Inventories, Input Costs and Productivity Gains from Trade Liberalizations*

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Abstract

Trade liberalizations and the associated input tariff reductions have been documented to increase firm level productivity. We revisit this result incorporating the fact that sourcing internationally is inventory intensive. After tariff drops, firms switch to lower variable and higher inventory holding costs goods. We show that when firm's sourcing strategies change, the use of aggregate price deflators systematically leads to mismeasured material input usage. We study the relevance of this potential bias during India's trade liberalization in the early 1990s. First, we document that inventory holdings of intermediate goods increased significantly in response to input tariffs. Second, we extend a standard productivity estimation procedure with a control function for firm level input costs and re-estimate the productivity gains. We find that the input cost mismeasurement accounts for 20 to 40% of the productivity gains. Consistent with the gradual adjustment to the tariff reductions, the bias in the response of firm level productivity is backloaded.

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1 Introduction

One of the most widely celebrated gains from trade liberalizations are the productivity enhancing effects of improved access to foreign intermediate goods. In particular, input tariff reductions have been documented to result in large within firm productivity increases in many episodes, countries and datasets.[1] Common explanations of these effects are linked to learning effects, increased access to novel and better varieties and investment into technical change.[2] What has so far been overlooked in the literature is that international sourcing entails large inventory premiums relative to domestic sourcing. Hence, while switching towards foreign inputs reduces the variable cost of materials it also entails an increase in inventory holding costs. The direct association between inventory holding costs and input tariffs challenges the identification of the elasticity of revenue-based productivity to input tariffs.

This paper revisits the effect of input tariff reductions on within firm productivity growth incorporating the fact that sourcing internationally is inventory intensive and that firm's sourcing and inventory related costs are heterogeneous. We study the relevance of mismeasured productivity gains in the case of India's trade liberalization of the 1990s. We make three main contributions. First, we analytically show how changes in inventories systematically bias the real measure of material inputs when using aggregate price deflators. Second, we provide evidence that inventories increase strongly when firms switch towards foreign inputs and input tariffs drop. Third, we extend a standard productivity estimation procedure with a control function for firm level input costs that accounts for inventory related costs and re-estimate the productivity gains. We find that the input cost mismeasurement accounts for 20 to 40% of the productivity gains. Consistent with the gradual adjustment to the tariff reductions, the bias in the response of firm level productivity is backloaded.

Holding inventories is costly. On top of the purchase price, the valuation of inventories include costs that can be broadly classified into (1) ordering costs such border and documentary compliance costs, transportation and receiving costs; and (2) holding costs such as interest, taxes, insurance, warehouse expenses, physical handling costs, clerical and inventory control, obsolescence, deterioration and pilferage. According to Richard-

[1] See for example Amiti and Konings (2007) for Indonesia, Topalova and Khandelwal (2011) for India, Fernandes (2007) for Colombia, Schor (2004) for Brazil and Hu and Liu (2014) for China.

[2] See Kasahara and Rodrigue (2008), Goldberg et al. (2010) and Bloom et al. (2016).

son (1995), the holding costs alone are on average 40% of the annual value of inventories. Thereby, for a firm that holds 25% of their purchases as inventories these costs amount to 10% of the value of material purchases. Our paper builds on the fact that imported goods are more intensively held as inventories. If firms increase their inventory holdings after switching towards foreign sources, the cost advantages from lower tariffs are countered by the increase in inventory holding costs. Naturally, given the increase in foreign sourcing after trade liberalizations, the benefits of importing outweigh the costs from increased inventory holdings. However, the implied increases in inventory costs are non-negligible and significantly impact the valuation of material inputs into production.

The inventory premium of importers has been documented by previous empirical work. Using firm level balance sheet data from various countries, Nadais (2017) shows that importer's hold on average larger amounts of inventories, even conditional on firm size. Alessandria et al. (2010) estimates that Chilean manufacturers hold more than twice as many months worth of foreign inputs on hand than of domestic inputs. Common explanations to this premium are the existence of larger ordering costs (Alessandria et al. (2013), Hornok and Koren (2015)), longer shipping times (Hummels and Schaur (2013)) or higher demand uncertainty (Bekes et al. (2017)). We confirm the inventory premium of importers within India's manufacturing firms in the 1990s. Firm's inventories as well as their inventory-usage ratio increase with their import intensity and also directly with lower input tariffs. The effect is sizeable. In response to the median input tariff decline of 20 percentage points, the average inventory-usage more than doubles.

The fact that inventory costs respond strongly to changes in trade policy challenges the identification of the elasticity of productivity to the policy change. This is because the presence of inventory costs produce a systematic mismeasurement of real material usage when inventory levels change. Material input into production is imputed from material purchases and the change in inventories. The common approach to convert nominal material input into real quantities is to deflate the former using aggregate price indexes. However, these indexes do not take into account inventory holding costs. Hence, the measured material input is biased by the product of these costs and the change in inventories. Unfortunately, neither direct measures of inventory holding costs nor quantities of material inputs are typically observed.[3] To make progress we borrow the

[3] While some datasets actually contain information on firm's output prices (De Loecker et al. (2016)), given that most production processes use multiple inputs measured in different units, the availability of

insight of a simple model with inventories and dual sourcing, in which a firm's average input costs are characterized by its import intensity and its inventory-usage ratio. We then extend the standard productivity estimation procedure of Ackerberg et al. (2015) with a control function that includes both, import intensity and the inventory-usage ratio. This approach is similar to that in De Loecker et al. (2016) but accounts for the mismeasurement of inputs due to heterogeneous sourcing and inventory management strategies.[4]

We study the relevance of this mismeasurement in the estimated effects of tariffs on within firm productivity growth during India's trade liberalization of the 1990s. In our baseline specification, we find that when controlling for heterogeneous input costs the elasticity of within-firm productivity growth to input tariffs almost halves. Not controlling for the effects of mismeasured input costs widely overestimates the effect of input tariffs on firm performance. This result is robust to a wide array of alternative productivity estimation assumptions and procedures as well as estimation specifications. Throughout the different robustness checks, mismeasurement of input costs accounts for 20 to 50% of the elasticity estimated when those are disregarded.

The mismeasurement stemming from changes in input and inventory costs relies on firm's changing their sourcing and inventory management behavior. It's been well documented that trade adjusts gradually to policy changes and that most of the response is in the long run.[5] Hence, one would expect the bias and the productivity gains to be similarly backloaded. We investigate this using local projections (Jordà (2005)) to estimate elasticities at various horizons. First, we confirm that trade as well as the inventory-usage only adjusted gradually to input tariff reductions, with the full adjustment occurring after 3 and 4 years, respectively. Next, we estimate how productivity responds to input tariff cuts at different horizons. The findings are twofold. First, under the input cost corrected productivity estimate, the gains materialize and remain relatively constant two years after the input tariff reductions. Second, consistent with the input cost mismeasurement to unfold once trade adjusts, the elasticity of the non-corrected productivity estimate diverges from the corrected one after four years.

quantities of material inputs in large manufacturing datasets appears almost insurmountable.

[4]De Loecker et al. (2016) observe quantities of output and control for the positive correlation between output and input quality (and price) by controlling for quality proxies such as market share, output prices and a firm's export status. We focus on a different source of mismeasurement of the quantity of inputs.

[5]See for example Khan and Khederlarian (2019), Yilmazkuday (2019) and Boehm et al. (2020).

The rest of the paper is organized as follows. Section 2 demonstrates why changes inventory holding costs lead to systematic mismeasurement of real input usage. Section 3 describes the data and provides some background to India's trade liberalization of the 1990s. Section 4 documents how India's manufacturing firms significantly changed their inventory management practices in response to input tariff reductions. Section 5 lays out our empirical approach to controlling for rising inventory costs and heterogeneous sourcing practices when estimating firm level productivity. Section 6 presents the results of estimating the elasticity of productivity to input tariff reductions using the input cost corrected and non corrected productivity measures. Section 8 concludes.

2 Mechanism

This section defines why changes in firm's inventory levels produce systematic mismeasurement in its real material input into production. First, we define how inventories are valued under standard accounting practices. Then, we describe how real materials into production are imputed and how the use of aggregate price deflators is insufficient to obtain the real input into production when inventories change and holding inventories is costly.

Holding inventories is not free-of-charge. Standard accounting practices value inventories by three broad categories: (1) the purchase price, (2) ordering costs such border and documentary compliance costs, transportation and receiving costs; and (3) holding costs such as interest, taxes, insurance, warehouse expenses, physical handling costs, clerical and inventory control, obsolescence, deterioration and pilferage. While ordering costs are larger for foreign transactions (Hummels and Schaur (2013), Hornok and Koren (2015)) , it is the holding costs that are at the heart of the mismeasurement that we study. Firms that increase their inventory holdings because of the larger ordering costs and delivery lags involved in foreign sourcing (Alessandria et al. (2010), Alessandria et al. (2013)), also face high holding costs as trade increases. According to Richardson (1995), holding costs are on average 40% of the annual value of inventories. Thereby, for a firm that holds 25% of their purchases as inventories these costs amount to 10% of the value of material purchases. Importantly, holding costs are neglected in aggregate price deflators. Moreover, they are specific to each firm's sourcing and inventory management strategy.

Quantities of material input used in production are typically not observed by accountants nor researchers. The second best option is to use the imputed nominal cost of goods sold established by the law of motion for inventories:

$$Q_{ft}^{nom} = c_{ft}^{z} Z_{ft} + c_{f,t-1}^{s} S_{f,t-1} - c_{ft}^{s} S_{ft}$$

where Q^{nom} is the nominal measured material input into production or consumption of materials, Z are purchases and S inventories. c^z and c^s are the unit value of purchases and inventories, respectively. While c^s is valued as described above and c^z includes the purchase price and ordering costs. We now illustrate how the standard procedure to deflate nominal material input using aggregate price indexes yields a systematic bias when inventories change. The driver of the bias is the fact that price indexes use ex-factory prices which are close to c^z, but exclude inventory holding costs. Assuming that the price index indeed reflects all firm's purchase prices and ordering costs ($c_{ft}^z = c_t^z$) and that $c^s = (1+\varphi(\cdot))c^z$, dividing the expression above by c^z yields:

$$\tilde{Q}_{ft} \equiv \frac{Q_{ft}^{nom}}{c_t^z} = \underbrace{Z_{ft} - \Delta S_{ft}}_{\text{Real Input}} - \underbrace{\varphi(\cdot)\Delta S_{ft}}_{\text{Measurement Bias}} \tag{1}$$

From the expression above it is obvious that when inventory levels change between periods and $\varphi(\cdot) > 0$, the measurement bias term will be nonzero. Above we discussed that for common inventory-sales ratios, holding costs are non-negligible as a share of the total value of purchases, so that $\varphi(\cdot) > 0$ or $c^s > c^z$. Hence, when inventory levels increase, $\Delta S > 0$, the bias will make measured material inputs be less than the real input. Hence, firms will appear to produce with less input making them look more productive.

The described potential source of mismeasurement is especially consequential when estimating firm performance in the context of a trade liberalization.[6] This is because (1) after trade liberalizations firms increase their inventory holdings significantly ($\Delta S > 0$); and (2) the transition towards the new inventory levels is gradual. In section 4 we confirm the inventory premium for India's manufacturing firm during the 1990s and also document that firm's inventory levels rose sharply in response to reduced input tariffs. In section 7 we show that during the episode studied here the adjustment took at least three years

[6]Nonetheless, this mismeasurement might be relevant more generally when estimating the response to shocks that are accompanied by large changes in inventory practices.

to complete. These findings call for the need to control for inventory holding costs when estimating productivity in the context of trade liberalizations. In section 5 we propose a control function approach that corrects for increased holding and heterogeneous ordering costs and purchase prices.

3 Data and Trade Policy Background

This section first describe the data. Second, it provides some brief background to India's trade liberalization of the 1990s, which is a widely used case study for the relationship between firm performance and trade. Third, it discusses the exogenous nature of the tariff reductions.

3.1 Data

We use firm-level balance sheet and income statement information from the Prowess database by the Centre for Monitoring of the Indian Economy. This database has been used in previous studies of the effects of India's trade liberalization on firm performance because it tracks firms over time and spans the entire liberalization period. Firms included in the database are publicly listed and while the dataset accounts for a large fraction of India's industrial activity it is not well suited for the analysis of firm entry and exit.[7] Importantly to our purpose, besides the standard variables used in the estimation of production functions, it contains information on firm's inventory holdings of intermediate goods, as well their domestic and foreign purchases of those goods.

Our analysis focuses on manufacturing firms from the 14 most important 2-digit sectors between 1989 and 2002.[8] Our baseline sample includes 32,124 observations of 5,453 firms in 91 4-digit industries. Table 1 provides summary statistics for the 2-digit sectors. Prowess classifies firms into 4-digit industries using the National Industry Classification (NIC) (2008 revision). We use concordances from the Ministry of Finance in order to merge the firm-level data with the 4-digit NIC (1998 revision) industry level input and

[7]See Topalova and Khandelwal (2011).

[8]There are 22 manufacturing sectors in the 2-digit National Industry Classification (1998 revision). We dismiss 8 of them because the number of observations is insufficient to estimate reliable production functions (As in De Loecker et al. (2016)). For the same reason, we merge 4 sectors with others. We are left with 10 sectors for which we estimate the production functions separately. See the Data Appendix for a full description of our baseline sample design.

output tariffs from Topalova and Khandelwal (2011). Output tariffs in Topalova and Khandelwal (2011) are calculated as the average over HS-6 products using the concordance by Debroy and Santhanam (1993). Input tariffs, the key policy variable in this paper, are computed by weighting the industry-level output tariffs with India's 1993-94 Input-Output matrix, that is, $\tau_{st}^{IN} = \sum_{s'} \alpha_{s,s'} \tau_{s't}^{OUT}$, where $\alpha_{s,s'}$ is the share of industry s' in the value of industry s. Finally, we obtain aggregate and wholesale industry specific deflators from the Ministry of Industry.

3.2 India's Trade Liberalization

After World War II and its independence, India followed a strategy of heavy government regulation and economic self-sufficiency. In the 1970s and early 1980s, India's trade regime was characterized by high nominal tariffs and multiple non-tariff barriers, such as import licenses, quantitative imports and export restrictions, government purchases preferences for domestic producers, etc.[9] In late 1980s under the leadership of Rajiv Gandhi India initiated a set of market-oriented reforms. However, by 1990 India's tariff regime remained one of the most restrictive in Asia.

India's trade liberalization was prompted by its vulnerability to the economic consequences of the Gulf War. India had already been accumulating fiscal and current account deficits in the late 1980s, when the Gulf War lead to a sudden rise in oil prices, a drop in remittances from Indian expatriates and a drop foreign export demand. Large capital outflows eventually required India to demand a Stand-By-Arrangement from the IMF. In addition to other stabilization programs, the arrangement required India to significantly open its economy by removing tariff and non-tariff barriers uniformly across sectors. Panel D in Figure 1 shows how India's simple average tariffs went from 81% in 1990 to 29% in 1997 and then remained relatively stable until 2002. As can be seen in Panel B of Figure 1, this drop in tariffs was followed by a steady rise in imports (and exports). Between 1990 and 2002, India's imports almost doubled, from 8.5% to 15.2%. Figure 1 also illustrates that while tariff cuts were implemented relatively fast, in contrast with the gradual nature of usual trade agreements (Khan and Khederlarian (2019)), imports responded more gradually and continued to grow even when tariffs had already settled by 1997.

[9]See Topalova (2010) for an extensive discussion.

3.3 Trade Policy Endogeneity

Given accurate measurement of productivity, the most important endogeneity concern when estimating the effect of tariffs on firm level performance is reversal causality. It is well established that tariff rates are generally not exogenous and that they are correlated with political economy motives. For example, it could be that policymakers lower tariffs only in those industries that are most competitive. However, in contrast with such concerns, India's trade reform was the result of an externally imposed adjustment program, implemented relatively fast and mostly unanticipated.

As argued in previous studies of this episode, simple inspection of the tariff reductions suggests that tariff rates fell uniformly across industries and that no or few distinctions were made. Figure 2 shows that the trade liberalization not only reduced the level of industry-level input tariffs, but also significantly reduced its dispersion. In fact, the coefficient of variation of input tariffs fell from 0.32 in 1990 to 0.19 in 2002. Figure 3 further corroborates that tariff changes between 1990 and 2002 were well predicted by their initial tariff in 1990, with little variation around the average correlation of -0.60.

4 Inventories, Trade and Tariffs

This section shows that inventories of intermediate inputs into production expand with foreign sourcing. While the inventory premium of importers have been documented previously (Alessandria et al. (2010), Nadais (2017)), the results presented here also establish a direct link between input tariffs and increase inventory holdings. As discussed above, inventory holdings are costly. Hence, when firms switch to foreign sources, the cost advantages of tariff reductions or other non-tariff barriers are countered by increased inventory levels.

We focus on inventories of intermediate goods because, as discussed in section 2, those are used to impute the usage of material inputs into production. Precisely, inventories of intermediate goods, S^{IG}, are the sum of inventories of raw materials and stores and spares. In our baseline results, we consider S^{IG} over the firm's usage or consumption of raw materials, Q^{RM} during the same period. Variables in logs are denoted in lowercase throughout the paper.[10] The inventory-usage ratio, $s/q \equiv \ln(S^{IG}/Q^{RM})$, are directly

[10]Except ratios which are logs of the ratio.

linked to the importance of the inventory holding costs relative to the total costs of materials. If the average months worth of inputs on hand increase holding costs such as interest, taxes, insurance, warehouse expenses, physical handling costs, clerical and inventory control, obsolescence, deterioration and pilferage will increase with it.

We estimate how India's manufacturing firms inventory management responded to the trade liberalization by estimating the following equation;

$$\begin{aligned} s/q_{ft} =& \beta^d D^{RM}_{ft} + \beta^{mz} m/z_{ft} + \beta^{IN}\tau^{IN}_{st} + \beta^{OUT}\tau^{OUT}_{st} \\ &+ \beta^q q^{RM}_{ft} + \sum \beta^x X_{ft} + \alpha_{st} + u_{ft} \end{aligned} \tag{2}$$

where f denotes firm, t year and s a 4-digit NIC industry. D^{RM}_{ft} is an indicator variable for the firm's importer status (of raw materials), $m/z \equiv \ln(M^{RM}/Z^{RM})$ is the log of the ratio of foreign purchases over total purchases of raw materials, and X_{ft} is a vector of firm control variables that include age, squared age, and the firms ownership category. We include 2-digit sector-year fixed effects, α_{st}, to control for differential inventory intensities of across sectors and business cycle. Finally we control for the firm's size by including the total consumption of raw materials.[11] We are particularly interested in how firms adjust their inventory-usage ratio as they initiate (β^d) or increase (β^{mz}) sourcing their inputs from abroad. In addition, we are interested in how the average inventory-usage ratio of firms responded to lower tariffs (β^{OUT}) and input tariffs (β^{IN}).

The results of estimating (2) are reported in Table 2. Column 1 shows that the inventory-usage ratio drops with the firm's consumption of raw materials; that is, inventories rise with firm size, but the elasticity is less than one. Column 2 and 3 confirm the inventory premium for importers. Column three implies that firms that imports hold on average more month worth of inputs on hand than those that source only domestically. Column four documents adds the intensive margin of foreign sourcing of inputs. For a 10% increase in the import intensity of inputs, the inventory-usage ratio increases by 7%.

Columns 4 to 6 introduce tariffs into the estimation. The coefficient on both tariffs are significant and sizeable. While the inventory-usage increases with lower input tariffs, it decreases with output tariffs. The magnitude of the response to input tariffs is

[11] The link between inventories and size is important to control for (Nadais (2017)). In the simple Economic Order Quantity model in which firms hold inventory holdings are driven by the trade off between fixed ordering costs and inventory holding costs, the elasticity of inventories to demand is 0.5. Hence as firm's demand expands their inventory-sales ratio declines.

especially large. For the median tariff cut throughout the sample period of 20pp, the inventory-usage ratio triples. The interpretation of this sizeable effect requires some further explanation. According to the importer inventory premium, increases in inventories due to tariff reductions are due to increased trade. Although column 7 illustrates that when controlling for trade and size the coefficient drops by 50%, these results indicate in industries with lower input tariffs, inventories went up for all firms, unconditionally of their import status. This could be due to unobserved foreign sourcing linkages (wholesale intermediaries) or aggregation issues such as buyers and sellers within the same industry affecting each other's inventory management and ordering strategies.

Table 3 presents the estimates of (2) with firm fixed effects and the interaction of input tariffs and import intensity. The inventory premium for import intensity is robust and almost unchanged even under the restrictive within firm variation.[12] However, the effect of input tariffs is now only significant when interacted with import intensity. As input tariffs dropped, the inventory-usage are increasing in the firm's import intensity. Interestingly, the coefficient on output tariffs remains positive and significant suggesting that increased import competition might have spurred firms to increase the efficiency of their inventory management. The results of this section[13] provide strong evidence that firm's inventory holdings are closely linked to its international sourcing and the country's trade regime. As a consequence, when trade liberalizes and firms increase their purchases of material inputs, their inventory holding costs expand.

5 Productivity Estimation with Inventory Costs

This sections described how to estimate productivity controlling for the potential mismeasurement of real material inputs stemming from changes in inventories and heterogeneous sourcing strategies. First, we illustrate how this mismeasurement might affect the estimation of the production function and how to control for it. Second we layout our baseline production function estimation procedure.

[12] Although $\hat{\beta}^d$ remains positive in four out of five specification, it drops significantly and changes sign when firm size is not controlled for. With within firm variation β^d is identified of firms that change their import status. These changes are infrequent and likely to be selected on a group firms experimenting shocks in productivity or demand.

[13] Tables C.1 and C.3 of the Appendix show that the results reported above are robust under alternative choices of fixed effects, a balanced sample of firms, and alternative definitions of the dependent variable and of the firm size controls.

5.1 Unobserved Material Input Cost

One of the biggest challenges in the estimation of production functions is to convert nominal variables into their real or quantity counterpart. Given the progress on the identification of the unobserved productivity, more recent work has focused on the consequences of unobserved firm-level prices and costs.[14] For example, Kugler and Verhoogen (2012) provide evidence of the complementarity between output and input prices within Colombian manufacturing firms. This finding is rationalized with a model of heterogeneous firms that endogenously choose their products' input and output quality.[15] In light of this potential bias, De Loecker et al. (2016), using output quantities as the dependent variable, control for input quality using output price and market share as proxies. Although our approach here is close to theirs, it differs in the source of bias we address. Section 2 showed, that even using disaggregate industry deflators, input quantities will be mismeasured within firms over time when their inventory-usage changes.

We consider the log output of firm f at time t to be given by a Cobb-Douglas production function:[16]

$$y_{ft} = \beta_l l_{ft} + \beta_k k_{ft} + \beta_m q_{ft} + \omega_{ft} + \varepsilon_{ft} \tag{3}$$

We assume that the elasticity of output with respect to inputs is the same within 2-digit sectors and estimate production functions separately for all 2-digit sectors. ω_{ft} is the firm's productivity and ε_{ft} a measurement error or unanticipated productivity shock term. We follow Topalova and Khandelwal (2011) in the construction of variables.[17] In our baseline, we assume that the mismeasurement from changing input costs affects only material inputs, q_{ft}. When firm level input costs deviate from the wholesale price deflators, measured input is $\tilde{q}_{ft} = q_{ft} c^m_{ft}$ and the production function should be estimated

[14] Another important source of potential bias is the fact that most manufacturing firms are multi-product. We abstract from this and focus on the bias stemming from unobserved inventory holding costs.

[15] De Loecker and Goldberg (2014) show that positively correlated input and output prices will at least partially neutralize each other, thereby undermining the biases from unobserved firm level prices in revenue based productivity estimates.

[16] Recall that variables denoted in lowercase are in logs.

[17] In particular, we use gross fixed assets and depreciation and follow Balakrishnan et al. (2000) to construct capital. Nominal capital is deflated using a deflator constructed from the series on gross capital formation. We use salaries and wages for labor and deflate it using the wholesale price index. Output is measured as the value of gross output deflated with industry-specific wholesale price index. In the baseline, we deflate materials using the aggregate wholesale price index as in Topalova and Khandelwal (2011).

as:

$$
\begin{aligned}
y_{ft} =& \beta_l l_{ft} + \beta_k k_{ft} + \beta_m (\tilde{q}_{ft}/c^m_{ft}) + \omega_{ft} + \varepsilon_{ft} \\
=& \underbrace{\beta_l l_{ft} + \beta_k k_{ft} + \beta_m \tilde{q}_{ft}}_{\equiv \beta_x x_{ft}} - \beta_m c^m_{ft} + \omega_{ft} + \varepsilon_{ft}
\end{aligned} \tag{4}
$$

We now illustrate the source of bias. Suppose a firm sources input materials domestically, it doesn't hold inventories of those inputs, and factors of production are correctly deflated using industry or aggregate wholesale price indexes. Then, in the next period, because tariffs on its inputs go down instead of buying just-in-time domestically it sources internationally and holds inventories. However, it still operates with the same physical quantities of all inputs and its productivity is unchanged. Given that the wholesale price indexes don't account for the inventory holding costs, the deviation of the firm's true material cost, c^m from the price index will be positive and measured material input will be less than the true. This difference will then go into the residual or productivity term, indicating that the firm has increased its productivity.[18]

To control for this source of bias one would want to include inventory holding costs, in addition to deviations of firm's non-inventory input costs from the wholesale price indexes. However, these are generally unobserved. To make progress we use the insights of a simple version of the Economic Order Quantity (EOQ) model with dual sourcing. In this model the average cost of materials is a function of the import intensity and the inventory-usage ratio.[19] In our baseline we consider a second order polynomial expansion of import intensity, $m/z_{ft} \equiv \ln(M^{RM}_{ft}/Z^{RM}_{ft})$ and $s/q_{ft} \equiv \ln(s^{IG}_{ft}/q^{RM}_{ft})$:

$$
c^m_{ft} \approx \sum_{i=0}^{2} \sum_{j=0}^{2-i} \delta_{ij} \times s/q^i_{ft} \times m/z^j_{ft} \tag{5}
$$

By plugging (5) into (4) we control for the unobserved firm-level input costs including inventory holding costs and identify the productivity term:

$$
y_{ft} = \beta_x x_{ft} - \beta_m (c^m(m/z_{ft}, s/q_{ft}; \delta) + \omega_{ft} + \varepsilon_{ft} \tag{6}
$$

[18]In the Appendix B we describe a model with dual sourcing in which the foreign good is stockpiled. We show that in this model there is a systematic increase in firm's productivity after a decline of the relative price of the foreign good if additional inventory holding costs are neglected.

[19]Under some assumptions, the EOQ model model with constant demand provides a closed form of the average material costs in the presence of inventory holding costs. See Appendix A.

Equation (6) is the main departure from the standard approaches to estimating productivity in the literature on the productivity enhancing effects of trade liberalizations. To assess the relevance of the potential bias from mismeasured input costs, we will compare our results to those of estimating (6) while assuming $c^m = 0$.

5.2 Productivity Identification

After having established the necessity to introduce control function $c^m((m/z_{ft}, s/q_{ft})$ into the production function, in this subsection we describe the identification of the parameters of (6).[20] Our production function identification follows the prevailing approach in the literature[21], namely the control function approach of Olley and Pakes (1996) and Levinsohn and Petrin (2003) with the Ackerberg et al. (2015) correction. The control function approach establishes that unobserved productivity can be proxied using a static input demand equation. In our baseline, we consider that the material input demand equation is given by productivity ω_{ft} and a list of state variables:

$$\tilde{q}_{ft} = q_{ft}(\omega_{ft}, k_{ft}, l_{ft}, m/z_{ft}, s/q_{ft}, X_{ft}) \tag{7}$$

The included state variables require some explanation. While capital is the standard state variable in Levinsohn and Petrin (2003), including labor follows from the correction established by Ackerberg et al. (2015) that is now standard in the literature. Because $\tilde{q} = q + c^m$ includes the unobserved input cost c^m, we also include the two variables that we use to proxy for c^m, that is, $m/z_{ft}, s/q_{ft}$. X_{ft} is a vector of lagged variables that might affect the firm's material demand function. These variables are $\tau^{OUT}_{s,t-1}, \tau^{IN}_{s,t-1}, D^x_{f,t-1}, D^m_{f,t-1}$, where D^x and D^m are exporter and (raw materials) importer dummies.

Under the assumptions that $q_{ft}(\cdot)$ is strictly increasing in ω_{ft} and ω_{ft} being a scalar, the the function $q_{ft}(\cdot)$ can be inverted to $\omega_{ft} = \omega(\tilde{q}_{ft}, k_{ft}, l_{ft}, m/z_{ft}, s/q_{ft}, X_{ft})$. This expression can then be substituted into (6) to obtain:

$$y_{ft} = \beta_x x_{ft} - \beta_m(c^m(m/z_{ft}, s/q_{ft}; \delta)) + \omega(\tilde{q}_{ft}, k_{ft}, l_{ft}, m/z_{ft}, s_{ft}/q_{ft}, X_{ft}) + \varepsilon_{ft} \tag{8}$$

Equation (8) is estimated in the first stage using a third order polynomial expansion

[20] Section 6.3 performs numerous robustness checks of the decisions taken along the way.

[21] See for example De Loecker and Warzynski (2012), De Loecker et al. (2016) and Brandt et al. (2017).

of $\omega(\cdot)$. The first stage serves the sole purpose of eliminating ε, the unanticipated productivity shock or measurement error. All parameters are identified in the second stage, in which $\hat{y}_{ft} = y_{ft} - \hat{\varepsilon}_{ft}$ estimated in the first stage is used as the dependent variable. Using (6) and by making a guess on the parameters β_x, δ an estimate of $\hat{\omega}_{ft}$ is obtained. We assume that ω_{ft} follows a Markov process of order one defined by function $g(\cdot)$:

$$\omega_{ft} = g(\omega_{f,t-1}, X_{ft}) + \nu_{ft} \tag{9}$$

We include the same vector of variables $\tau^{OUT}_{s,t-1}, \tau^{IN}_{s,t-1}, D^{x}_{f,t-1}, D^{m}_{f,t-1}$ in the productivity process to accommodate the findings of research of the effects on exporter status (Atkin et al. (2017)) and importer status (Kasahara and Rodrigue (2008), Halpern et al. (2015)) on productivity. Moreover, as demonstrated in De Loecker (2013), if tariffs affect productivity then they should be included in its law of motion. ν_{ft} is the productivity shock observed by the firm, but not the econometrician. In our baseline we assume $g(\cdot)$ follows an AR1 process:

$$\hat{\omega}_{ft} = \rho\hat{\omega}_{f,t-1} + \rho_x X_{ft} + \nu_{ft} \tag{10}$$

By estimating (9) the estimated residual $\hat{\nu}_{ft}$ is obtained. We assume that ν_{ft} is unrelated to $Y_{ft} = \{k_{ft}, l_{ft}, \tilde{q}_{f,t-1}, m/z_{f,t-1}, s/q_{f,t-1}\}$, so that

$$\mathbb{E}(\nu_{ft} Y_{ft}) = 0 \tag{11}$$

Finally, the vector of parameters $\{\beta_k, \beta_l, \beta_m, \{\delta_i\}^5_{i=1}\}$ is estimated to be the one that minimizes the sample analog of (11).[22] The timing assumptions in (11) are standard with the exception of moments for $m/z_{f,t-1}, s/q_{f,t-1}$, since these are typically not included in the production function estimation. We take the view that the current productivity shock is likely to be correlated with the contemporaneous import intensity and inventory-usage, but not with the lagged.

At last we block-bootstrap[23] over the entire procedure and set the final vector $\{\hat{\beta}_k, \hat{\beta}_l, \hat{\beta}_m, \{\hat{\delta}_i\}^5_{i=1}\}$ equal to the mean over all bootstrap repetitions, we define the total

[22]We use the optimization algorithm provided by Ackerberg et al. (2015) to obtain the vector of parameters that minimizes the sum of squared residuals of the sample analog of (11). Our initial guess on the parameters is from the simple OLS regression.

[23]By block-bootstrapping we draw the entire time series of a firm.

factor productivity that corrects for the measurement bias in material input costs as:

$$t\hat{f}p_{ft} = y_{ft} - \hat{\beta}x_{ft} + \hat{\beta}_m \hat{c}^m_{ft}(m/z_{ft}, s/q_{ft}; \hat{\delta}) \tag{12}$$

Before we conclude this section, note that $\{\delta_i\}_{i=1}^5$ is estimated as $\hat{\delta}_i = -\hat{\gamma}_i/\hat{\beta}_m$, where γ_i are the estimated coefficients on the variables of the control function (5) in the second stage of the production function estimation.

6 Results

This section documents how the elasticity of firm level productivity to input tariffs differs when input cost heterogeneity and inventory holding costs are neglected. First, we present our baseline estimation equation. Second, we present the main results. Third, we perform numerous robustness checks.

6.1 Estimation Equation

We follow the tradition of Pavcnik (2002) and Amiti and Konings (2007) and estimate the effects of a trade liberalization by considering how firm level productivity responded to measures of trade openness. In particular, we consider the response of tfp_{ft} with and without c^m in response to lagged output and input tariffs at the 4-digit industry level:

$$\widehat{tfp}_{ft} = \beta^{IN}\tau^{IN}_{s,t-1} + \beta^{OUT}\tau^{OUT}_{s,t-1} + \alpha_f + \alpha_t + u_{ft} \tag{13}$$

We include year fixed effects, α_t, to account for aggregate manufacturing trends. Following most of the literature, we include firm fixed effects, α_f, so that the productivity gains are identified using firm-level variation across time. Hence, the coefficients of interest β^{IN}, β^{OUT} should be interpreted as the average firm level productivity growth across all firms in industry s in response to changes applied to import tariffs on inputs and output tariffs.

6.2 Baseline Results

Table 4 presents the results of estimating the effect of firm level productivity with and without the input cost control function, c^m, under different fixed effects. In the odd numbered columns we present the results when productivity is estimated with $c^m = 0$, that is, without inventory holding costs and input cost heterogeneity; and in even numbered columns we present the results when productivity is estimated including $c^M(m/z_{ft}, s/q_{ft})$ in the form of a second order polynomial expansion.

In the first two columns we include industry fixed effects. When estimating tfp with c^m, the elasticity of productivity to input tariffs halves. When controlling for some firm fixed effects such as age, size and ownership, the coefficient drops even more. When industry-year fixed effects are included, the input cost channel still explains 43% of the effect when c^m is excluded. In the last two columns we report the results of our baseline specification including firm fixed effects. Including the input cost control function almost halves the elasticity, from -0.92 to -0.5. These results indicate that not accounting for the input costs significantly overestimates the effect of input tariff reductions on productivity.

While the effect of including input cost heterogeneity into the estimation of productivity significantly affects the elasticity of productivity to input tariffs, the results are less clear in the case of output tariffs. In columns 1 to 4 the coefficient on output tariffs remains the same when including c^m. Under industry-year fixed effects the coefficient drops significantly. On the contrary, with firm fixed effects the coefficient rises with c^m. The fact that there is on clear pattern in the effect of including c^m in the productivity estimate when it comes to output tariffs is consistent with the facts documented in section 7.1. Input tariffs directly affect firm's inventory and sourcing strategies and, as a consequence, their input costs; however, the link between input costs and output tariffs is less straightforward.

6.3 Robustness

This section provides further evidence of the importance of accounting for changing input costs when estimating the effect of input tariffs on productivity by illustrating the bias under alternative input cost, productivity and production function specifications.

Specification of c^m — In our baseline we specify c^m as proxied by a second order polynomial expansion of m/z_{ft} and s/q_{ft}. Here we test how changing the specification for c^m affects the bias we find. Table 5 reports the results. Column 1 and report the baseline impact. In column 3 instead of (5), we define the proxy of c^m to be $c^m_{ft} \approx \delta_0 + \delta_1 m/z_{ft} + \delta_2 s/q_{ft}$, abbreviated as pol(1) in this and later tables. The contribution of

c^m to the effect of τ^{IN} on $tfp(c^m = 0)$ remains sizeable at 27%. Although the results from section 4 showed that m/z and s/q are strongly related, in column 4 and 5 we attempt to distinguish the contributions of the two. Controlling for both again reduces the elasticity of productivity to input tariffs, but more so in the case of s/q.

Factor allocation of c^m — In our baseline approach we assume that all input and inventory holding costs are linked to material input. However, it can be argued that expenses such as physical handling or clerical inventory control might be imputed to labor. To assess the robustness of our results to alternative factor allocations of c^m, we consider $\delta_i = \gamma_i/(\beta_l+\beta_k+\beta_m)$ and $\delta_i = \gamma_i$, for $i = 1, .., 5$. In the first case, input costs are allocated according to the factor shares in the production function. The second case shall be viewed as a flexible factor share allocation of c^m, in the sense, that not necessarily the allocation of c^m across factors coincides with the factors shares of input quantities into production. Table 6 reports the results. Columns 2 and 3 show that assigning c^m to all factors increases the gap for both cases, when c^m is a first and second order expansion of m/z_{ft} and s/q_{ft}. Similarly, under the flexible factor share allocation of c^m in columns 4 and 5, the gap remains significant and sizeable at 33% and 39% for polynomial of order 1 and 2, respectively.

Specification of the Productivity Process $g(\cdot)$ — In our baseline the process of unobserved productivity in (9) is specified as in (10). In Table 7 we consider three alternative specifications of (9). In columns 1-3 we consider $\hat{\omega}_{ft} = \rho\hat{\omega}_{f,t-1} + \nu_{ft}$,thereby excluding lagged importer and exporter status as well as lagged tariffs. In columns 4-6 we consider $\hat{\omega}_{ft} = \rho\hat{\omega}_{f,t-1} + \tau^{IN}_{s,t-1} + \tau^{OUT}_{s,t-1} + \nu_{ft}$, excluding lagged exporter and importer status. Finally, in columns 7-9 we consider a second order polynomial expansion of $g(\omega_{f,t-1}, X_{ft})$. In all cases the gap between the elasticity with and without the input cost control function remains between 20% and 40%.

Moment Assumptions — In our baseline we follow Ackerberg et al. (2015) in assuming that there are adjustment costs to labor, making it a state variable, so that $\mathbb{E}(\nu_{ft} l_{ft}) = 0$. As a robustness check we allow labor to adjust freely, so that the identifying moment for the labor coefficient is $\mathbb{E}(\nu_{ft} l_{f,t-1}) = 0$. Columns 1-3 of Table 8 shows that the gap remains large and input cots explain 40% of the elasticity of tfp to τ^{IN}. In columns 4-6 we further extend our baseline moment assumptions to $\mathbb{E}(\nu_{ft} X_{ft}) = 0$. Again, the estimate controlling for input costs is smaller than the one that neglects it, although now the size of the gap is less than in the baseline.

Others — Table 9 documents the results of additional robustness checks. In columns 1 and two we estimate the production function including energy (power and fuels) in the production function as in Topalova and Khandelwal (2011). In columns 3 and 4 we focus on the sample of firms that existed before 1991. In columns 5 and 6 we control for the changes in the exchange rate interacted with a dummy of the lagged importer status.[24] In all three cases, the elasticity of productivity to input tariffs is significantly larger when input costs are not controlled for. Lastly, in columns 7-8, we deflate materials by industry specific wholesale price indexes. The coefficient even with $c^m = 0$ drop significantly, similar to the effect of controlling only for m/z_{ft} as in column 4 of Table 5. When controlling for c^m the coefficient drops even further. However, overall when compared to column 7, the drop is smaller (18%) then in the baseline in which materials are deflated using aggregate price deflators.

7 Dynamic Productivity Gains

The previous section provided evidence that the average or cross-sectional elasticity of firm level productivity to input tariffs is significantly overstated by the neglect of input and, particularly, inventory holding costs. We argue that this is due to the mechanism described in section 2, i.e. the rise in inventory costs due to import switching. If this is the case, the bias should coincide with the rise in imports and inventories. To further investigate this underlying mechanism, in this section we study the dynamic effects of the trade trade liberalization on trade, inventories and productivity. Consistent with the gradual adjustment to the tariff reductions, we find that the bias in the response of firm level productivity is backloaded.

7.1 Trade and Inventories

It is well documented that trade responds gradually to trade liberalizations. Typically the ratio of long-run to short-run trade elasticities is between two and three (Yilmazkuday (2019), Khan and Khederlarian (2019), Boehm et al. (2020)). However, most of these

[24] India's currency experimented a continued devaluation throughout the sample period (See Figure 1). Although the change in the exchange rate changes are year fixed effects, there might be some heterogeneous response that is correlated with the response to tariffs.

studies estimate elasticities using disaggregate product level data from customs and administrative datasets. Unfortunately, firm level HS-6 product import data is not available for India over the period studied here. Therefore, we restrict the analysis to firm's total imports of raw materials and consider their response to input tariffs.

We use the local projection method in Jordà (2005) to estimate dynamic trade and inventory-usage elasticities. Precisely, we estimate the following equation:

$$\Delta_h y_{f,t+h} = \beta_h^{IN} \Delta_h \tau_{s,t+h}^{IN} + \beta_h^{OUT} \Delta_h \tau_{s,t+h} + \delta_{st} + u_{ft} \tag{14}$$

A few explanations are required here. First, on the left hand side we consider changes in $y = \{m/z, s/q\}$, that is, the import intensity of raw materials and the inventory-usage ratio of intermediate goods over the horizons $h \geq 0$. Note that by dividing imports by total purchases (consumption) of raw materials we are controlling for demand and productivity shocks and focus on the import switching (inventory usage) pattern. Second, on the right hand side, we consider accumulated changes in tariffs over the same horizons h as in Boehm et al. (2020).[25] Third, we include 2-digit sector-year fixed effects to account for sector specific shocks.

The results of estimating (14) for $h = 1, ..., 5$ with $y = m/z$ are reported in Figure 4. On impact, input tariffs have no effect on imports. After 2 years, the trade elasticity is around -4 but imprecisely measure. Only after 3 years the trade elasticity becomes significant and large. It is around -9 and stays there. These trade elasticities are in the upper bound previous estimates.[26] Figure 5 shows the dynamic response of s/q, the inventory-usage ratio, to changes in τ^{IN}. Again the response is backloaded, as the 4 year elasticity is more than twice as large as the 1-year elasticity. Interestingly, the elasticity of the inventory-usage ratio settles after 4 years, one year after the trade response settles. These findings suggest that Indian manufacturing firms only responded to the incentives of lower input tariffs after around 2-3 years and completed their transition towards a new inventory-usage ratio after 4 years.

[25] Fixing the change of tariffs at $h = 0$ and looking over changes in y over $h > 0$ would potentially pick up later changes in tariffs since tariffs change annually and are generally correlated. See Boehm et al. (2020) for a more detailed discussion.

[26] See for example Head and Ries (2001), Romalis (2007), Baier and Bergstrand (2007)

7.2 Productivity

The results of section 6 documented that the average elasticity of productivity to input tariffs without controlling for input costs exceeded that with the proposed control. Here we study how the two measures of productivity behave over different horizons. Inspection of (1) suggests that material inputs will be mismeasured only during the transition towards the new stationary inventory-usage ratio, i.e. when $\Delta S > 0$. In that sense, the bias should arise whenever inventories (and trade) change significantly. We estimate the dynamic elasticity of productivity to input tariffs by considering the same local projection approach as in the previous subsection. Note that this equation is the same as the one used in the cross-sectional analysis (13), but in first differences.

For each $h = 1, ..., 5$ we estimate;

$$\Delta_h tfp_{f,t+h}(c^m) = \beta_h^{IN} \Delta_h \tau_{s,t+h-1}^{IN} \beta_h^{OUT} \Delta_h \tau_{s,t+h-1}^{OUT} + \delta_t + u_{ft} \tag{15}$$

We estimate (15) for $tfp(c^m = 0)$ and for the tfp estimated controlling for inputs costs with the baseline specification of c^m defined in (5). The results are illustrated in Figure 6. As you can see, the two elasticities are nearly indistinguishable in the first three years after the tariff change. This is when trade and inventories have both not yet responded strongly to the trade liberalization. But after three years, coinciding with the trade elasticity becoming significant and reaching its long run level, the two elasticities begin diverging. While $tfp(c^m = 0)$ further decreases and tfp with c^m remains constant. After 4 years, when the inventory-usage ratio settles, the difference between $tfp(c^m = 0)$ and tfp with the baseline specification of c^m becomes significant. We conclude that the dynamics of the productivity response to the trade liberalization are consistent with the fact that once inventory holding costs significantly rose, input cost mismeasurement lead to estimated increase in firm level productivity.

8 Conclusions

This paper proposes that around 20-40% of the increase in within firm productivity in response to input tariff reductions is due to mismeasured material input costs. The mismeasurement occurs because when firms switch towards foreign sources after input tariff reductions, the variable cost reductions are partially offset by increased inventory holding costs, such as interest rates warehouse expenditures, clerical and handling costs, etc. We document that Indian manufacturers increased their inventory-usage ratio substantially after tariff reductions, suggesting that inventory holding costs indeed rose after the trade liberalization. To assess the impact of these costs as well as the across firm sourcing heterogeneity that is not captured in price deflators, we introduce a control function approach into an otherwise standard productivity estimation procedure. We find that for a large range of alternative specifications controlling for input costs proxied through the inventory-usage ratio and import intensity systematically yields a lower elasticity of productivity to input tariffs.

These findings illustrate that when inventories and firm performance respond simultaneously to the same shock or policy, estimating the elasticity of the latter requires controlling for unobserved inventory holding costs. This will be the case not only when firms start (stop) sourcing from abroad, but also when they decide to increase or diversify the linkages in their supply chains, for example. In those cases, price deflators are ill suited to capture changes in firm's inventory management. More generally, for many industries storage and inventories are an essential ingredient of their production process. Although storage is not included in the transformation of goods, it might be an important cost component thereby potentially biasing the conversion of nominal inputs into real inputs. In that sense, an interesting question that we intend to investigate in the future is whether the previously documented increase in markups after trade liberalizations (De Loecker et al. (2016), Brandt et al. (2017)) might be in part due to confounding increases in inventory holding costs.

Finally, this paper emphasizes that trade liberalizations affect multiple margins of the firm's sourcing decisions. Firms not only need to decide from where to source their inputs, but also how often and how much to order. These decisions depend on more than just tariffs. While most of the literature has proxied trade openness using tariffs to evaluate the effects on firm performance, understanding how firm performance is affected by non-tariff barriers such as shipping times, ordering costs or demand uncertainty is important for policy recommendation. In the future we are planning to use the behavior of inventories and trade frequency to study how tariffs and non-tariff barriers correlated during India's trade liberalization and disentangle their role in driving firm performance improvements.

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Table 1: Summary Statistics

	NIC 2-Digit Sector	N	Firms	Industries	m/z_{ft}^{RM}	s/q_{ft}^{IG}	τ_{1990}^{IN}	τ_{2001}^{IN}
15	Food products and beverages	3,573	747	15	0.03	0.15	0.30	0.15
					(0.12)	(0.34)	(0.10)	(0.04)
17	Textiles, apparel	4,553	782	8	0.08	0.31	0.34	0.12
					(0.16)	(0.33)	(0.06)	(0.02)
21	Motor vehicles, trailers	1,089	178	3	0.16	0.26	0.34	0.14
					(0.19)	(0.29)	(0.00)	0.00)
24	Electrical machinery and communications	7,685	1195	10	0.17	0.27	0.33	0.14
					(0.22)	(0.35)	(0.04)	(0.02)
25	Fabricated metal products	2,080	345	4	0.15	0.27	0.34	0.13
					(0.19)	(0.38)	(0.04)	(0.01)
26	Machinery and equipment	1,572	242	7	0.09	0.57	0.22	0.09
					(0.16)	(0.71)	(0.08)	(0.03)
27	Rubber and plastic	4,105	779	9	0.13	0.30	0.36	0.14
					(0.21)	(0.42)	(0.03)	(0.01)
29	Chemicals	2,808	417	17	0.11	0.58	0.31	0.12
					(0.16)	(0.62)	(0.01)	(0.00)
31	Paper and paper products	2,327	384	11	0.22	0.46	0.36	0.14
					(0.24)	(0.53)	(0.04)	(0.02)
34	Nonmetallic mineral products	2,332	384	7	0.11	0.36	0.33	0.13
					(0.17)	(0.48)	(0.02)	(0.01)
	Total	32,124	5,453	91	0.12	0.33	0.32	0.13
					(0.20)	(0.45)	(0.06)	(0.02)

Note: Columns 6 and 7 are averages over the full sample period, 1989-2002. Standard error are in the parentheses.

Table 2: Inventories, Importer Premium and Tariffs

Dep. Var.: s/q_{ft}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
q_{ft}^{RM}	-0.17***	-0.22***	-0.22***	-0.21***	-0.21***	-0.31***	
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	
D_{ft}^{RM}		0.52***	0.37***	0.36***	0.35***	0.33***	
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	
m/z_{ft}			0.68***	0.66***	0.68***	0.66***	
			(0.03)	(0.04)	(0.04)	(0.04)	
τ_{st}^{IN}				-5.07***	-5.49***	-4.69***	-6.34***
				(0.25)	(0.25)	(0.25)	(0.27)
τ_{st}^{OUT}					1.65***	1.51***	2.16***
					(0.12)	(0.11)	(0.12)
2-Digit NIC-Year FE	✓	✓	✓	✓	✓	✓	✓
Firm Controls						✓	
Observations	31428	31428	31428	28339	28339	28339	28339
Adjusted R^2	0.209	0.242	0.250	0.260	0.265	0.294	0.183

Note: This table contains result from equation (2). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Heterogeneous Response of Inventories

Dep. Var.: s/q_{ft}	(1)	(2)	(3)	(4)
q_{ft}^{RM}	-0.40***	-0.39***	-0.40***	
	(0.02)	(0.02)	(0.02)	
D_{ft}^{RM}	0.089***		0.091***	-0.047**
	(0.02)		(0.02)	(0.02)
$(m/z)_{ft}^{RM}$	0.55***	0.83***	0.76***	0.69***
	(0.06)	(0.09)	(0.09)	(0.10)
τ_{st}^{IN}	0.34	0.57	0.53	0.67
	(0.37)	(0.38)	(0.38)	(0.41)
$m/z_{ft} \times \tau_{st}^{IN}$		-1.29***	-1.36***	-0.99**
		(0.38)	(0.38)	(0.43)
τ_{st}^{OUT}	0.42***	0.43***	0.43***	0.43***
	(0.11)	(0.11)	(0.11)	(0.11)
Year FE	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Observations	27510	27510	27510	27510
Adjusted R^2	0.632	0.632	0.632	0.594

Note: The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Input Costs, Productivity and Tariffs - Baseline

$t\hat{f}p_{ft}(c^m)$	(1) $c^m = 0$	(2) c^m poly(2)	(3) $c^m = 0$	(4) c^m poly(2)	(5) $c^m = 0$	(6) c^m poly(2)	(7) $c^m = 0$	(8) c^m poly(2)
$\tau_{s,t-1}^{IN}$	-1.10***	-0.53***	-1.07***	-0.41**	-1.13***	-0.64***	-0.92***	-0.50**
	(0.12)	(0.16)	(0.11)	(0.16)	(0.13)	(0.18)	(0.16)	(0.20)
$\tau_{s,t-1}^{OUT}$	0.51***	0.49***	0.49***	0.49***	0.51***	0.28***	0.14***	0.20***
	(0.05)	(0.06)	(0.04)	(0.06)	(0.05)	(0.07)	(0.04)	(0.05)
Contribution of $\hat{c}^m$		52%		62%		43%		46%
Year FE	✓	✓	✓	✓			✓	✓
Firm age, size & ownership			✓	✓				
2-Digit NIC FE	✓	✓	✓	✓				
2-Digit NIC - Year FE					✓	✓		
Firm FE							✓	✓
Observations	32124	32124	32124	32124	32124	32124	31304	31304
Adjusted R^2	0.074	0.271	0.091	0.303	0.083	0.307	0.628	0.780

Note: The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Robustness - Input Cost Proxy function, c^m

$\hat{tfp}_{ft}(c^m)$	$c^m = 0$	c^m poly(2)	c^m poly(1)	Only m/z_{ft}	Only s/q_{ft}
$\tau^{IN}_{s,t-1}$	-0.92***	-0.50**	-0.67***	-0.68***	-0.54***
	(0.16)	(0.20)	(0.18)	(0.19)	(0.17)
$\tau^{OUT}_{s,t-1}$	0.14***	0.20***	0.17***	0.15***	0.069*
	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)
Contribution of $\hat{c}^m$		46%	27%	26%	41%
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304
Adjusted R^2	0.628	0.780	0.617	0.655	0.720

Note: All results are from estimating (13). $c^m = 0$ estimates tfp without including the input cost control function. c^m poly(2) (poly(1) is the second (first) order polynomial expansion of m/z_{ft} and s/q_{ft}, defined in (5). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Robustness - Factor Shares of c^m

		All factors		Flexible	
$\hat{tfp}_{ft}(c^m)$	$c^m = 0$	c^m poly(1)	c^m poly(2)	c^m poly(1)	c^m poly(2)
$\tau^{IN}_{s,t-1}$	-0.92***	-0.59***	-0.38*	-0.62***	-0.56***
	(0.16)	(0.17)	(0.23)	(0.17)	(0.19)
$\tau^{OUT}_{s,t-1}$	0.14***	0.080**	0.14**	0.11***	0.22***
	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)
Contribution of $\hat{c}^m$		36%	59%	33%	39%
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304
Adjusted R^2	0.628	0.703	0.885	0.652	0.799

Note: All results are from estimating (13). Columns 2 and 3 define $\delta_i = -\gamma_i/(\beta_l + \beta_k + \beta_m)$ and columns 4 and 5 $\delta_i = -\gamma_i$. See section 6.3. In column 1, $c^m = 0$ estimates tfp without including the input cost control function. c^m poly(2) (poly(1) is the second (first) order polynomial expansion of m/z_{ft} and s/q_{ft}, defined in (5). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Robustness - Productivity Process, $g(\cdot)$

$\hat{tfp}_{ft}(c^m)$	$g(\omega_{f,t-1})$			$g(\omega_{f,t-1}, \tau^{OUT}_{s,t-1}, \tau^{IN}_{s,t-1})$			$g(\omega_{f,t-1}, X_{ft})$ poly(2)		
	$c^m = 0$	c^m poly(1)	c^m poly(2)	$c^m = 0$	c^m poly(1)	c^m poly(2)	$c^m = 0$	c^m poly(1)	c^m poly(2)
$\tau^{IN}_{s,t-1}$	-0.98***	-0.77***	-0.63***	-1.33***	-0.94***	-0.81***	-0.87***	-0.61***	-0.65***
	(0.16)	(0.16)	(0.16)	(0.16)	(0.15)	(0.16)	(0.16)	(0.16)	(0.17)
$\tau^{OUT}_{s,t-1}$	0.10***	0.19***	0.11***	0.15***	0.11***	0.12***	0.12***	0.048	0.029
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Contribution of $\hat{c}^m$		21%	36%		29%	39%		32%	25%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.638	0.648	0.621	0.628	0.625	0.611	0.629	0.621	0.651

Note: All results are from estimating (13). Columns 1-3 estimate productivity excluding X_{ft} from (9). Columns 4-6 estimate productivity excluding D^x, D^m from (9). Columns 7-9 estimate (9) as a second order polynomial instead of (10). $c^m = 0$ estimates tfp without including the input cost control function. c^m poly(2) (poly(1) is the second (first) order polynomial expansion of m/z_{ft} and s/q_{ft}, defined in (5). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Robustness - Moment Assumptions

$\hat{tfp}_{ft}$	Flexible Labor			Moments on X_{ft}		
	$c^m = 0$	$c^m = 0$ poly(1)	c^m poly(2)	$c^m = 0$	c^m poly(1)	c^m poly(2)
$\tau^{IN}_{s,t-1}$	-0.90***	-0.54***	-0.54***	-0.96***	-0.74***	-0.75**
	(0.17)	(0.17)	(0.20)	(0.16)	(0.16)	(0.29)
$\tau_{s,t-1}$	0.12***	0.069*	0.19***	0.13***	0.10***	0.053
	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)	(0.05)
Contribution of $\hat{c}^m$		40%	40%		23%	22%
Firm FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.633	0.633	0.716	0.622	0.617	0.695

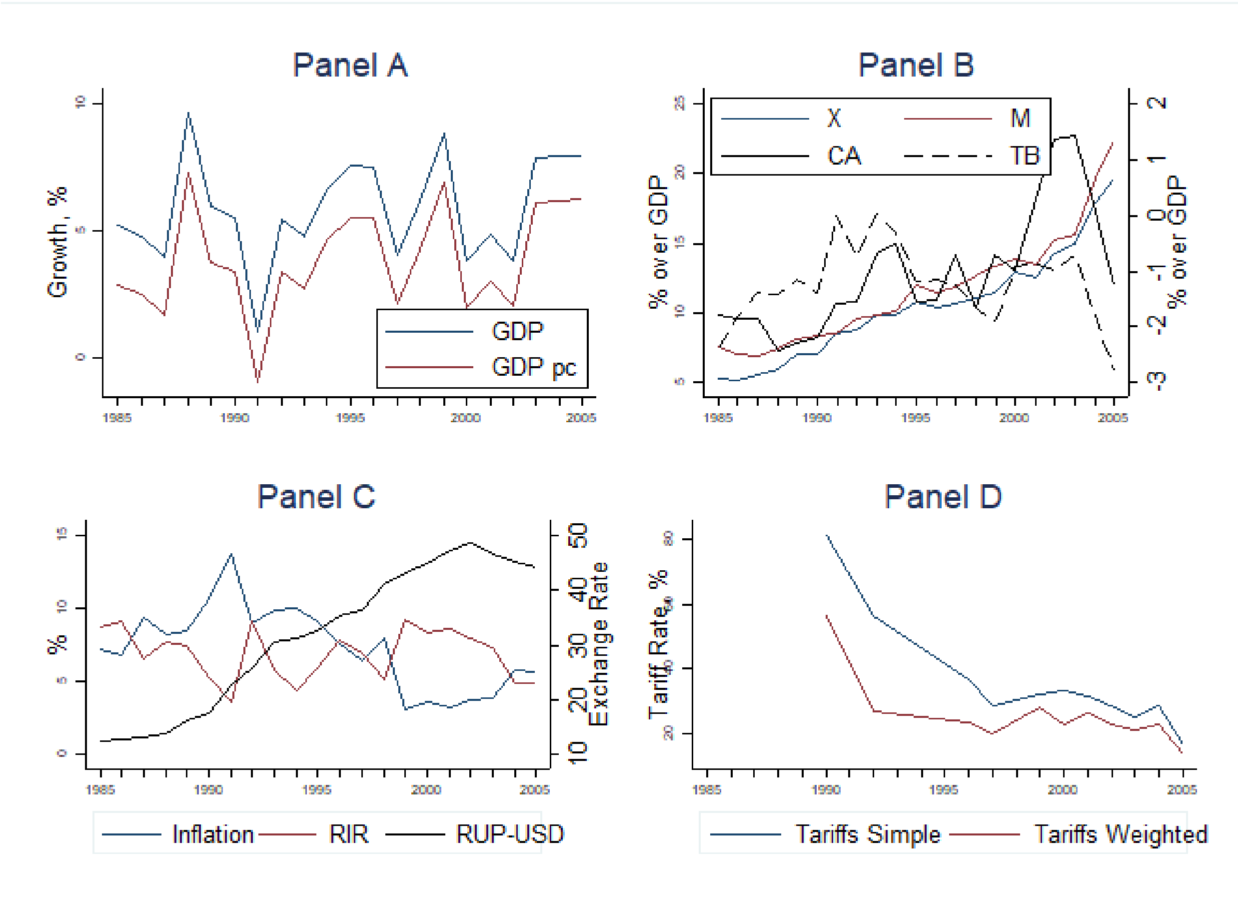
Note: All results are from estimating (13). Columns 1-3 differ from the baseline by imposing $\mathbb{E}(\nu_{ft} l_{f,t-1}) = 0$ instead of $\mathbb{E}(\nu_{ft} l_{ft}) = 0$. Columns 4-6 extend the baseline moment assumption in (11) with $\mathbb{E}(\nu_{ft} l_{ft}) = 0$, where X_{ft} includes lagged tariffs and lagged importer and exporter status. $c^m = 0$ estimates tfp without including the input cost control function. c^m poly(2) (poly(1) is the second (first) order polynomial expansion of m/z_{ft} and s/q_{ft}, defined in (5). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Robustness - Various

$\hat{tfp}_{ft}(c^m)$	Inc. Energy		Firms before 1990		Exchange Rate		Industry WPI	
	$c^m = 0$	c^m poly(1)	$c^m = 0$	c^m poly(1)	$c^m = 0$	c^m poly(2)	$c^m = 0$	c^m poly(1)
$\tau^{IN}_{s,t-1}$	-0.77***	-0.39**	-0.99***	-0.57***	-0.89***	-0.54***	-0.66***	-0.54***
	(0.15)	(0.16)	(0.19)	(0.20)	(0.16)	(0.20)	(0.17)	(0.18)
$\tau^{OUT}_{s,t-1}$	0.13***	0.21***	0.14***	0.18***	0.14***	0.20***	0.11***	0.17***
	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)
$D^{RM}_{f,t-1}$					-0.11	0.18**		
					(0.07)	(0.08)		
Xrate × $D^{RM}_{f,t-1}$					0.038**	-0.037		
					(0.02)	(0.02)		
Contribution of $\hat{c}^m$		49%		42%		39%		18%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	30646	30646	14314	14314	31304	31304	31304	31304
Adjusted R^2	0.628	0.772	0.658	0.653	0.628	0.780	0.641	0.610

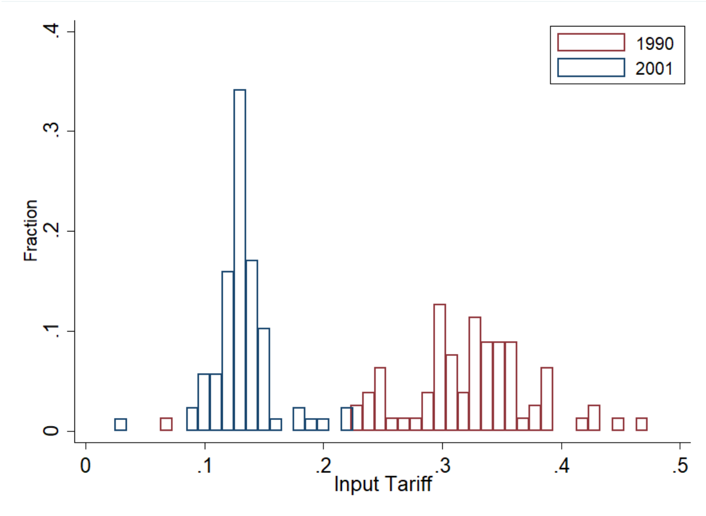
Note: All results are from estimating (13). $c^m = 0$ estimates tfp without including the input cost control function. c^m poly(2) is the second order polynomial expansion of m/z_{ft} and s/q_{ft}, defined in (5). c^m poly(1) is the first order polynomial expansion of the two variables. The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1: Macroeconomic Context of India's Trade liberalization



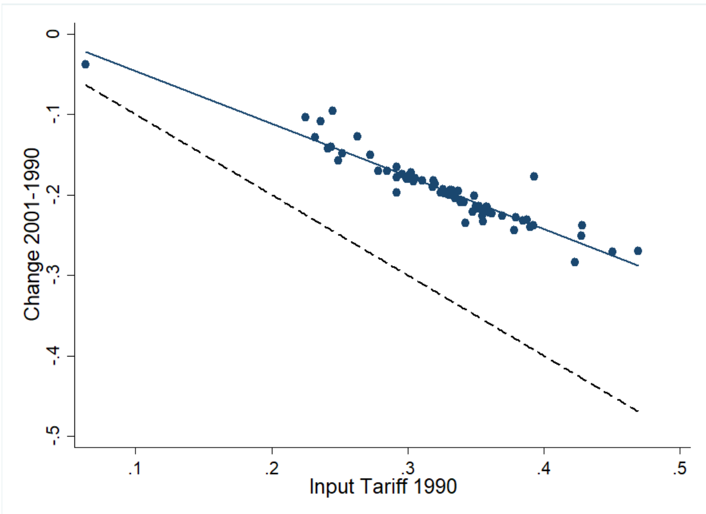
Note: Data is from The World Bank Development Indicators.

Figure 2: Input Tariff Distributions in 2001 and 1990



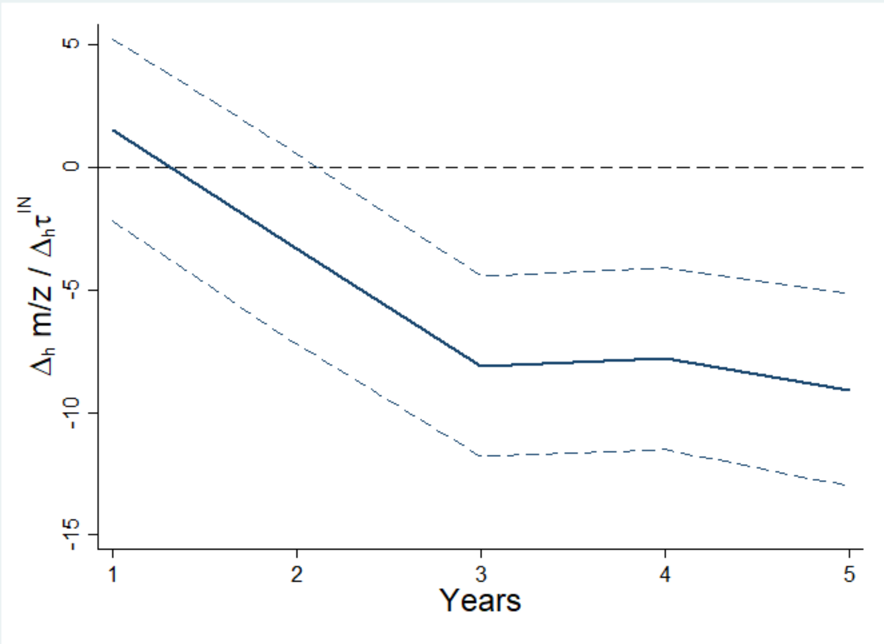
Note: This figure plots the distribution of India's input tariffs at the 4-digit industry level. We can see a marked shifting of the distribution to the left as well as the reduction in the variation in tariffs across industries.

Figure 3: Changes in Input Tariff by Initial Level



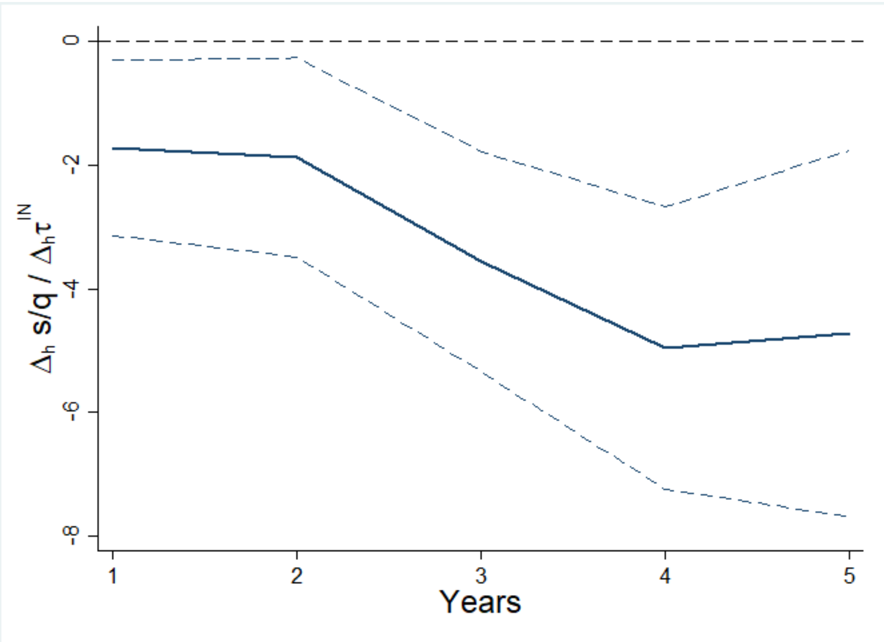
Note: The correlation between the level of input tariffs in 1990 and the change until 2001 is -0.6. The dashed grey line has a slope of -1 for comparison.

Figure 4: Dynamic Response of the Import Intensity to Input Tariffs



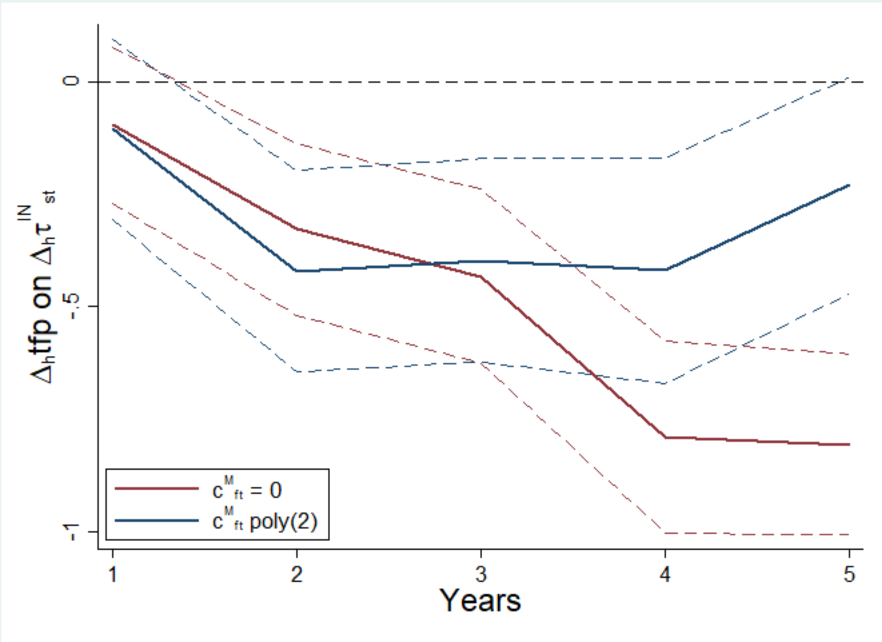
Note: Estimates for each year correspond to the results of estimating (14) for $h = 1, ..., 5$ with $y = m/z_{ft}$. The dashed lines are the 68% confidence interval or one standard error.

Figure 5: Dynamic Response of the Inventory-Usage to Input Tariffs



Note: Estimates for each year correspond to the results of estimating (14) for $h = 1, ..., 5$ with $y = s/q_{ft}$. The dashed lines are the 68% confidence interval or one standard error.

Figure 6: Dynamic Response of TFP to Input Tariffs



Note: The red line is the dynamic response of $tfp(c^m = 0)$ to change in τ^{IN} and the blue line is the dynamic response when tfp is estimated controlling for input costs with the baseline specification of c^m in (5). Estimates for each year correspond to the results of estimating (15) for $h = 1, ..., 5$ with the two productivities. The dashed lines are the 68% confidence interval or one standard error.

Appendix

A Material Costs in the EOQ Model

The Economic Order Quantity model captures the sourcing problem of a firm that faces the trade off between paying a fixed ordering cost and inventory holding costs. Optimization leads to a $(\underline{s}, \overline{s})$ ordering behavior in which the firm runs down their inventories and then replenishes with the same order size. As a consequence the model is able to generate varying frequencies and sizes of purchases that depend on the relative size of ordering and holding costs. The importer premium that motivates the increase in inventories after a trade liberalization is captured through higher ordering costs for foreign purchases than for domestic ones.

The model is set up as follows. A representative firm faces a constant demand Q_i for inputs $i \in \{d, f\}$, where d denotes the domestic and f denotes the foreign input. For simplicity, it is assumed that demand for each input is independent of the other, so that the amount of each input's inventories decrease at the same rate as stock is depleted to fill demand. For simplicity, we also assume that there are no delivery lags and that the order is placed and arrives at the exact time that inventories reach zero. Consequently, the firm never stocks-out and the quantity purchased of each input ordered Z_i is always the same. Given the constant demand, each input's usage of inventories is linear and the average inventory holdings is $Z_i/2$ units (See Figure **??**).

Every time the firm places an order it pays the variable cost c^i and the fixed cost of ordering k_i. For simplicity we assume that the import intensity, $\alpha \equiv Q_f/Q$, where $Q = Q_d + Q_f$, is constant. For each unit of input held in stock during period t, the firm pays an inventory holding cost, ht, which corresponds to an average cost of holding inventories of $hZ_i/2$.[27] Hence, the total cost the firm incurs is:

$$TC^m(Q) = c_d(1-\alpha)Q + c_f\alpha Q + k_d\frac{(1-\alpha)Q}{Z_d} + k_f\frac{\alpha Q}{Z_f} + \frac{h(Z_d + Z_f)}{2} \tag{A.1}$$

Note that Q_i/Z_i is the average number of orders. (A.1) illustrates the trade off the firm faces. If it purchases more frequently and in smaller quantities, it pays more ordering costs but less inventory holding costs. If it places larger and more infrequent orders, it

[27] See Weiss (1982), Nadais (2017).

pays less ordering costs but larger inventory holding costs. The cost minimization yields the following expressions for the optimal ordering size:

$$Z_d^* = \sqrt{\frac{2k_d(1-\alpha)Q}{h}} \tag{A.2}$$

$$Z_f^* = \sqrt{\frac{2k_f\alpha Q}{h}} \tag{A.3}$$

The optimal order increases with the size of the fixed ordering costs and as inventory holding costs decline.[28] Now, consider the average cost in this sourcing setting:

$$C^m \equiv \frac{TC^m(Q)}{Q} = c_d(1-\alpha) + c_f\alpha + k_d\frac{(1-\alpha)}{Z_d} + k_f\frac{\alpha}{Z_f} + \frac{h(Z_d+Z_f)}{2Q} \tag{A.4}$$

After substituting Z_i^* into (A.4) and some algebra, we obtain:

$$C^m = c_d + (c_f - c_d)\alpha + 2\Big(\frac{k_d(1-\alpha)h}{2Q}\Big)^{1/2} + 2\Big(\frac{k_f\alpha h}{2Q}\Big)^{1/2} \tag{A.5}$$

Finally, using the optimally condition $k_d(1-\alpha) = k_f\alpha = \frac{Z_i^2 h}{2Q}$ for $i \in \{d, f\}$ and $S = Z/2$ we obtain that:

$$\begin{aligned} C^m &= c_d + (c_f - c_d)\alpha + 2\frac{Z_d h}{2Q} + 2\frac{Z_f h}{2Q} \\ &= c_d + (c_f - c_d)\alpha + 4h\frac{S}{Q} \end{aligned} \tag{A.6}$$

This expression indicates that the cost of materials is a function of both import intensity and the inventory-usage ratio. Hence it justifies proxying the deviation of firm's cost of material inputs with these two observables.

[28]Note also that if $Q_f = Q_f(c_f, \tau) = A(c_f\tau)^{-\sigma}$, i.e. demand for the foreign input is CES of the input cost and tariffs, then as tariffs decline the size of the order increases with an elasticity of 0.5 with respect to the increase in demand.

B A Model of Dual Sourcing and Inventories

C Tables and Figures

Table C.1: Inventories & Tariffs - Sample Selection and Fixed Effects

Dep. Var.: s/q_{ft}	(1)	(2)	(3)	(4)	(5)	(6)
q_{ft}^{RM}	-0.31***	-0.31***	-0.34***	-0.31***	-0.25***	-0.38***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
D_{ft}^{RM}	0.33***	0.34***	0.51***	0.31***	0.24***	0.35***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
m/z_{ft}	0.66***	0.66***	0.65***	0.69***	0.64***	0.68***
	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)	(0.03)
τ_{st}^{IN}	-4.69***	-4.27***	-5.55***	-3.84***	-4.26***	-4.03***
	(0.25)	(0.23)	(0.20)	(0.27)	(0.27)	(0.24)
τ_{st}^{OUT}	1.51***	1.39***	0.56***	1.23***	1.21***	1.22***
	(0.11)	(0.10)	(0.10)	(0.13)	(0.13)	(0.10)
Firm Controls	✓	✓	✓	✓	✓	✓
2-Digit NIC-Year FE	✓			✓	✓	✓
2-Digit Industry FE		✓				
Year FE		✓	✓			
Sample	Base	Base	Base	Year<1997	Firms <1990	All
Observations	28339	28339	28339	13573	13308	33086
Adjusted R^2	0.294	0.293	0.210	0.317	0.308	0.315

Note: This table contains result from equation (2). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.2: Inventories & Tariffs - Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.:	s/q_{ft}	s^{IG}_{ft}	s^{IG}_{ft}/y_{ft}	s^{RM}_{ft}/q^{RM}_{ft}	s/q_{ft}	s/q_{ft}
q^{RM}_{ft}	-0.31***	0.69***		-0.27***		
	(0.01)	(0.01)		(0.01)		
y_{ft}			-0.24***			-0.22***
			(0.01)			(0.01)
z^{RM}_{ft}					-0.27***	
					(0.01)	
D^{RM}_{ft}	0.33***	0.33***	0.35***	0.38***	0.32***	0.25***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
m/z_{ft}	0.66***	0.66***	0.64***	0.83***	0.66***	0.69***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
τ^{IN}_{st}	-4.69***	-4.69***	-2.14***	-4.41***	-4.89***	-6.02***
	(0.25)	(0.25)	(0.24)	(0.27)	(0.25)	(0.26)
τ^{OUT}_{st}	1.51***	1.51***	0.67***	1.43***	1.58***	1.99***
	(0.11)	(0.11)	(0.11)	(0.12)	(0.11)	(0.12)
Firm Controls	✓	✓	✓	✓	✓	✓
2-Digit NIC-Year FE	✓	✓	✓	✓	✓	✓
Observations	28339	28339	28339	27863	28329	28339
Adjusted R^2	0.294	0.682	0.230	0.246	0.281	0.245

Note: This table contains result from equation (2). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.3: Inventories & Tariffs - Firm FEs & Import Intensity

Dep. Var.: s/q_{ft}	(1)	(2)	(3)	(4)
q_{ft}^{RM}	-0.40***	-0.39***	-0.40***	
	(0.02)	(0.02)	(0.02)	
D_{ft}^{RM}	0.089***		0.091***	-0.047**
	(0.02)		(0.02)	(0.02)
$(m/z)_{ft}^{RM}$	0.55***	0.83***	0.76***	0.69***
	(0.06)	(0.09)	(0.09)	(0.10)
τ_{st}^{IN}	0.34	0.57	0.53	0.67
	(0.37)	(0.38)	(0.38)	(0.41)
$m/z_{ft} \times \tau_{st}^{IN}$		-1.29***	-1.36***	-0.99**
		(0.38)	(0.38)	(0.43)
τ_{st}^{OUT}	0.42***	0.43***	0.43***	0.43***
	(0.11)	(0.11)	(0.11)	(0.11)
Year FE	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Observations	27510	27510	27510	27510
Adjusted R^2	0.632	0.632	0.632	0.594

Note: This table contains result from equation (2). The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.4: Effect of Input Tariffs and TFP - Response of Importers

	$g(\omega_{f,t-1}, d^x_{f,t-1}, d^m_{f,t-1})$				$g(\omega_{f,t-1})$			
$\hat{tfp}_{ft}(c^m)$	$c^m = 0$	c^m poly(2)	$c^m = 0$	c^m poly(2)	$c^m = 0$	c^m poly(2)	$c^m = 0$	c^m poly(2)
$\tau^{IN}_{s,t-1}$	-0.64***	-0.34**	-0.57***	-0.31**	-0.68***	-0.43***	-0.61***	-0.37***
	(0.12)	(0.14)	(0.13)	(0.15)	(0.12)	(0.12)	(0.12)	(0.12)
$\tau^{IN}_{s,t-1} \times m/z_{ft}$	-0.38***	-0.40**			-0.39***	-0.49***		
	(0.13)	(0.17)			(0.14)	(0.14)		
$\tau^{IN}_{s,t-1} \times D^{RM}_{ft}$			-0.18***	-0.11			-0.20***	-0.17***
			(0.05)	(0.07)			(0.06)	(0.06)
$\tau_{s,t-1}$	0.08***	0.11***	0.07***	0.11***	0.06***	0.07***	0.06***	0.07***
	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
m/z_{ft}	0.21***	0.17***			0.22***	0.19***		
	(0.03)	(0.04)			(0.03)	(0.03)		
D^{RM}_{ft}			0.06***	0.03*			0.08***	0.04***
			(0.01)	(0.02)			(0.01)	(0.01)
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.629	0.780	0.629	0.780	0.639	0.621	0.639	0.621

Note: The robust standard error are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$