Second, our finding of the strong R&D-capital synergy effect suggests that trade liberalization is important to exert/augment the effect of R&D investment on firm productivity and vice versa. Moreover, trade policies of the developing countries should encourage capital imports from developed countries as those capital goods can generate more productivity gains. Last but not least, we find that capital import also induces R&D investment and thus, import policies of

[28] The rest 5% of the productivity gains comes from the complementarity between capital and intermediates tariff reductions.

[29] We merge the product tariff rates with the product import values at the HS6-digit product-country-year level and calculate the average tariff rates of capital and intermediate goods using import values as the weight. The highly disaggregated tariff and trade data are from WITS dataset by World Bank and BACI dataset from CEPII, respectively. The definition of low-income country is the same as that in Section 4.4. Note that the average tariff rates calculated here are different from the ones in our main analysis which are merged with the manufacturing firm data.

developing countries are also important for their domestic R&D and innovation.

7 Concluding Remarks

International sourcing of inputs has become more important in global trade than ever. However, the channels through which international sourcing influence productivity remains an important question in international trade and development economics. 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 52% 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 can generate significant long-term productivity gains through R&D-capital synergy, R&D-inducing, and direct dynamic productivity effects, which in total account for 43% of the productivity gains from capital import. In contrast, 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 also speak 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 intermediates 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 intermediates imports. Further studies endeavoring to fully solve firms' dynamic decisions on capital and intermediates import are also encouraged to completely evaluate the gains from tariff liberalization in the short, medium, and long run.

References

[1] Ackerberg, Daniel A., Kevin Caves and Garth Frazer, "Identification properties of recent production function estimators," Econometrica, 2015, 83 (6), 2411-2451.

[2] Amiti, M and Joep Konings, "Trade liberalization, intermediate inputs, and productivity: Evidence from Indonesia," The American Economic Review, 2007, 97 (5), 1611-1638.

[3] Aw, Bee Yan, Mark J Roberts, and Daniel Yi Xu,"R&D investment, exporting, and productivity dynamics," The American Economic Review, 2011, 101 (4), 1312-1344.

[4] Bas, Maria and Antoine Berthou, "The decision to import capital goods in India: Firms' financial factors matter," The World Bank Economic Review, 2012, 26 (3), 486-513.

[5] Bas, Maria and Vanessa Strauss-Kahn, "Does importing more inputs raise exports? Firm-level evidence from France," Review of World Economics, 2014, 150 (2), 241-275.

[6] Bloom, Nicholas, Mirko Draca, and John Van Reenen, "Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity," The Review of Economic Studies, 2016, 83 (1), 87-117.

[7] Bøler, Esther Ann, Andreas Moxnes, and Karen Helene Ulltveit-Moe, "R&D, international sourcing, and the joint impact on firm performance," The American Economic Review, 2015, 105 (12), 3704-3739.

[8] Brandt, Loren, Johannes Van Biesebroeck, Luhang Wang, and Yifan Zhang, "WTO accession and performance of Chinese manufacturing firms," The American Economic Review, 2017, 107, 2784-2820.

[9] Burstein, Ariel, Javier Cravino, and Jonathan Vogel, "Importing skill-biased technology," American Economic Journal: Macroeconomics, 2013, 5 (2), 32-71.

[10] Coe, David T. and Elhanan Helpman, "International R&D spillovers," European Economic Review, 1995, 39 (5), 859-887.

[11] Eaton, Jonathan and Samuel Kortum, "Trade in capital goods," European Economic Review, 2001, 45 (7), 1195-1235.

[12] Gandhi, Amit, Salvador Navarro, and David Rivers, "On the identification of gross output production functions," Journal of Political Economy, 2020, 128 (8).

[13] Goldberg, Pinelopi, Amit Khandelwal, Nina Pavcnik, and Petia Topalova, "Trade liberalization and new imported inputs," The American Economic Review, 2009, 99 (2), 494-500.

[14] Goldberg, Pinelopi Koujianou, Amit Kumar Khandelwal, Nina Pavcnik, and Petia Topalova, "Imported intermediate inputs and domestic product growth: Evidence from India," The Quarterly Journal of Economics, 2010, 125 (4), 1727-1767.

[15] Gopinath, Gita, and Brent Neiman, "Trade adjustment and productivity in large crises," The Quarterly Journal of Economics, 2014, 104 (3), 793-831.

[16] Grieco, Paul LE, Shengyu Li, and Hongsong Zhang, "Input prices, productivity and trade dynamics: Long-run effects of liberalization on Chinese paint manufactures," Working paper, 2017.

[17] Halpern, Laszlo, Miklos Koren, and Adam Szeidl, "Imported inputs and productivity," The American Economic Review, 2015, 105 (12), 3660-3703.

[18] Hasan, Rana, "The impact of imported and domestic technologies on the productivity of firms: Panel data evidence from Indian manufacturing firms," Journal of Development Economics, 2002, 69 (1), 23-49.

[19] Kasahara, Hiroyuki and Beverly Lapham, "Productivity and the decision to import and export: Theory and evidence," Journal of International Economics, 2013, 89 (2), 297-316.

[20] Kasahara, Hiroyuki and Joel Rodrigue, "Does the use of imported intermediates increase productivity? Plant-level evidence," Journal of Development Economics, 2008, 87 (1), 106-118.

[21] Keller, Wolfgang, "Are international R&D spillovers trade-related?: Analysing spillovers among randomly matched trade partners," European Economic Review, 1998, 42 (8), 1469-1481.

[22] Keller, Wolfgang, "International technology diffusion," Journal of Economic Literature, 2004, 42 (3), 752-782.

[23] Keller, Wolfgang and Stephen R. Yeaple, " Multinational enterprises, international trade, and productivity growth: Firm-level evidence from the United States," Review of Economics and Statistics, 2009, 91(4),821-831.

[24] Kim, Kyoo Il, Yao Luo, and Yingjun Su, "A robust approach to estimating production functions: Replication of the ACF procedure," Journal of Applied Econometrics, 2019, 34 (4), 612-619.

[25] Koren, Miklos and Marton Csillag, "Machines and machinists: Importing skill-biased technology," Technical Report, mimeo, Central European University 2017.

[26] Lee, Jong-Wha, "Capital goods imports and long-run growth," Journal of Development Economics, 1995, 48 (1), 91-110.

[27] Levinsohn, James and Amil Petrin, "Estimating production functions using inputs to control for unobservables," The Review of Economic Studies, 2003, 70 (2), 317-341.

[28] Li, Hongbin, Lei Li, and Hong Ma, "Skill-biased imports and demand for skills in China," Working paper, 2015.

[29] Liu, Qing and Larry D. Qiu, "Intermediate input imports and innovations: Evidence from Chinese Firms' patent filings," Journal of International Economics, 2016, 103, 166-183.

[30] Mazumdar, Joy, "Imported machinery and growth in LDCs," Journal of Development Economics, 2001, 65 (1), 209-224.

[31] Muendler, Marc-Andreas, "Trade, technology and productivity: A study of Brazilian manufacturers 1986-1998," Working paper, 2004.

[32] Mutreja, Piyusha, B. Ravikumar, and Michael Sposi, "Capital goods trade, relative prices, and economic development," Review of Economic Dynamics, 2018, 27, 101-122.

[33] Olley, GS and A Pakes, "The dynamics of productivity in the telecommunications equipment industry," Econometrica, 1996, 64 (6), 1263-1297.

[34] Parro, Fernando, "Capital-skill complementarity and the skill premium in a quantitative model of trade," American Economic Journal: Macroeconomics, 2013, 5 (2), 72-117.

[35] Topalova, Petia and Amit Khandelwal, "Trade liberalization and firm productivity: The case of India," Review of Economics and Statistics, 2011, 93 (3), 995-1009.

[36] Van Biesebroeck, Johannes, "Revisiting some productivity debates," Technical Report, National Bureau of Economic Research 2003.

[37] Vogel, Alexander and Joachim Wagner, "Higher productivity in importing German manufacturingfirms: Self-selection, learning from importing, or both?," Review of World Economics, 2010, 145 (4), 641-665.

[38] Wang, Zheng and Yu Zhihong, "Trading partners, traded products, and firm performances of China's exporters and importers: does processing trade make a difference?," World Economy, 2012, 35(12), 1795-1824.

[39] Yu, Miaojie, "Processing trade, tariff reductions and firm productivity: Evidence from Chinese firms," The Economic Journal, 2015, 125(585), 943-988.

[40] Zhang, Hongsong, "Static and dynamic gains from costly importing of intermediate inputs: Evidence from Colombia," European Economic Review, 2017, 91, 118-145.

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 A5. We also include the lagged capital and intermediates imports as IVs in the estimation. Both capital and intermediates imports are sensitive to the reduction of capital and intermediates tariffs. One percentage increase of the reduction in capital (intermediates) tariff leads to 0.120 (0.086) percent increase of the probability of importing capital goods, and 0.167 (0.062) percent increase of the probability of importing intermediate goods.

[Insert Table A5 around here]

The exclusion condition check is reported in Table A6. 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 A6 around here]

A3 Counterfactual Simulation

First, we estimate the following decision equations for d_{jt}^k, d_{jt}^m, d_{jt}^{rd}, and ω_{jt} based on our sample.

(1) $d_{jt}^k = \hat{d^k}(\Delta t_{jt,2001}^k, \Delta t_{jt,2001}^m, d_{jt-1}^k, d_{jt-1}^m, \omega_{jt-1}, z_{jt-1}) + \varepsilon_{jt}^k$;

(2) $d_{jt}^m = \hat{d^m}(\Delta t_{jt,2001}^k, \Delta t_{jt,2001}^m, d_{jt-1}^k, d_{jt-1}^m, \omega_{jt-1}, z_{jt-1}) + \varepsilon_{jt}^m$;

(3) $d_{jt}^{rd} = \hat{d^{rd}}(d_{jt-1}^{rd}, d_{jt}^k, d_{jt}^m, \omega_{jt}, z_{jt}) + \varepsilon_{jt}^{rd}$;

(4) $\omega_{jt} = \hat{\omega}(\omega_{jt-1}, d_{jt-1}^k, d_{jt-1}^m, d_{jt-1}^{rd}) + \varepsilon_{jt}^{\omega}$,

where the change of tariff is defined as tariff changes since 2001, that is, $\Delta t_{jt,2001}^h = t_{j,t}^h - t_{j,2001}^h$, $h \in \{k, m\}$. Control variables, z_{jt-1}, include export status, log of capital size and year fixed effects. $\{\varepsilon_{jt}^k, \varepsilon_{jt}^m, \varepsilon_{jt}^{rd}, \varepsilon_{jt}^{\omega}\}$ are assumed to be i.i.d with zero mean. Table A12 reports the estimation for the first three equations. The estimation of the fourth equation follows the results in column (2) in Table 4.

[Insert Table A12 around here]

Second, we calculate the simulated $\{\widetilde{d}_{jt}^k, \widetilde{d}_{jt}^m, \widetilde{d}_{jt}^{rd}, \widetilde{\omega}_{jt}\}$ based on five scenarios:

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

(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 intermediates 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 $\{\widetilde{d}^k_{jt,2001}, \widetilde{d}^m_{jt,2001}, \widetilde{d}^{rd}_{jt,2001}, \widetilde{\omega}_{jt,2001}\}$ according to the following process:

1. **Step 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. **Step 2:** Generate random number p^k_{jt}, p^m_{jt}, p^{rd}_{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 0.364 standard deviation, which equals the estimated standard deviation of $\varepsilon^{\omega}_{jt}$.
3. **Step 3:** In the first period, $n = 1$ (year=2001), let $\widetilde{d}^j_{p,1} = d^j_{p,1}$ and $\widetilde{\omega}_{j,1} = \omega_{j,1}$, where $p = \{k, m, rd\}$.
4. **Step 4:** When $n > 1$, calculate $\widetilde{\omega}_{j,n} = \hat{\omega}(\widetilde{\omega}_{j,n-1}, \widetilde{d}^k_{j,n-1}, \widetilde{d}^m_{j,n-1}, \widetilde{d}^{rd}_{j,n-1})$.
5. **Step 5:** 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 $\widetilde{d}^{rd}_{j,n}$.
6. **Step 6:** In period $n + 1$, follow the above steps (4)-(5) until the last observation of each j is fulfilled.

Finally, repeat the previous process 100 times by generating different random numbers for $\{p^k_{jt}, p^m_{jt}, p^{rd}_{jt}\}$.

There were 153,304 firms in 2001, among which 21,466 firms imported either capital or intermediate goods in 2001 (excluding pure processing firms). In our simulation, 11,658 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 1.51% 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 intermediates 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 intermediates tariff reduction. Figure 5 compares the gains from capital and intermediates tariff reduction. Around 63% 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	
Share of gross output of importing firms (%)	44.9	
Share of employment of importing firms (%)	33.5	
Firm variables	Mean	S.D.
Gross output (million RMB)	71.6	597.4
Value added (million RMB)	18.8	160.8
Capital stock (million RMB)	24.8	271.3
Labor (number of employees)	258	918.7
Intermediate inputs (million RMB)	53.1	470.8
R&D participation rate	0.12	0.32

Note: Our dataset covers manufacturing firms from 2000 to 2007, including importers and non-importers. 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 updated 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
Consumption goods (%)	2.0	3.7
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 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	82.07	10.68	9.23	5.38	10.34	0.17	0.29
	(235.12)	(1.25)	(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	72.52	10.35	8.72	5.27	10.00	0.52	0.13
	(283.18)	(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	123.88	11.22	9.86	5.73	10.84	0.61	0.27
	(590.46)	(1.53)	(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	78.87	9.72	8.08	4.60	9.35	0.08	0.10
	(187.62)	(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	81.89	9.90	8.28	4.75	9.53	0.16	0.12
	(253.05)	(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: This is the full sample including ordinary and processing trade, as well as firms that do not trade. "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 Intermediates Imports on Productivity

Dependent variable: Log gross output	(1)	(2)	(3)
Labor (log L)	0.069***	0.069***	0.069***
	(0.0006)	(0.0006)	(0.0006)
Intermediate inputs (log M)	0.860***	0.859***	0.861***
	(0.0003)	(0.0003)	(0.0003)
Capital (log K)	0.036***	0.035***	0.035***
	(0.0004)	(0.0004)	(0.0004)
Import k	0.022***	0.0175***	0.009***
	(0.0007)	(0.0007)	(0.0008)
Import m	0.019***	0.0178***	0.007***
	(0.0003)	(0.0003)	(0.0003)
Import k * Import m	0.015***	0.015***	0.004***
	(0.0008)	(0.0009)	(0.0009)
R&D participation		0.039***	0.039***
		(0.0002)	(0.0002)
R&D participation * Import k		0.010***	0.009***
		(0.002)	(0.002)
R&D participation * Import m		0.0014	0.0015
		(0.001)	(0.001)
R&D participation * Import k * Import m		-0.001	-0.004*
		(0.002)	(0.002)
Share of import k			0.110***
			(0.004)
Share of import m			0.133***
			(0.003)
Share of import k * Share of import m			0.002
			(0.019)
Productivity evolution ρ	0.991***	0.989***	0.989***
	(0.0006)	(0.0006)	(0.0006)
Import k (lag)	0.0050***	0.0045***	0.0048***
	(0.0009)	(0.0009)	(0.0010)
Import m (lag)	0.00002	-0.0001	0.00006
	(0.0003)	(0.0003)	(0.0003)
Import k (lag) * Import m (lag)	0.0004	0.0008	0.0007
	(0.0010)	(0.0010)	(0.0011)
R&D participation (lag)	0.0021***	0.0024***	0.0024***
	(0.0001)	(0.0002)	(0.0002)
Share of import k (lag)			0.009*
			(0.005)
Share of import m (lag)			0.005**
			(0.002)

Share of import k (lag) * Share of import m (lag)			-0.013
			(0.021)
Observations	860,799	849,531	846,976

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 Intermediates Imports on R&D Participation

Dependent variable: R&D participation	(1)	(2)
R&D participation (lag)	0.618***	0.618***
	(0.007)	(0.007)
Import k	0.023***	0.019***
	(0.006)	(0.007)
Import m	0.003	0.004
	(0.003)	(0.004)
Import k * Import m	-0.009	-0.008
	(0.008)	(0.009)
Share of import k		0.061***
		(0.019)
Share of import m		-0.032**
		(0.014)
Share of import k * Share of import m		0.034
		(0.102)
lnTFP	0.017***	0.017***
	(0.002)	(0.002)
Export participation	0.018***	0.018***
	(0.004)	(0.004)
Log capital	0.015***	0.015***
	(0.002)	(0.002)
Fixed Effects	Yes	Yes
Observations	854,052	852,481
Adjusted R-squared	0.466	0.466

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 are clustered at 2-digit industry level. * $p < .10$, ** $p < .05$, *** $p < .01$.

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

Dependent variable: Log gross output	(1) Long-term investment	(2) Gross investment
Labor (log L)	0.070***	0.068***
	(0.0004)	(0.0005)
Intermediate inputs (log M)	0.859***	0.862***
	(0.0003)	(0.0004)
Capital (log K)	0.028***	0.029***
	(0.0001)	(0.0002)
Import k	0.019***	0.012***
	(0.0007)	(0.0009)
Import m	0.019***	0.014***
	(0.0003)	(0.0004)
Import k * Import m	0.014***	0.024***
	(0.0008)	(0.0010)
R&D participation	0.040***	0.033***
	(0.0002)	(0.0003)
R&D participation * Import k	0.008***	0.011***
	(0.002)	(0.002)
R&D participation * Import m	-0.002***	0.005***
	(0.0006)	(0.0007)
R&D participation * Import k * Import m	0.001	-0.007***
	(0.002)	(0.002)
Productivity evolution ρ	0.983***	0.950***
	(0.0006)	(0.0007)
Import k (lag)	0.0060***	0.0040***
	(0.0009)	(0.0010)
Import m (lag)	-0.0001	0.0007**
	(0.0002)	(0.0003)
Import k (lag) * Import m (lag)	-0.00004	0.0025***
	(0.0009)	(0.0011)
R&D participation (lag)	0.0033***	0.0036***
	(0.0001)	(0.0002)
Observations	849,126	571,915

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 Imports on Productivity (Different Estimation Methods)

GO: gross output VA: value added	(1) GNR-GO	(2) ACF-GO	(3) ACF-VA
Labor (log *L*)	0.128***	0.047***	0.415***
	(0.002)	(0.0007)	(0.002)
Intermediate inputs (log *M*)	0.691***	0.917***	
	(0.0007)	(0.0015)	
Capital (log *K*)	0.095***	0.008***	0.255***
	(0.001)	(0.0006)	(0.002)
Import k	0.037*	0.010***	0.032***
	(0.020)	(0.0008)	(0.006)
Import m	0.056***	0.013***	0.035***
	(0.007)	(0.0004)	(0.003)
Import k * Import m	-0.005	0.012***	0.083***
	(0.024)	(0.0009)	(0.007)
R&D participation	0.035***	0.023***	0.133***
	(0.003)	(0.0003)	(0.002)
R&D participation * Import k	0.093**	0.014***	0.053***
	(0.046)	(0.002)	(0.012)
R&D participation * Import m	0.041**	0.001	0.039***
	(0.020)	(0.0009)	(0.006)
R&D participation * Import k * Import m	-0.007	-0.008***	-0.036**
	(0.047)	(0.002)	(0.014)
Productivity evolution ρ	0.720***	0.974***	0.877***
	(0.015)	(0.0007)	(0.0010)
Import k (lag)	0.012**	0.001	0.017**
	(0.005)	(0.001)	(0.007)
Import m (lag)	0.003	-0.0018***	-0.005**
	(0.002)	(0.0003)	(0.002)
Import k (lag) * Import m (lag)	0.008	0.0033***	0.042***
	(0.006)	(0.0010)	(0.007)
R&D participation (lag)	0.019***	0.0021***	0.036***
	(0.001)	(0.0002)	(0.001)
Observations	820,900	820,756	828,765

Note: GNR and ACF refer to the methods proposed by Gandhi, Navarro, and Rivers (2020) and Ackerberg, Caves, and Frazer (2015), respectively. Firms that imported only through processing trade are excluded. We winsorize the share of intermediate inputs at 1% and 99% for the estimations in the table. All regressions control for firm ownership (state, private, and foreign ownership). Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 8: Effects of Imports on Productivity (IV Approach)

Dependent variable: Log gross output	(1)	
Labor (log *L*)	0.081***	(0.0006)
Intermediate inputs (log *M*)	0.846***	(0.0004)
Capital (log *K*)	0.028***	(0.0001)
Import k	0.011***	(0.002)
Import m	0.026***	(0.0004)
Import k * Import m	0.043***	(0.002)
R&D participation	0.050***	(0.0002)
R&D participation * Import k	0.049***	(0.005)
R&D participation * Import m	0.018***	(0.001)
R&D participation * Import k * Import m	-0.052***	(0.005)
Productivity evolution ρ	0.974***	(0.0006)
Import k (lag)	0.006***	(0.002)
Import m (lag)	-0.0002	(0.0003)
Import k (lag) * Import m (lag)	-0.002	(0.003)
R&D participation (lag)	0.002***	(0.0002)
Observations	826,850	

Note: We employ the changes of capital and intermediates tariff since 2000, the lagged capital and intermediates imports, and the lagged R&D participation as instrumental variables for capital and intermediates imports and R&D participation in the first stage estimation. Firms that import only through processing trade are excluded. We winsorize the gross output at 1% and 99%. We also control for the firm ownership (state, private, and foreign ownership). * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 9: Sourcing from High- versus Low-Income Countries

Dependent variable: Log gross output	(1)	
Labor (log *L*)	0.062***	(0.0003)
Intermediate inputs (log *M*)	0.859***	(0.0003)
Capital (log *K*)	0.036***	(0.0002)
Import k from *high*-income countries	0.020***	(0.0004)
Import m from *high*-income countries	0.015***	(0.0002)
Import k & m from *high*-income countries	0.007***	(0.0005)
Import k from *low*-income countries	0.019***	(0.0018)
Import m from *low*-income countries	0.029***	(0.0003)
Import k & m from *low*-income countries	0.027***	(0.0023)
R&D participation	0.040***	(0.0001)
R&D participation*Import k from *high*-income countries	0.0064***	(0.0009)
R&D participation*Import m from *high*-income countries	0.0016***	(0.0005)
R&D participation*Import k & m from *high*-income countries	-0.0005	(0.0011)
R&D participation*Import k from *low*-income countries	0.0009	(0.0030)
R&D participation*Import m from *low*-income countries	-0.012***	(0.0008)
R&D participation*Import k & m from *low*-income countries	0.0034	(0.0037)
Productivity evolution ρ	0.988***	(0.0017)
Import k from *high*-income countries (lag)	0.0038***	(0.0005)
Import m from *high*-income countries (lag)	0.0010***	(0.0001)
Import k & m from *high*-income countries (lag)	-0.0024***	(0.0005)
Import k from *low*-income countries (lag)	0.0019	(0.0019)
Import m from *low*-income countries (lag)	0.0005*	(0.0003)
Import k & m from *low*-income countries (lag)	-0.0001	(0.0021)
R&D participation (lag)	0.0014***	(0.0001)
Observations	849,531	

Note: We define high-(low-) income countries as the countries where the GDP per capita in 2000 was greater than (smaller than or equal to) 10,000 USD (constant price in 2010). Firms that import only through processing trade are excluded. We control for the firm ownership (state, private, and foreign ownership). Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 10: Decomposition of Productivity Gains from Import (in percentage)

	Capital import	Intermediate import	Cap. & Inter. import	Total gains
1. Immediate effect	0.97***	1.05***	0.08	2.10***
	(0.09)	(0.05)	(0.11)	(0.05)
R&D synergy effect	0.25***	0.05	-0.10	0.20***
	(0.10)	(0.05)	(0.11)	(0.06)
% of immediate	25.7***	4.8	/	9.4***
	(8.48)	(4.7)		(2.6)
2. Dynamic effect	0.29***	0.03	0.01	0.33***
	(0.07)	(0.03)	(0.07)	(0.03)
Induced-R&D effect	0.05***	0.004	-0.01	0.04***
	(0.02)	(0.008)	(0.02)	(0.01)
% of dynamic	17.1***	14.9	/	11.5***
	(7.20)	(524)		(2.48)
3. Total gains	1.26***	1.08***	0.09	2.43***
	(0.14)	(0.06)	(0.15)	(0.06)

Note: Firms that import only through processing trade are excluded. Calculation is based on specifications in column (3) of Table 4 and column (2) of Table 5. Bootstrap standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 11: Revenue Gains from Per Dollar Import (USD in current price)

	Capital Import	Intermediate Import	Cap. & Inter. Import	Import
1. Immediate effect	9.12***	1.92***	0.14	3.19***
	(0.82)	(0.08)	(0.18)	(0.07)
R&D synergy effect	2.31***	0.09	-0.18	0.29***
	(0.91)	(0.09)	(0.18)	(0.08)
% of immediate	25.4***	4.7	/	9.2***
	(8.40)	(4.6)		(2.50)
2. Dynamic effect	3.18***	0.06	0.02	0.58***
	(0.78)	(0.05)	(0.16)	(0.04)
Induced-R&D effect	0.46***	0.007	-0.03	0.06***
	(0.16)	(0.014)	(0.03)	(0.01)
% of dynamic	14.6***	12.0	/	9.76***
	(6.32)	(91.1)		(2.14)
3. Total gains	12.3***	1.98***	0.16	3.77***
	(1.39)	(0.11)	(0.29)	(0.10)

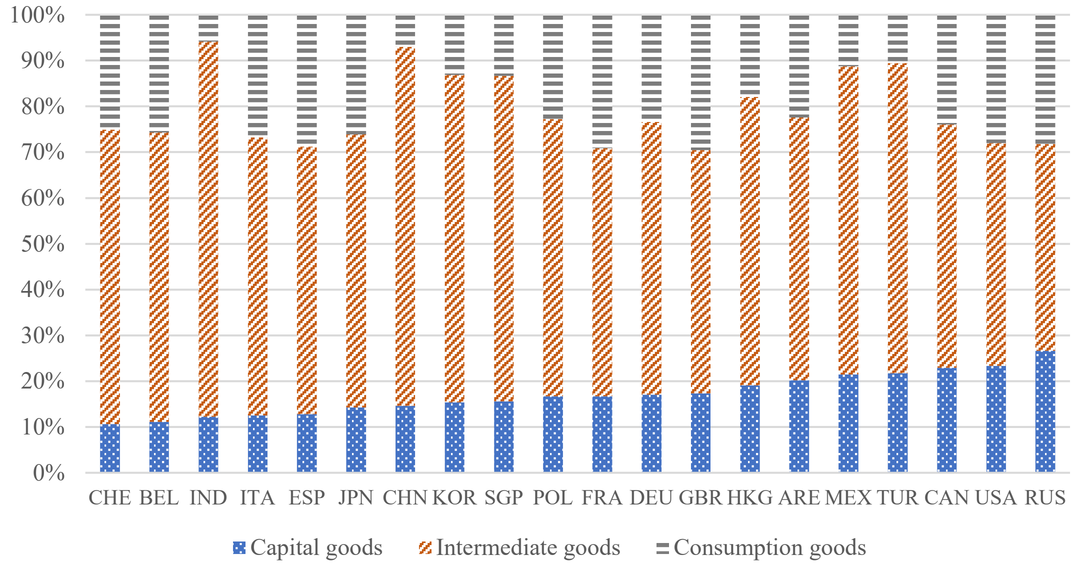
Note: Firms that import only through processing trade are excluded. Calculation is based on specification in column (3) of Table 4 and column (2) of Table 5. Bootstrap standard errors in parentheses. * p < .10, ** p < .05, *** p < .01.

Table 12: Tariff Liberalization and Import Decisions

	(1) Capital import	(2) Intermediate import
Change of capital tariff since 2001	-0.083***	-0.126***
	(0.006)	(0.008)
Change of intermediate tariff since 2001	-0.101***	-0.057***
	(0.006)	(0.008)
Capital import (lag)	0.446***	0.168***
	(0.003)	(0.003)
Intermediate import (lag)	0.146***	0.558***
	(0.002)	(0.002)
lnTFP (lag)	0.010***	0.014***
	(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
Year Fixed Effect	Yes	Yes
R-squared	0.375	0.473

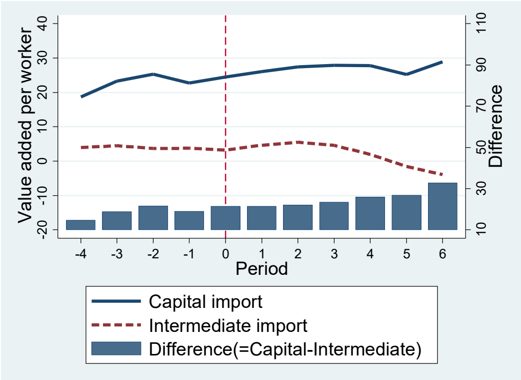
Note: Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Figure 1: Import Structure across Countries/Regions, 2016

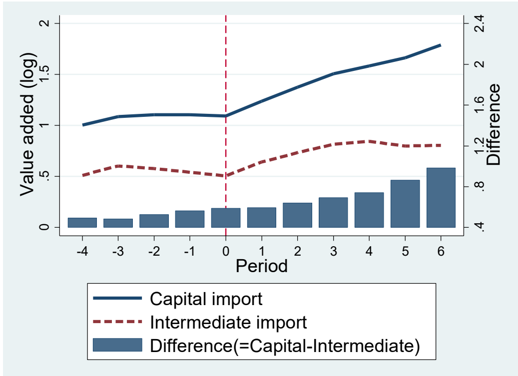


Source: UN Comtrade.

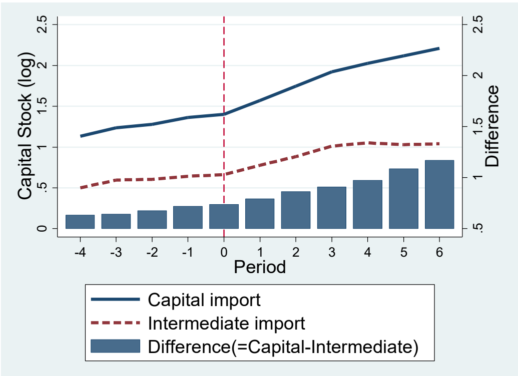
Figure 2: Dynamic Comparison



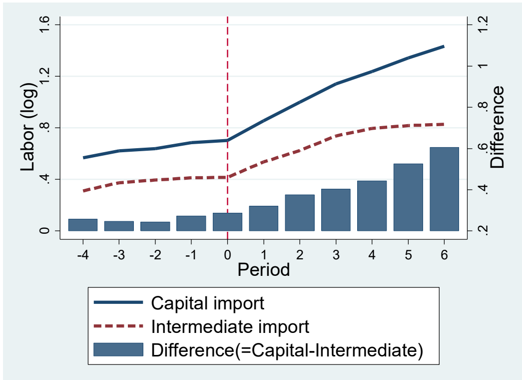
(a) VAPW



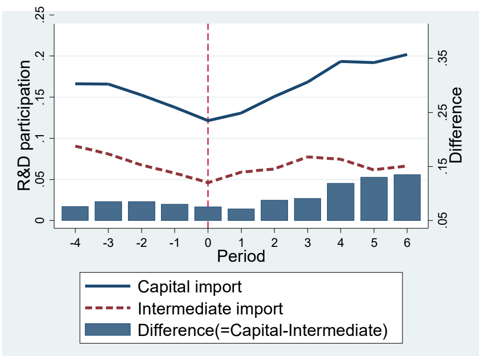
(b) lnVA



(c) lnK



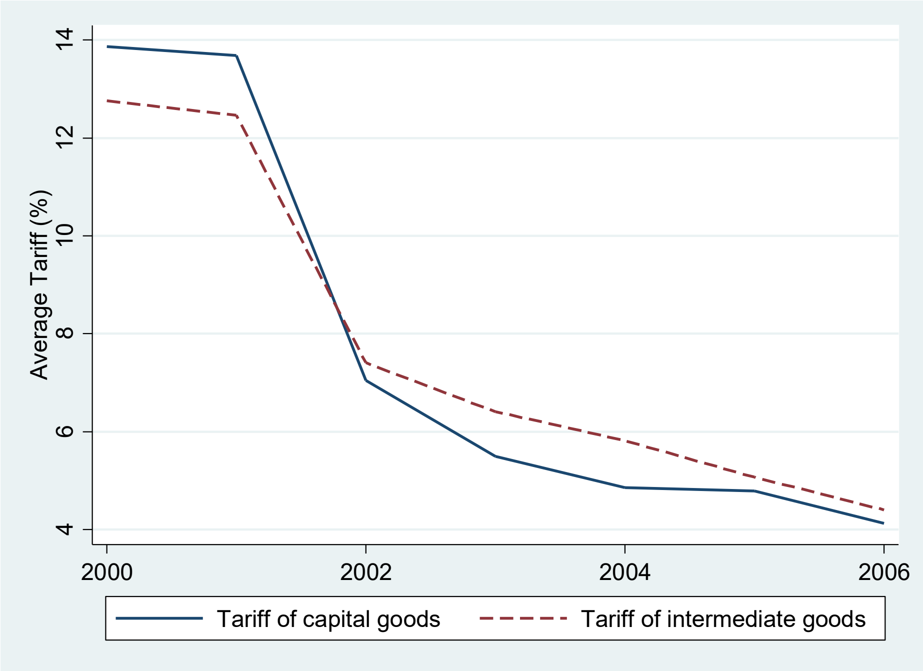
(d) lnL



(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. The difference between the two lines is statistically significant.

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

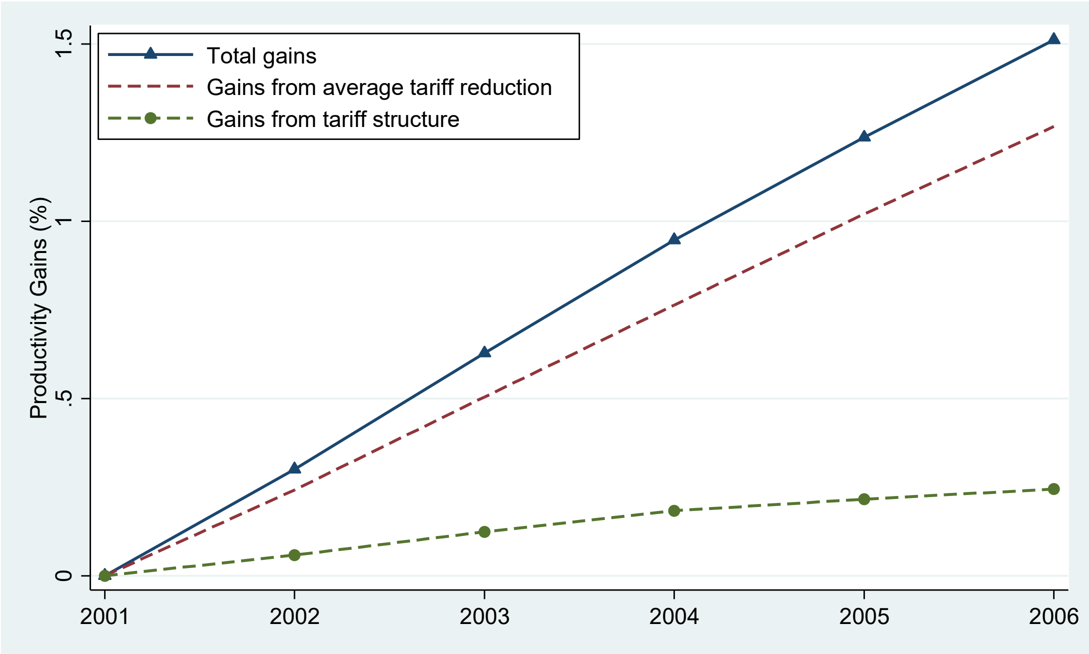
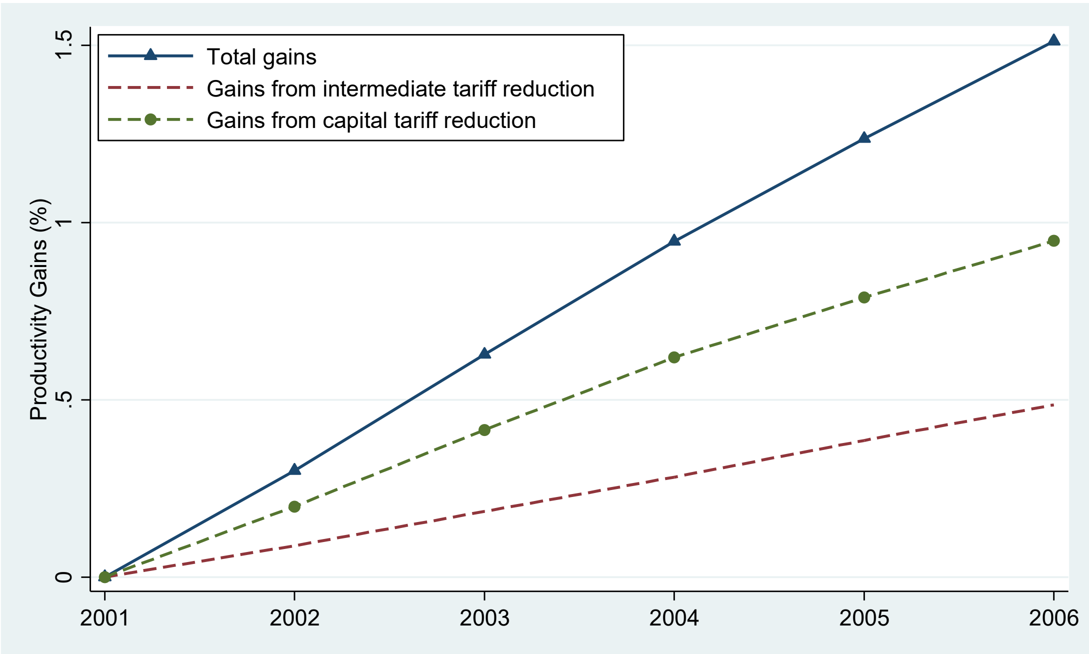


Figure 5: Productivity Gains from Tariff Reduction: Capital versus Intermediate Tariff



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: Interactive Effects between R&D and Imports in the Productivity Evolution

Dependent variable: Log gross output	(1)	(2)	(3)
Labor (log *L*)	0.069***	0.069***	0.069***
	(0.0006)	(0.0006)	(0.0006)
Intermediate inputs (log *M*)	0.860***	0.859***	0.861***
	(0.0003)	(0.0003)	(0.0003)
Capital (log *K*)	0.036***	0.035***	0.035***
	(0.0004)	(0.0004)	(0.0004)
Import k	0.022***	0.018***	0.009***
	(0.0007)	(0.0007)	(0.0008)
Import m	0.019***	0.018***	0.007***
	(0.0003)	(0.0003)	(0.0003)
Import k * Import m	0.015***	0.015***	0.004***
	(0.0008)	(0.0008)	(0.0009)
R&D participation		0.039***	0.039***
		(0.0002)	(0.0002)
R&D participation * Import k		0.010***	0.009***
		(0.0019)	(0.0019)
R&D participation * Import m		0.0014	0.001
		(0.0009)	(0.0007)
R&D participation * Import k * Import m		-0.001	-0.004**
		(0.0020)	(0.0021)
Share of import k			0.110***
			(0.004)
Share of import m			0.133***
			(0.003)
Share of import k * Share of import m			0.002
			(0.019)
Productivity evolution ρ	0.991***	0.989***	0.989***
	(0.0006)	(0.0006)	(0.0006)
Import k (lag)	0.0050***	0.0048***	0.0050***
	(0.0009)	(0.0010)	(0.0011)
Import m (lag)	0.00002	-0.0002	-0.00005
	(0.0003)	(0.0003)	(0.0003)
Import k (lag) * Import m (lag)	0.0004	0.0003	0.0003
	(0.0010)	(0.0011)	(0.0012)
R&D participation (lag)	0.0021***	0.0024***	0.0023***
	(0.0001)	(0.0002)	(0.0002)
R&D participation (lag) * Import k (lag)		-0.0010	-0.0007
		(0.0023)	(0.0025)
R&D participation (lag) * Import m (lag)		0.0005	0.0005

		(0.0007)	(0.0007)
R&D participation (lag)		0.0013	0.0012
* Import k (lag) * Import m (lag)		(0.0026)	(0.0027)
Share of import k (lag)			0.009*
			(0.005)
Share of import m (lag)			0.005**
			(0.002)
Share of import k (lag) * Share of import m (lag)			-0.013
			(0.021)
Observations	860,799	849,531	846,976

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 A4: Effects of Lag Imports on R&D Participation

Dependent variable: R&D participation	(1)	(2)
R&D participation (lag)	0.620***	0.620***
	(0.007)	(0.007)
Import k (lag)	0.025***	0.023***
	(0.004)	(0.004)
Import m (lag)	0.002	0.003
	(0.003)	(0.004)
Import k (lag) * Import m (lag)	-0.006	-0.006
	(0.006)	(0.007)
Share of import k (lag)		0.050***
		(0.016)
Share of import m (lag)		-0.020
		(0.014)
Share of import k (lag) * Share of import m (lag)		0.023
		(0.075)
lnTFP (lag)	0.020***	0.020***
	(0.002)	(0.002)
Export participation (lag)	0.014***	0.014***
	(0.004)	(0.004)
Log capital (lag)	0.014***	0.014***
	(0.001)	(0.001)
Fixed Effects	Yes	Yes
Observations	854,188	852,526
Adjusted R-squared	0.466	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 are clustered at 2-digit industry level. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A5: First Stage Checks of IV Regressions

	(1) Capital import	(2) Intermediate import
Change of capital tariff since 2000	-0.120***	-0.167***
	(0.006)	(0.008)
Change of intermediate tariff since 2000	-0.086***	-0.062***
	(0.006)	(0.007)
Capital import (lag)	0.445***	0.167***
	(0.003)	(0.003)
Intermediates import (lag)	0.143***	0.550***
	(0.002)	(0.002)
Export status (lag)	0.024***	0.071***
	(0.000)	(0.001)
Capital (log *K*, lag)	0.008***	0.010***
	(0.000)	(0.000)
Year Fixed Effect	Yes	Yes
Observations	921,193	921,193
R-squared	0.374	0.474

Note: Firms that import only through processing trade are excluded. Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A6: 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)
Intermediates 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 A7: Effects of Imports on R&D Participation (IV Approach)

Dependent variable: R&D participation	(1)	(2)
R&D participation (lag)	0.617***	0.617***
	(0.007)	(0.007)
Import k	0.133***	0.134***
	(0.028)	(0.028)
Import m	-0.013*	-0.011
	(0.008)	(0.008)
Import k * Import m	-0.091***	-0.088***
	(0.031)	(0.032)
Share of import k		-0.057
		(0.040)
Share of import m		-0.035*
		(0.020)
Share of import k * Share of import m		0.217*
		(0.124)
lnTFP	0.016***	0.017***
	(0.002)	(0.002)
Export participation	0.017***	0.017***
	(0.004)	(0.004)
Log capital	0.015***	0.015***
	(0.001)	(0.002)
Fixed Effects	Yes	Yes
Observations	852,914	851,343
Adjusted R-squared	0.466	0.465

Note: We employ the changes of capital and intermediates tariff since 2000 and the lagged capital and intermediates imports as instrumental variables for capital and intermediates imports in the first stage estimation. 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 are clustered at 2-digit industry level. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A8: Transition Probabilities of Import Status

	Import k only (t)	Import m only (t)	Import k & m (t)	No import (t)
Import k only (t-1)	0.159	0.148	0.156	0.537
Import m only (t-1)	0.014	0.491	0.145	0.350
Import k & m (t-1)	0.021	0.169	0.631	0.179
No import (t-1)	0.003	0.018	0.007	0.972

Note: Firms that imported only through processing trade are excluded. Import status refers to the imports through ordinary trade.

Table A9: Comparison of Input Elasticities

Paper	Method	Labor	Materials	Capital
Yu (2015)	OP	0.077	0.842	0.065
	System-GMM	0.104	0.749	0.031
This paper	Benchmark	0.069	0.859	0.035
	OP	0.070	0.859	0.028
	IV	0.081	0.846	0.028
	GNR	0.128	0.691	0.095

Note: Yu (2015) reports the estimated input elasticities at the 2-digit industry level. We calculate the average elasticities in Yu (2015) weighted by the observations of 2-digit industries in our sample.

Table A10: Input Tariffs and Firm Productivity

Dependent variable: ln (TFP)	(1)
Capital input tariff	-0.511***
	(0.093)
Intermediate input tariff	-0.143*
	(0.067)
Capital * Intermediate input tariffs	0.773
	(0.614)
Constant	1.252***
	(0.007)
Year fixed effect	Yes
Firm fixed effect	Yes
Observations	1,152,438
R-squared	0.512

Note: Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A11: Effects of Imports and Exports on Productivity

Dependent variable: Log gross output	(1)
Labor (log *L*)	0.071***
	(0.0006)
Intermediate inputs (log *M*)	0.859***
	(0.0003)
Capital (log *K*)	0.018***
	(0.0004)
Import k	0.019***
	(0.0008)
Import m	0.018***
	(0.0004)
Import k * Import m	0.015***
	(0.0010)
Export participation	0.010***
	(0.0002)
R&D participation	0.040***
	(0.0002)
Import k * R&D participation	0.010***
	(0.002)
Import m * R&D participation	0.001
	(0.001)
Import k * Import m * R&D participation	-0.0008
	(0.002)
Productivity evolution ρ	0.985***
	(0.0006)
Import k (lag)	0.0056***
	(0.0010)
Import m (lag)	-0.0005*
	(0.0003)
Import k (lag) * Import m (lag)	0.0005
	(0.001)
Export participation (lag)	0.0002**
	(0.0001)
R&D participation (lag)	0.0032***
	(0.0002)
Observations	838,829

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

Table A12: Import Decisions in Simulation

	(1) Capital import	(2) Inter. import	(3) R&D participation
Change of capital tariff since 2001	-0.083***	-0.126***	
	(0.006)	(0.008)	
Change of intermediate tariff since 2001	-0.101***	-0.057***	
	(0.006)	(0.008)	
Capital import (lag)	0.446***	0.168***	
	(0.003)	(0.003)	
Inter. import (lag)	0.146***	0.558***	
	(0.002)	(0.002)	
lnTFP (lag)	0.010***	0.014***	
	(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)	
R&D participation (lag)			0.639***
			(0.009)
Capital import			0.029***
			(0.005)
Inter. import			0.003
			(0.004)
lnTFP			0.013**
			(0.005)
Export participation			0.010*
			(0.005)
Log capital			0.016***
			(0.002)
Year Fixed Effect	Yes	Yes	Yes
Observations	952,623	952,623	891,308
R-squared	0.375	0.473	0.457

Note: Standard errors in parentheses. * p < .10, ** p < .05, *** p < .01.