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Inventories, Input Costs, and Productivity Gains from Trade Liberalizations

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Abstract

Sourcing internationally entails additional costs due to larger per inventory holdings. When firms switch toward foreign sources, these unobserved costs increase. This paper revisits the effect of trade liberalization on firms' productivity taking into account the inventory premium of importing and input cost heterogeneity. Through model simulations, the paper shows that in the presence of inventory holding costs, their omission in revenue-based productivity measures leads to a systematic overestimation of the elasticity of productivity to input tariffs. Controlling for the firm's import intensity and inventory usage in the estimation of productivity corrects for the bias. The paper studies the relevance of this potential bias during India's trade liberalization in the early 1990s. First, it documents that inventory holdings of intermediate goods increased significantly with import intensity and input tariffs. Second, it extends a standard productivity estimation procedure with a control function of the various firm-level input costs. The mismeasurement channel accounts for around 35 percent of the estimated 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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Inventories, Input Costs, and Productivity Gains from Trade Liberalizations*

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1 Introduction

One of the most widely celebrated gains from trade liberalization is the productivity enhancing effect of improved access to foreign intermediate goods on domestic firms. In particular, input tariff reductions have been documented to result in large within firm productivity increases, especially in developing economies. Common explanations are a higher quality in the foreign varieties or imperfect substitution between foreign and domestic inputs. However, there is yet no conclusive answer to why firms do not grab these low hanging fruits before the trade reforms (De Loecker and Goldberg (2014)); and, similarly, why do only a relatively small fraction of firms import even after the reforms.[1] This paper provides insights to these questions by arguing that there are additional costs of engaging in international trade that are typically neglected and that lead to an overestimation of the productivity enhancing effect of input tariff reductions. Precisely, sourcing internationally implies larger inventory holding costs. And when firms switch towards foreign sources, these costs increase.

We make four main contributions. First, we show that in a model of heterogeneous firms, dual sourcing and an inventory premium for importing, when firms switch to foreign sources due to lower input tariffs, the use of revenue based measures of productivity leads to a systematic upward bias in the tariff elasticity of productivity. Second, we show that the bias is overcome by controlling for import intensity and the inventory-usage ratio. Third, we provide evidence that indeed inventories increase strongly when firms switch towards foreign inputs and input tariffs drop. Fourth, we extend a standard productivity estimation procedure with a control function for firm level input costs and apply it to India's trade liberalization of the 1990s. We find that the elasticity of productivity to input tariffs drops by 37% when including the control function. Consistent with the mismeasurement explanation, the bias in the productivity response is driven by inventory intensive firms and industries and occurs at the same time that trade and inventories respond to the tariff reductions.

Inventory holding costs are generally unobserved and difficult to measure, challenging the estimation of revenue based productivity. Due to the lack of quantity output and input data, researchers have resorted to estimating revenue based productivity as opposed

[1] For example, Halpern et al. (2015) estimate that Hungarian firms that import pay a sunk cost of importing that is 35 times lower than the one faced by non-importers.

to physical productivity.[2] To close the gap between the two, revenues and nominal inputs into production are then deflated with wholesale price indexes. These are typically constructed using ex-factory gate prices reported by selling firms. On the input side, these indices omit the inventory holding costs associated with materials. Hence, on the output side, these costs will be attributed to differences in markups or physical productivity if firms include these costs in pricing their output.

This mismeasurement is especially relevant in the context of international trade and in the case of developing countries. On the one hand, it is well known that inventory levels are typically higher in developing countries.[3] On the other hand, costs associated with holding inventories become sizeable when firms source from abroad. This is because international per shipment costs - those paid independently of the order size - are especially large, given that the nature of trade includes border and documentary compliance costs, administrative order-processing costs, and larger transportation and receiving costs. To economize on the per shipment costs, firms order infrequently and in large amounts, resulting in the inventory premium of international sourcing.[4] Carrying inventories entails forgoing interest rates, additional insurance and warehouse expenses, and costs associated with the depreciation of goods. Assuming that these costs represent a conservative 40% of the value of inventories, these costs make for around 8% of a firm's total costs, given a monthly inventory-usage ratio of 4 and a material expenditure share of 60%. When trade liberalizes and the price of foreign inputs drops, firms that switch from domestic sources to foreign sources incur in these additional costs, establishing a direct link between input tariffs, import intensity and the mismeasurement of revenue based productivity.

We propose to correct for this mismeasurement by introducing an input cost control function including the firm level import intensity and the inventory-usage ratio in the estimation of the production function. We validate this approach through a model that captures the essence of the mismeasurement. In the model, firms differ in their productiv-

[2]The availability of quantities of material inputs in large manufacturing data sets appears almost insurmountable due the use of multiple inputs measured in multiple units in most production processes. More recent work De Loecker et al. (2016) has used information on firms' output prices, overcoming the issue of deflating revenues. However, the challenge remains that these prices might not reflect markups but rather unobserved input costs that are excluded from the material expenditure share.

[3]For example, Gausch and Kogan (2001) report that manufacturing firms in a group of developing countries hold between 2 to 5 times more inventories of raw materials than US firms.

[4]See Alessandria et al. (2010) and Hornok and Koren (2015b).

ity and produce using labor and intermediate inputs, with the latter being a composite of a foreign and a domestic intermediate good. While the domestic good is sourced flexibly, the existence of an ordering cost and a delivery lag in the case of the foreign good leads to (1) a productivity threshold for importing and (2) inventory holdings of the foreign good. In response to a tariff reduction, more firms import, import intensity of importing firms increases and so do their inventory holdings. Simulations of the model show that when variables are calculated as in the data, the productivity elasticity to tariffs is overestimated. Using a control function including import intensity and inventory-usage in the production function estimation removes the bias.

To study the empirical relevance of this potential bias we study India's trade liberalization of the 1990s. First, we confirm the inventory premium of importers within India's manufacturing firms. Firm's inventories and their inventory-usage increase with the firm's import intensity and also directly with lower input tariffs. The effects are sizeable. On the one hand, the inventory-usage ratio is almost 3 times larger for a firm that imports all of its inputs relative to one of the same industry-year that only sources domestically. On the other hand, firms in industries with lower input tariffs hold on average larger inventory-usage ratios, with a sizeable elasticity of -5. These findings suggest that firm's ordering and inventory holding costs increased in response to the same policy shock used to evaluate productivity gains, namely the reduction in input tariffs.

Second, we extend an otherwise standard productivity estimation procedure with the input cost control function validated in the model simulations. We follow the prevailing approach in the most recent literature on the effects of trade liberalizations on productivity by using the control function approach of Olley and Pakes (1996) and Levinsohn and Petrin (2003) with the correction of Ackerberg et al. (2015). In our baseline specification of the productivity estimation, we find that when controlling for unobserved firm level input costs, the elasticity of within-firm productivity growth to input tariffs drops by 37%. Not controlling for the effects of mismeasured input costs overestimates the effect of input tariffs on firm performance. This result is robust to a wide array of alternative productivity estimations and specifications. Throughout the different robustness checks, the mismeasurement of input costs accounts for 20 to 50% of the elasticity obtained when those are disregarded. We also document that the bias is driven by firms and industries that are relatively inventory intensive.

Given the focus on within firm variation, the mismeasurement that we refer to occurs as firms increase their foreign sourcing and inventory holdings. Accordingly, the bias should arise precisely at the same time that firms respond to the input tariff reductions. In that sense, it is 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 by estimating elasticities at various horizons. First, we confirm that import intensity and the inventory-usage adjust gradually to input tariff reductions, with the full adjustment occurring after 3 and 4 years, respectively. Next, we estimate the dynamic response of productivity to input tariff cuts. The findings are twofold. First, under the corrected productivity estimate, the gains materialize and remain relatively constant after 4 years. Second, consistent with the timing of the trade and inventory adjustment, the elasticity of the non-corrected productivity estimate diverges from the corrected one after 3 to 4 years.

The rest of the paper is organized as follows. Section 2 describes the input cost mismeasurement. Section 3 lays out a model that captures the essence of the bias and validates our correction. Section 4 lays out the empirical implementation of the correction. Section 5 first demonstrates why the mismeasurement was potentially consequential in the case of India's trade liberalization the 1990s and then applies our correction to re-estimate the productivity gains. Section 6 studies the dynamic response and documents that the mismeasurement aligns well with the timing of the trade and inventory adjustment. Section 7 concludes.

Related Literature

The main contribution of this paper is to the empirical literature on the effects of trade liberalizations on domestic firms' productivity growth. Early studies on the trade reforms of Latin American countries in the 1970s and 1980s established that manufacturing firms in import competing industries experienced strong relative productivity growth (Tybout and Westbrook (1994), Tybout et al. (1991), Pavcnik (2002)). A large body of research followed by studying the response of within firm productivity growth to input and output tariffs reductions. A consistent finding of this work is that most of the firm level gains are related to input tariff reductions (Schor (2004) for Brazil, Amiti and Konings (2007) for

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

Indonesia, Fernandes (2007) for Colombia, Topalova and Khandelwal (2011) for India, Hu and Liu (2014) for China, etc.), highlighting the role of enhanced access to foreign inputs relative to the pro-competitive gains from output tariff reductions. For example, Amiti and Konings (2007) find that for Indonesian manufacturers a 10 percentage point fall in input tariffs leads to a productivity gain of 12 percent for firms that import their inputs. These large effects have been explained through various mechanisms, such as learning effects from importing (Kasahara and Rodrigue (2008)), differential quality embedded in foreign varieties (Halpern et al. (2015), Fieler et al. (2018)) or the adoption of novel inputs (Goldberg et al. (2010)). Our results indicate that the elasticity of productivity to input tariffs is overestimated by between 20% to 50% under standard approaches that do not control for the ordering and inventory holding costs of inputs.

One of the biggest challenges in the estimation of production functions is to convert nominal variables into their real or quantity counterpart. While traditionally the main concern addressed by researchers has been the endogeneity between firm's input decisions and productivity, recent work has emphasized the importance of heterogeneous firm-level prices.[6] For example, Kugler and Verhoogen (2012) provide evidence of the complementarity between output and input prices within Colombian manufacturing firms. However, only under a restricted set of assumptions are correlated input and output prices going to neutralize each other and lead to unbiased productivity estimates (De Loecker and Goldberg (2014)). To address this bias, Brandt et al. (2017) use very disaggregate industry data from firm level surveys and construct input price deflators from input-output tables. De Loecker et al. (2016) in turn implement a control function approach very similar to ours, using output prices, market shares and export status to control for the quality complementarity between inputs and outputs.[7] This paper argues that sourcing internationally entails additional costs that are not captured by price deflators and require a control function in the estimation of productivity.

We also contribute to the literature on the relationship between inventories and trade. In particular, the input cost heterogeneity that drives the productivity mismeasurement is directly related to the inventory premium associated with international sourcing documented previously. Using firm level balance sheet data from various countries, Nadais

[6]Another important source of potential bias is the fact that most manufacturing firms are multi-product. We abstract from this bias here as has most of the literature.

[7]More recently, Morlacco (2020) controls for firm level deviations from industry level price deflators by exploiting observed firm level input and output price differences in customs transaction data.

(2017) shows that importers hold on average larger amounts of inventories, even conditional on firm size. Alessandria et al. (2010) estimate that Chilean manufacturers hold more than twice as many months' worth of foreign inputs on hand than of domestic inputs. Common explanations for this premium are the existence of larger ordering costs (Alessandria et al. (2013), Hornok and Koren (2015a)), longer shipping times (Hummels and Schaur (2013)) or higher demand uncertainty (Bekes et al. (2017)). This paper shows that the inventory premium of international sourcing is also consequential in the measurement of the productivity response to trade shocks.

2 Mechanism

This section illustrates why the omission of firm level inventory holding costs is potentially consequential in the estimation of productivity when firms switch to sourcing internationally. First, we formulate a firm's average cost of material inputs in the simplest ordering model that incorporates per shipment and inventory holding costs. Second, we argue that these costs are especially important for firms that engage in international trade. Third, we discuss how, under standard revenue based approaches to estimating productivity, for firms that switch to foreign sources the increase in these costs will appear as increased markups or physical productivity.

To set the stage for the relevance of ordering and holding costs, we formulate the simplest ordering model, namely the Economic Order Quantity (EOQ) model. The EOQ model determines the firm's optimal ordering behavior when fixed per shipment costs are balanced against inventory holding costs. By assuming a constant demand Q for its inputs, the existence of fixed ordering costs leads the firm to order infrequently and run down its inventories linearly. Here we consider that the firm uses a fixed proportion $1-m/z$ of a domestic good D and m/z of a foreign good F as inputs.[8] While sourcing D only implies the payment of the unit price C^z, the purchase of F requires a per shipment cost $\kappa_F > 0$. To save on the per shipment cost, the firm orders F infrequently and uses its inventory holdings S_F to fulfill its demand, Q_F. Holding inventories comes at the cost C^h_t for each unit of inventory held during t. Given the linear depletion of inventories, the average cost of holding inventories is $C^h\overline{S}$, where $\overline{S}$ is the average inventory holdings.

[8] The model of section 3 relaxes this to show how reduced tariffs lead to mismeasured input costs.

Under this setup, the total cost of materials is:

$$TC^q = \underbrace{C_D^z(1-m/z)Q}_{\text{Variable Cost Domestic}} + \underbrace{C_F^z(m/z)Q}_{\text{Variable Cost Foreign}} + \underbrace{\kappa_F \frac{m/zQ}{Z_F}}_{\text{Ordering Cost Foreign}} + \underbrace{C^h\overline{S}}_{\text{Inventory Holding Costs}} \quad (1)$$

where Z_F denotes the amount of F that is purchased every time the firm orders (the S in the sS ordering schedule). Dividing (1) by Q yields the following expression of the average cost of materials the firm pays in this setting:

$$C^q = C_D^z + (C_F^z - C_D^z)m/z + \frac{\kappa_F m/z}{Z_F} + C^h\frac{\overline{S}}{Q} \quad (2)$$

There are two takeaways from this expression. First, the material cost unambiguously increases with the inventory-usage ($\overline{S}/Q$) of a firm's inputs.[9] The intuition is that the holding costs increase with the amount of time materials remain unused in the warehouse. Second, even if $C_F^z < C_D^Z$, increasing import intensity might still result in an increase of the average cost if ordering costs are sufficiently large (and the quantities per shipment are relatively small).

The ordering and holding costs firms incur when sourcing internationally are substantially larger than when they source domestically. On the one hand, some ordering costs such as border and documentary compliance costs, administrative order-processing costs are specific to international sourcing; while others, such as transportation and receiving costs, are substantially larger when sourcing from abroad.[10] The existence of these per shipment costs leads firms to order infrequently and in large amounts relative to domestic orders. On the other hand, carrying inventories is costly. Some of the costs associated with inventory holdings are forgone interest rates, taxes, insurance, warehouse expenses, physical handling costs, clerical and inventory control, obsolescence, deterioration and pilferage. And because of the inventory premium of importing these costs are especially relevant for firms that engage in international sourcing. Table 3 illustrates this premium in the sample of Indian manufacturers used in section 5 to study the link between firm

[9]Here the inventory carrying costs increase linearly with the time spent in the warehouse and do not depend on the amount of inventories. Nadais (2017) finds that to fit this model to the data, carrying costs must be convex in the amount of inventories held. This suggests the existence of economies of scale in inventory management.

[10]According to The Trading Across Borders of the Doing Business Report by The World Bank, in 2009 it still took Indian importers an average of around 26 days to clear containers from ports and involved administrative costs of around $930 (USD 2009).

performance and trade. Importing firms are classified according to their import intensity distribution. The inventory-usage ratio almost doubles when moving from the lower quartile to the top 5 percentile.[11] Given the material expenditure share and assuming that holding costs represent a conservative 40% of the value of inventories,[12], these costs represent 7% of the total costs for a firm in the lower quartile, but 13% for a firm in the top 5 percentile. The higher inventory-usage for foreign sourcing is precisely justified by larger per shipment ordering costs.[13]

These additional input costs from sourcing internationally are especially consequential when measuring the productivity response to input tariff reductions. Firms that respond to input tariff reductions by increasing their foreign input share, while purchasing at lower purchase prices, incur additional per shipment and inventory holding costs. Given the lack of physical quantity data, the use of aggregate or industry-specific price indexes to deflate nominal output and input values will be ill suited to capture the heterogeneity in firm level input costs described above. This is because, if firms pass through these additional costs into their prices, the use of aggregate deflators in the estimation of productivity will identify these unobserved costs as either markups or physical productivity. Hence, there is a systematic link between this source of productivity mismeasurement and the switch towards foreign sources triggered by input tariff reductions.[14]

To correct for this potential bias, one would ideally like to control for all the input costs that are included in the firm's price setting. To make progress on the lack of such data, we use the insights from the average input cost under the EOQ model above. Equation (2) suggests that the firm's relative average cost is tightly linked to its import intensity and inventory-usage. Intuitively, the import intensity captures the importance of purchase price differentials, the frequency of orders and ordering costs, while the inventory-usage ratio is directly linked the holding costs it incurs. Next, we lay out a model that captures the mechanism described here and show how a proxy function of firm's input costs in the estimation of productivity corrects the mismeasurement.

[11]Note also, that the average inventory-usage of 0.33 is much larger than the typical values of US manufacturers that lie between 0.12 and 0.18. It is well established that inventory holdings are larger than in developed countries. Gausch and Kogan (2001) argue that this is due to poor infrastructure and market development deficiencies.

[12]Richardson (1995) estimates them to be 25%-50%. As noted in Gausch and Kogan (2001) these costs tend to be larger in developing countries due to higher interest rates, for example.

[13]See for example Alessandria et al. (2010), Kropf and Sauré (2014) or Hornok and Koren (2015b).

[14]We formulate the mismeasurement more formally in section 4.1.

3 Model: Gains from Importing with Inventories

The model presented in this section incorporates the inventory premium of importing into an otherwise standard framework of the firm level productivity gains of importing. The goal is to (1) illustrate how additional costs of ordering and inventory holding lead to an overestimated response of revenue based productivity to tariff reductions; and (2) to validate the proxy function to control for the mismeasurement. First, we lay out the model setup. Second, we describe the standard productivity estimation approach within the model. Third, we present the results of the model simulations that demonstrate the mismeasurement and its correction.

3.1 Setup

We consider the partial equilibrium problem of monopolistically competitive firms that produce using labor and materials, with the latter being a composite of a domestic and foreign good. Two elements are critical to capture the mismeasurement described above. First, there is an inventory premium for the foreign good. While the domestic good is sourced flexibly, there is a fixed ordering cost and a delivery lag associated with the purchase of the foreign good. This leads firms to order the foreign good infrequently and in relatively large quantities, accumulating inventories in a $(\underline{s}, \overline{s})$ ordering fashion.[15] Hence, when tariffs on imports fall, firms will switch towards the foreign good and increase their average inventory holdings. Second, firms are heterogeneous in productivity and only the most productive ones will pay the ordering costs to import the foreign good.

Formally, we consider an industry composed by a continuum of firms denoted by i that each period t produce output Y_{it} according to a Cobb-Douglass production technology:

$$Y_{it} = e^{\omega_{it}} L_{it}^{(1-\beta_q)} \left(Q_{D,it}^{(\gamma-1)/\gamma} + \nu Q_{F,it}^{(\gamma-1)/\gamma} \right)^{\beta_q \gamma/(\gamma-1)} \tag{3}$$

where ω is the log of firm's Hicks neutral productivity that evolves according to $\omega_{it} = \rho\omega_{i,t-1} + \varepsilon_{it}$ with the productivity shock being log-normally distributed, $\varepsilon \sim \mathbb{N}\left(\frac{-\sigma_\omega^2}{2}, \sigma_\omega^2\right)$; L is labor and Q_D and Q_F the quantities of domestic (D) and foreign (F) intermediate

[15] The modeling of the inventory problem is similar to that in Alessandria et al. (2010) and Alessandria et al. (2011). The two main differences here are the introduction of a substitute of the storable good and the autocorrelation of the precautionary motive for inventories, which we model as stemming from productivity shocks instead of demand shocks.

goods used in production; β_q is the share of materials in the production function and γ the elasticity of substitution between the domestic and foreign good; and ν is a parameter that is the quality advantage of the foreign good. Note that the composite CES structure and quality advantage of the foreign good will lead to total factor productivity gains when firms expand their usage of foreign inputs.[16]

Firms sell their output at the price P and face a static, constant-elasticity-of-substitution (σ) demand for its product, so that $Y = P^{-\sigma}$. Each period firms make four decisions: The usage of foreign materials (Q_F), the hiring of inelastically supplied labor (L), the purchases of domestic materials ($Z_D > 0$), and whether or not to import material and, if so, how much ($M > 0$). While the first three decisions are static in nature, the last one is dynamic. The decision on whether to import depends on the firm's state variables, namely its inventory holdings of the foreign good (S_F) and its current productivity level. If the firm decides to import, it pays a fixed cost of ordering κ_F in addition to the variable purchase cost and an ad valorem tariff $\tau > 0$ on each unit. Denoting the firm's value of ordering as $V^o(S_F, \omega)$ and of not ordering $V^n(S_F, \omega)$, firm's value at each period is $V(S_F, \omega) = \max[V^o(S_F, \omega), V^n(S_F, \omega)]$. The firm's problem is:

$$\begin{aligned} V^o(S_F, \omega) &= \max_{Q_F, L, Z_D, Z_F} PY - WL - C^z_D Z_D - \tau C^z_F M - \kappa_F + \frac{E\left[V(S'_F, \omega')|\omega\right]}{1+r} \\ V^n(S_F, \omega) &= \max_{Q_F, L, Z_D} PY - WL - C^z_D Z_D + \frac{E\left[V(S'_F, \omega')|\omega\right]}{1+r} \end{aligned} \tag{4}$$

subject to

$$Q_F \leq S_F \tag{5}$$

$$S'_F = \begin{cases} (1 - C^h)[S_F - Q_F + M] & \text{if import} \\ (1 - C^h)[S_F - Q_F] & \text{otherwise} \end{cases} \tag{6}$$

where W, C^z_D, C^z_F denote the wage and the purchase prices of domestic and foreign materials, respectively. The restriction in (5) implies that firms can only use their beginning-of-period inventories for production purposes so that effectively there is a one period delivery lag in the sourcing of the foreign input. This, in addition to the fixed cost of ordering, will lead firms to order large quantities and run down their inventories, which evolve according to (6). The fact that inventories depreciate at the rate C^h implies a

[16]This specification is similar to Halpern et al. (2015). The gains from imperfect substitution across input varieties go back to Hall (1988) and are also modeled in Gopinath and Neiman (2014).

trade-off between ordering more frequently to avoid the holding costs and ordering infrequently to avoid paying κ_F. Hence, while for domestic inputs all purchases are used in the same period ($Z_D = Q_D$), the usage of the foreign input is restricted by their current inventory holdings.

In this setting, after a tariff reduction and the subsequent drop of τC_F^z relative to C_D^z, imports increase both at the extensive (lower importing threshold) and intensive margin (higher relative usage of F). For firms that increase their import intensity, the holding costs due to higher inventory-usage and total ordering costs incurred increase. Critically, firms that hold inventories of the foreign good will price their goods with a constant markup over the marginal cost (of producing another unit) which includes the marginal value of another inventory unit of the foreign input; while, for firms that only source domestically, the price is the (same) constant markup over the marginal cost but the latter only includes the purchase price of the domestic input. Therefore, the heterogeneity in sourcing costs challenges the identification of revenue based productivity measures, given the use of aggregate price index deflators.

3.2 Productivity Estimation

To illustrate how available data confound productivity gains with increased costs from sourcing internationally, we estimate revenue based total factor productivity a_{it} under different versions of the following estimation equation:

$$\tilde{y}_{it} - \omega_{it} = \beta_l l_{it} + \beta_q \tilde{q}_{it} + \beta_q c(m/z_{it}, s/q_{it}) + a_{it} \tag{7}$$

where $c(m/z_{it}, s/q_{it})$ is the control function that proxies the additional ordering and inventory holding costs and is defined as a function of import intensity and inventory-usage. On the left hand side, there are deflated revenues defined as $\tilde{y}_{it} = p_{it} + y_{it} - p_t$, with p_t being the industry's output deflator defined below. Observation of true productivity ω_{it} in the model allows us to overcome the endogeneity between productivity, prices and input choices to focus on the bias in total factor productivity stemming from input cost heterogeneity.[17] On the right hand side, there are the quantity of log labor (l_{it}) and its share (β_l); the deflated material input valued at purchase price ($\tilde{q}_{it} = \log(Z_{D,it} +$

[17] By deducting ω from revenues on the left hand side we are eliminating the heterogeneity in marginal costs driven by productivity.

$\tau Q_{F,it}) - c_t^z)$ with c_t^z being the industry's material input deflator defined below and its share (β_q); the control function of input costs $c(\cdot)$ including the import intensity $m/z_{it} \equiv \log(M/(M+Z_D)$ and the inventory usage $s/q_{it} \equiv \log(S_F/(Q_F+Q_D)$; and, finally, the residual or total factor productivity a_{it}.

We consider three alternative variable definitions to estimate a_{it} using (7). First, to estimate the true total factor productivity gains from imperfect substitution and the quality advantage of F, instead of using $\tilde{y}_{it}$ and $\tilde{q}_{it}$, we use the actual quantity of output y_{it} on the left hand side, and the quantity of input $q_{it} = \log(Q_{D,it}+Q_{F,it})$ on the right hand side. Second, to estimate a_{it} under the standard approach with revenues and nominal inputs, we use $\tilde{y}_{it}$ with p_t defined as the simple average of firm's prices p_{it}, $\tilde{q}_{it}$ with q_t defined as the log of the weighted average input cost, and set $c_{it} = 0$.[18] Third, we estimate (7) as in the previous case but now set the control function $c(\cdot)$ to be a polynomial expansion of m/z_{it} and s/q_{it}.

3.3 Simulations

The model is calibrated under three different combinations of the fixed cost of ordering (κ_F), the depreciation rate C^h, and the persistence and variance of productivity. These parameters determine the firm-level and aggregate import intensity and inventory-usage. We report the range of parameter values used over the 3 simulations in Table 4. In all simulations we calibrate the elasticity of substitution between the foreign and domestic input (γ) to be 2, the material share (β_q) to be 0.6, the quality advantage of the foreign input (ν) to be 0.6; and the delivery lag to be 3 months by calibrating the model quarterly setting $r = 0.06^{1/4}$. To map into the observed annual data, we aggregate all the variables to the annual frequency.

To generate the data set for the regression analysis we simulate 5,000 firms under each of the three calibrations. The model is simulated for a total of 8 years and simulations are initiated at the steady state distribution over (S_F, ω). Firms face 2 unanticipated tariff reductions of -5% after the second year and -10% after the fourth year. We then pool the 3 simulations and estimate (7) to obtain the total factor productivity estimate, $\widehat{a}$, for each of the 3 alternative variable definitions described above. With those in hand

[18] That is $C_t^z = \frac{\sum_i Z_{D,it}+\tau M_{it}}{\sum_i Z_{D,it}+M_{it}}$. Results reported in Table 5 are similar if instead of the simple average of price we use the revenue-weighted average of prices to define the output deflator p_t; or if instead the weighted average of input costs, we used the simple average of these.

we estimate the elasticity of $\widehat{a}$ to the log of tariffs.

The simulation results are reported in Table 5. Column 1 reports the true effect of tariffs on total factor productivity. The elasticity of a_{it} to tariffs is -0.45. The productivity gains are the result of the quality advantage of F and the imperfect substitution between the two inputs. Column 2 reports the elasticity when instead of using quantities of output and inputs, revenues and nominal inputs are deflated as in the data. The elasticity almost triples to -1.26. In the next three columns, all variables are defined as in column 2, but the control function is included in (7). Column 4 includes only the linear term of m/z_{it} and s/q_{it}, column 4 their second order polynomial expansion, and column 5 their third order polynomial expansion. The bias is significantly reduced and becomes negligible in the case of the third order polynomial expansion. We view this result as a validation of the proxy variables for the additional costs from importing.

4 Productivity Estimation

This section describes the empirical implementation of the input cost control function in the estimation of productivity. While the model simulations of the previous section validate the proxy variables of the control function, its empirical implementation entails additional challenges. Besides the need for appropriate deflators, the main concern in the estimation of production functions is the endogeneity between firm's input decisions and its productivity. We build on the insights of the most recent literature. First, we show why the inclusion of a control function in the production function estimation is necessary to overcome biases from heterogeneous inventory holding costs. Second, we describe our baseline productivity identification strategy and estimation approach.

4.1 Unobserved Inventory Holding Cost

We now formally describe how increases in unobserved ordering and holding costs can potentially lead to overestimation of productivity or markups under standard approaches. Consider the log output of firm i at time t to be given by a Cobb-Douglas production function:[19]

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_q q_{it} + a_{it} \tag{8}$$

where a_{it} is the firm's productivity and $\beta_k, \beta_l, \beta_q$ are the output elasticies of capital (k), labor (l) and materials usage (q), respectively.[20] Generally, physical quantities of output and materials are unobserved.[21] To proxy their real value, revenues and nominal materials are typically divided by aggregate or industry-specific price indexes that are generally constructed using surveys of ex-factory gate prices reported by selling firms. Hence, as shown in De Loecker and Goldberg (2014), effectively the following equation is estimated:

$$\tilde{y}_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_q(\tilde{q}_{it} - c^{z*}_{it}) + p^*_{it} + a_{it} \tag{9}$$

where $\tilde{y}_{it} \equiv y_{it} + p^*_{it}$ are deflated revenues, $p^*_{it} = p_{it} - p_{jt}$ is the deviation between the firm's price and its corresponding industry j specific Wholesale Price Index (WPI). Similarly, $\tilde{q}_{it} \equiv q_{it} + c^{z*}_{it}$ are deflated nominal inputs, $c^{z*}_{it} = c^z_{it} - c^z_{jt}$ is the deviation between the firm's input acquisition cost and the industry's average or WPI.[22]

The mismeasurement arising from unobserved inventory holding costs is due to (1) the fact that c^z_{it} excludes inventory holding costs; but (2) firm's arguably pass these costs into their prices. Denoting the firm level material input cost that includes holding costs as c^q_{it}, given standard demand systems, $p_{it} \propto \beta_q c^q_{it}$, i.e. firms price their goods considering the entirety of material input costs, and not just their acquisition cost.[23] We can then rewrite (9) as:[24]

$$\tilde{y}_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_q \tilde{q}_{it} + \beta_q(\underbrace{c^{q*}_{it} - c^{z*}_{it}}_{\equiv c_{it}}) + a_{it} \tag{10}$$

[19]For exposition simplicity we focus on the Cobb-Douglas case. In the robustness checks of the results in section 5.4 we also consider the case of a translog production.

[20]In the implementation of our approach in section 5.4 we estimate the production functions at the 2-digit sectoral level as is common in the literature.

[21]We abstract from biases due to aggregate deflators for capital and labor.

[22]With the exception of Brandt et al. (2017) who calculate industry-specific input price deflators using a disaggregate input-output matrix, most of the literature deflates nominal material inputs using either aggregate or the same industry-specific wholesale price indexes. A more subtle point is that the input cost deflator (c^z_{jt}) does not include ordering costs, while accounting standards typically include these in the valuation of inputs (c^z_{it}).

[23]In any model of inventories, including the one in section 3, firms take into account the costs associated with inventory holdings when pricing their goods. Empirical evidence is scanter due to the lack of data. An exception is Kim (2020) who shows how US firms with initially high inventories were more likely to lower their prices after facing a negative credit supply shock.

[24]Note that if inventory holding costs are negligible, then we would be back to the setting of De Loecker and Goldberg (2014), who discuss when the input and output price bias exactly cancel out.

The term $c_{it} \equiv c^{q*}_{it} - c^{z*}_{it}$ is the omitted variable under standard approaches. Expression (10) illustrates why for a firm that incurs in relatively larger inventory holding costs the omitted variable will lead to an overestimation of its TFPR. This is because for such firms, $c^q_{it} - c^z_{it} > c^q_{jt} - c^z_{jt}$, so that $c_{it} > 0$ and the estimated residual $\beta_q c_{it} + a_{it} > a_{it}$. As argued in section 2, inventory holding costs increase as firms expand their international sourcing. While c_{it} is not observed, the model simulations of section 3 demonstrated that progress can be made by proxying c with a polynomial expansion of the firm's import intensity and inventory-usage. In our baseline we take a second order polynomial expansion that is expressed as follows:

$$c_{it} \approx c(m/z_{it}, s/q_{it}) = \sum_{n=0}^{2} \sum_{n'=0}^{2-n} \delta_{nn'} \times (s/q_{it})^n \times (m/z_{it})^{n'} \tag{11}$$

where s/q_{it} is the inventory-usage of materials used in production; and m/z_{it} are imports over total purchases of materials used in production. Note that both variables are generally available in firm's annual financial statements. We can now substitute (11) into (9) to obtain:

$$\tilde{y}_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_q \tilde{q} + \beta_q c(m/z_{it}, s/q_{it}; \delta) + a_{it} \tag{12}$$

The inclusion of $c(m/z_{it}, s/q_{it}; \delta)$ in equation (12) is the main departure of our approach from the literature on the productivity enhancing effects of trade liberalizations. While De Loecker et al. (2016) use the same approach of introducing a control function of firm-level input price heterogeneity in the production function, their focus is on the complementarity between input and output prices driven by unobserved quality and, therefore, their proxy variables of the firm level deflators are different from ours. To assess the importance of the potential bias from mismeasured input costs, in section 5.4 we will compare our results to those of estimating (12) under $c = 0$. Next, we describe our approach to identifying the parameters in (12) given the endogeneity of input choices and productivity.

4.2 Identification & Estimation

In the identification and estimation of the parameters of (12) we follow the insights of the most recent literature.[25] In particular, we address the endogeneity of firm's input choices and its productivity taking the control function approach established by Olley and Pakes (1996) and Levinsohn and Petrin (2003) with the correction of Ackerberg et al. (2015). This is the prevailing approach in the recent literature on the effects of trade liberalizations on productivity.[26] The main departure is that the inclusion of $c(s/q_{it}, m/z_{it}; \delta)$ in the production function requires additional moment assumptions to identify the parameters $\{\delta\}_{nn'}$ of the control function.

The first step in the control function approach of Olley and Pakes (1996) is to decompose the firm's productivity into two components, the productivity known to the firm when making input decisions, ω_{it}, and an unanticipated productivity shock or measurement error, ε_{it}. Hence, $a_{it} = \omega_{it} + \varepsilon_{it}$. The key insight of the control function approach is that ω_{it} can be proxied using a static input demand equation. In particular, following Olley and Pakes (1996), Levinsohn and Petrin (2003) show that under some assumptions the material equation can be inverted to obtain an expression of the unobserved productivity (by the econometrician). While Levinsohn and Petrin (2003) employ capital and ω_{it} as the sole state variables, Ackerberg et al. (2015)'s criticism requires that labor shall be viewed as an additional state variable to overcome potential collinearity in the labor and material demand,[27] Additionally, in the presence of per shipment and holding costs, we assume that the firm internalizes the complete unit cost of sourcing materials, c^q, when deciding its material demand. Hence, we formulate the material demand equation as:

$$\tilde{q}_{it} = q_t(\omega_{it}, k_{it}, l_{it}, c^q_{it}) \tag{13}$$

Under the assumption that ω_{it} is a scalar and that, conditional on the state variables, material demand is strictly increasing in ω_{it}, the material demand function can then be

[25] Section 5.4 performs numerous robustness checks of the decisions taken here.

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

[27] This requires assuming some adjustment costs in the hiring or firing of labor. See Ackerberg et al. (2015) for an extensive discussion.

inverted to obtain a function $h_t(\cdot)$ to proxy for ω_{it}:[28]

$$\omega_{it} = h_t(k_{it}, l_{it}, \tilde{q}_{it}, c^q_{it}) \tag{14}$$

We include c^q in (14) by introducing its proxy function (11), i.e. $c^q_{it} \approx c(m/z_{it}, s/q_{it})$. Then, substituting (14) into (12) with $a_{it} = \omega_{it} + \varepsilon_{it}$ defines the first stage of our baseline approach:

$$\begin{aligned}\tilde{y}_{it} &= \beta_l l_{it} + \beta_k k_{it} + \beta_q \tilde{q} + \beta_q(c(m/z_{it}, s/q_{it}; \delta)) + h_t(k_{it}, l_{it}, \tilde{q}_{it}, m/z_{it}, s/q_{it}) + \varepsilon_{it} \\ &= \phi_t(k_{it}, l_{it}, \tilde{q}_{it}, m/z_{it}, s/q_{it}) + \varepsilon_{it} \qquad (15)\end{aligned}$$

We proxy $h_t(\cdot)$ by using a polynomial expansion of order 3 in all its arguments. This explains the second equality in (15). Naturally, no parameters can be identified in the first stage and all parameters will be identified in the second stage. The first stage sole serves the purpose of estimating $\widehat{\phi_t} = y_{it} - \hat{\varepsilon}_{it}$, thereby removing the unanticipated productivity shock or measurement error.

Armed with $\widehat{\phi_t}$ from the first stage and an identification assumption on the process of productivity, the second stage estimates the production function after constructing the innovation in the productivity process. By assuming that productivity follows a Markov process, the parameters in (12) can then be identified exploiting timing assumptions previously used in the dynamic panel methods (Arellano and Bond (1991)). In addition to the lagged value of productivity, we follow De Loecker (2013) and include input and output tariffs in the process of productivity. Moreover, we include firms lagged exporter status (D^x_{it}) to accommodate for the potential effects of exporter status on productivity (De Loecker and Warzynski (2012), Atkin et al. (2017)). We denote the process of ω_{it} by $g(\cdot)$:

$$\omega_{it} = g(\omega_{i,t-1}, \tau^{OUT}_{j,t-1}, \tau^{IN}_{j,t-1}, D^x_{i,t-1}) + \zeta_{it} \tag{16}$$

where ζ_{it} is the contemporaneous productivity innovation (known to the firm). The

[28] Gandhi et al. (2017) criticize the control function approach using materials of Levinsohn and Petrin (2003) because conditional on the state variables, lagged materials provide little variation to explain contemporaneous material demand. We argue that in our setting, autocorrelation in input tariffs generates a link between the two. Therefore, we exclude input tariffs and other variables presumably important in the material demand to allow for sufficient explanatory power of lagged materials. In the robustness checks of our results we include various additional variables in $h(\cdot)$ as in De Loecker (2011) and De Loecker et al. (2016).

vector of parameters $\{\beta_k, \beta_l, \beta_q, \{\delta_{nn'}\}\}$ is then identified through the generalized method of moments using the following timing assumptions on the occurrence of ζ_{it} and the input acquisition decisions:

$$\mathbb{E}\Big[\zeta_{it}(\hat{\beta}_x, \{\hat{\delta}_{nn'}\}) \times (k_{it}, l_{it}, \tilde{q}_{i,t-1}, [(s/q_{i,t-1})^n \times (m/z_{i,t-1})^{n'}])'\Big] = 0 \tag{17}$$

While the first three moment conditions on capital, labor and lagged usage of materials are standard in the literature, the moment conditions on $s/q_{i,t-1}$ and $m/z_{i,t-1}$ are particular to the setting of this paper. We choose lagged values of the proxy variables for the following reasons. The s/q will certainly respond to the contemporaneous productivity innovation for the same reasons that contemporaneous material usage (q) might respond and also because firms inventory decisions are likely to respond. For example, a firm that becomes more productive might want to accumulate more inventories during an episode of bonanza. In the case of m/z, as in the model of section 3 in the presence of ordering costs of importing, there is a threshold for importing, making contemporaneous import status endogenous to productivity innovation.[29] We therefore assume that the productivity innovation is only orthogonal to past import intensity.[30]

In practice, the estimation proceeds as follows. First, by making a guess on the parameters $\{\beta_k, \beta_l, \beta_q, \{\delta_{nn'}\}\}$, an estimate of $\hat{\omega}_{it}$ is obtained as $\hat{\omega}_{it} = \widehat{\phi}_{it} - [\hat{\beta}_l l_{it} + \hat{\beta}_k k_{it} + \hat{\beta}_q \tilde{q} + \hat{\beta}_q (\sum_{n=0}^{2} \sum_{n'=0}^{2-n} \hat{\delta}_{nn'} \times (s/q)_{it}^{n} \times (m/z)_{it}^{n'})]$.[31] With the time series of ω_{it} we can then estimate the productivity process $g(\cdot)$. In our baseline approach we define $g(\cdot)$ to be linear in all its variables so that the productivity shock or innovation ζ is obtained from:

$$\hat{\omega}_{it} = \rho_\omega \hat{\omega}_{i,t-1} + \rho_{\tau,1} \tau_{j,t-1}^{OUT} + \rho_{\tau,2} \tau_{j,t-1}^{IN} + \rho_{D^x} D_{i,t-1}^{x} + \zeta_{it} \tag{18}$$

The vector of parameters $\{\beta_k, \beta_l, \beta_q, \{\delta_{nn'}\}\}$ is then estimated by minimizing the sum of squared residuals or the sample analog of the moment conditions specified above.[32] To

[29] See Kasahara and Lapham (2013) and Blaum et al. (2018) for a similar relationship.

[30] This is the same assumption as in Kasahara and Rodrigue (2008). Kasahara and Rodrigue (2008) include import status in the production function to control for the variety effects stemming from a material demand that is aggregated in a CES fashion. Moreover, Kasahara and Rodrigue (2008) include lagged importer status in the productivity process, $g(\cdot)$, to evaluate the (dynamic) learning effects of importing. Our results of section 5 are robust to following their approach and including only the inventory-usage as the proxy variable of c^q, since the effect of m/z is partially captured by the dummy variable.

[31] We set the guess to be the coefficients of the OLS regression of $\widehat{\phi}$ on the respective inputs and variables of c^q.

[32] We use the optimization algorithm provided by Ackerberg et al. (2015) to obtain the vector of

construct valid standard errors, we block-bootstrap[33] over the entire procedure and set $\{\hat{\beta}_k, \hat{\beta}_l, \hat{\beta}_m, \{\hat{\delta}_{nn'}\}\}$ equal to the mean over all the bootstrap repetitions. Finally, the total factor productivity that corrects for the measurement bias in material input costs is:

$$\hat{a}_{it} = \tilde{y}_{it} - [\hat{\beta}_l l_{it} + \hat{\beta}_k k_{it} + \hat{\beta}_q \tilde{q} + \hat{\beta}_q \hat{c}_{it}(m/z_{it}, s/q_{it}; \hat{\delta})] \quad (19)$$

Before we conclude this section, note that $\{\delta_{nn'}\}$ is estimated as $\hat{\delta}_{nn'} = -\hat{\varphi}_{nn'}/\hat{\beta}_q$, where $\varphi_{nn'}$ are the estimated coefficients on the variables of the control function (11) in the second stage of the production function estimation.

5 India's Trade Liberalization

We now apply the approach described above to India's trade liberalization of the 1990s. This episode has been widely used as a case study for the relationship between firm performance and trade liberalizations. In particular, the positive effect of input tariff reductions on firm level productivity has been highlighted in Topalova and Khandelwal (2011), Goldberg et al. (2010) and De Loecker et al. (2016), among others. First, we provide some background to the episode. Second, we describe the data. Third, we show how firms' inventory management responded to the liberalization, suggesting the importance of heterogeneous input costs. Fourth, we study the link between productivity and tariffs when applying the input cost control function approach described in section 4.

5.1 Trade Policy Background

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.[34] Although this period of protectionism was beginning to be reversed in the late 1980s as part of a set of market-oriented reforms, by

parameters that minimizes the sum of squared residuals of the moment conditions in (17).

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

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

1990 India's tariff regime remained one of the most restrictive in Asia.

These reforms were dramatically accelerated after India's balance-of-payments crisis in 1991. The fiscal and current account deficits that India had been accumulating in previous years became unsustainable in 1990 with the collapse of the Soviet Union (India's major trading partner), the Gulf War and the sudden rise in oil prices and a drop in remittances from Indian expatriates. In August 1991, the Government of India requested 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 B.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 B.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 B.1 also illustrates that, in contrast with the gradual nature of typical trade agreements (Khan and Khederlarian (2019)), while tariff cuts were implemented relatively fast, imports responded more gradually and continued to grow even when tariffs had already settled by 1997.

An appealing feature of India's trade reforms that has been emphasized by Topalova and Khandelwal (2011) is that the implementation of tariff reductions was relatively exogenous across industries because of the externally imposed nature of the reforms. A simple inspection of the input tariff levels across the 4-digit industries in Figure 2 reveals that (1) there was a strong reduction from a median input tariff of 0.32 in 1990 to 0.14 in 2001; and (2) the dispersion around the mean was also significantly reduced.[35] In fact, the coefficient of variation of input tariffs fell from 0.32 in 1990 to 0.19 in 2002. This suggests that tariff reductions were imposed uniformly with no or few distinctions across industries. Figure 3 further corroborates this by indicating that tariff changes between 1990 and 2001 were well predicted by the initial tariff level in 1990, with little variation around the average correlation of -0.60.

[35]The findings for reductions in output tariffs levels are similar. However, the level of output tariffs is generally larger, with the median being around 90% in 1990 and 30% in 2001. This illustrates how levels of tariffs are non-random at the beginning of the liberalization episode. Nonetheless, reductions are argued to be relatively random.

5.2 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 data set is used in the most important studies of the effects of tariff reductions on firm performance during this episode. The data set tracks firms over time and spans the entire liberalization period. Firms included in the database are medium to large size and mostly publicly listed. The aggregate of firms included represents around 70% of India's formal industrial activity. One downside of this data set is that because it is not a census of all manufacturing firms it is not well suited for the analysis of firm entry and exit.[36] Importantly to our purpose, besides the standard variables used in the estimation of production functions, the Prowess data set contains information on firms' 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.[37] Our baseline sample includes 32,124 observations of 5,453 firms in 91 4-digit industries. Table 1 provides some 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 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 are computed by multiplying all industry-level output tariffs by India's 1993-94 Input-Output matrix, that is, $\tau_j^{IN} = \sum_{j'} q^v_{j,j'}/q^v_j \tau^{OUT}_{j'}$, where $q^v_{j,j'}/q^v_j$ is the share of industry j' in the inputs used of industry j.

Aggregate wholesale and industry-specific deflators are obtained from the Ministry of Industry. We follow Topalova and Khandelwal (2011) in the choice of deflator and construction of each factor of production. In particular, we use gross fixed assets and

[36]Because firms included in the data set are relatively large, the exit and entry margin might not be as critical in the adjustment to the trade liberalization. We perform robustness checks of the results in section 5.4 using a balanced sample of firms over the entire period.

[37]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. 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.

depreciation and follow Balakrishnan et al. (2000) to construct the time series of capital.[38] Nominal capital is deflated using price index series for "Machinery and Tools". We use salaries and wages for labor and deflate it using the wholesale price index. Output is measured as the value of gross sales deflated with the firm's corresponding industry-specific wholesale price index. In the baseline, materials are deflated using the aggregate wholesale price index as in Topalova and Khandelwal (2011).[39]

5.3 Inventories, Trade and Tariffs

This section provides strong evidence of one of the two sources of potential understatement of firm level material usage during India's trade liberalization of the 1990s. Namely, inventory holdings and the inventory-usage ratio increased strongly in response to increased imports and lower input tariffs. Lack of data on the foreign and domestic prices of comparable inputs does not allow us to directly corroborate the second source of understatement. However, large heterogeneity in importing behavior are suggestive evidence of the potential mismeasurement in the use of aggregate or industry price deflators.

Inventory Premium

We focus on inventories of intermediate goods because 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. The inventory-usage ratio, $s/q \equiv \ln(S^{IG}/Q^{RM})$, are directly 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

[38]This method consists of the Perpetual Inventory Model with a correction for the fact that the value of capital is recorded at historic and not replacement cost. In order to arrive at a measure of the capital stock at its replacement cost for a base year (in the case assumed to be 1997), a revaluation factor is constructed by assuming a constant rate of change of the price of capital and a constant rate of growth of investment throughout the 20 year assumed lifetime of capital stock. This revaluation factor converts the capital in the base year into capital at replacement cost at current prices, which is then deflated using the capital deflator.

[39]In one of the robustness checks we deflate material usage with the firm's corresponding industry-specific price index.

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;

$$\begin{aligned} s/q_{it} =& \alpha^m D^m_{it} + \alpha^{mz} m/z_{it} + \alpha^{IN} \tau^{IN}_{jt} + \alpha^{OUT} \tau^{OUT}_{jt} \\ &+ \alpha^q q^v_{it} + \alpha^i \chi_i + D_{j_2,t} + u_{it} \end{aligned} \tag{20}$$

where j denotes a 4-digit NIC industry, D^m_{it} 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 χ_i is a vector of firm control variables that include age, squared age, and the firm's ownership category. We include 2-digit sector-year fixed effects, $D_{j_2,t}$, to control for differential inventory intensities of across sectors and the business cycle. Finally we control for the firm's size by including the value of the firm's consumption of raw materials, q^v. We are particularly interested in how firms adjust their inventory-usage ratio as they initiate (α^m) or increase (α^{mz}) sourcing their inputs from abroad. In addition, we are interested in how the average inventory-usage ratio of firms responded to lower tariffs (α^{OUT}) and input tariffs (α^{IN}).

The results of estimating (20) are reported in Table 6. 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.[40] Column 2 and 3 confirm the inventory premium for importers. In all specifications, the coefficients on D^m_{it} and m/z_{it} are positive significant and relatively stable. In terms of magnitude, a firm that imports all of its inputs holds on average 2.7 times more month of inputs on hand than a firm that only sources domestically (exp(0.33+0.66)). This relationship establishes that if imports increase due to lower input tariffs, inventory holdings rise.

Columns 4 to 6 introduce tariffs into the estimation. The coefficients on both tariffs are significant and sizeable. While the inventory-usage increases with lower input tariffs, it decreases with output tariffs. The response to input tariffs is especially large. For the median tariff cut throughout the sample period of 20pp, the inventory-usage ratio triples. This effect requires some further explanation. According to the importer inven-

[40] 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 firms' demand expands their inventory-sales ratio declines.

tory 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 or indirect importing.[41] If manufacturers are purchasing foreign inputs through wholesale intermediaries, then the increase in inventory holdings might be observed at both, the intermediary and the manufacturer. The positive coefficient on output tariffs can be viewed as the effect of pro-competitive forces from import competition that lead firms to cut on any dispensable resources.

Table 7 presents the estimates of (20) 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.[42] However, the effect of input tariffs is now only significant when interacted with import intensity. Given an input tariffs drop, the inventory-usage increases with the firm's import intensity. The results of this section provide strong evidence that firm's inventory holdings are closely linked to its international sourcing and the country's trade regime. Trade liberalizations lead firms to increase their purchases of material inputs as well as their inventory holdings.[43]

5.4 Productivity and Tariffs

This section presents the main results of the paper. We now apply the input cost control function approach in the estimation of productivity described in section 4 to India's trade liberalization.[44] Our focus is on comparing the elasticity of productivity to input tariffs when estimated including the control for firm level input costs as in (12) with the elasticity estimate when $c = 0$, the standard approach of the literature. We follow the

[41] Using Belgian firm-to-firm data, Dhyne et al. (2020) show how even though few firms directly import, many more use foreign inputs through domestic channels. Given the sample of relatively large firms this is likely to be the case here, too.

[42] In comparison with the results of Table 6, the coefficient on import status, $\hat{\alpha}^m$ drops significantly. This is because there is not a lot of within firm variation of import status. The coefficient also changes sign when firm size is excluded in column 4. This is the result of the positive correlation between import status and size.

[43] Tables A.1 and A.3 of the Appendix show that the results in Table 6 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.

[44] We report the output elasticities estimated under $c = 0$ and under our baseline approach in Table A.4 of the Appendix.

tradition of Amiti and Konings (2007) and estimate the effect of lagged tariff reductions[45] on within firm level productivity growth using the following estimation equation:

$$\widehat{a}_{it}(c) = \lambda^{IN}\tau^{IN}_{j,t-1} + \lambda^{OUT}\tau^{OUT}_{j,t-1} + D_i + D_t + u_{it} \tag{21}$$

Year fixed effects, D_t, are included to account for aggregate manufacturing trends. The inclusion of firm fixed effects, D_i, implies that the productivity gains are identified using within firm-level variation across time. Hence, the coefficients of interest λ^{IN}, λ^{OUT} should be interpreted as the average firm level productivity growth across all firms in response to changes applied to import tariffs on inputs and output tariffs. We cluster standard errors at the firm level as is standard in the literature.[46]

Baseline Results

Table 8 presents the results of estimating the effect of firm level productivity with and without the input cost control function, c^q, under different specifications of the proxy function of the firm level input cost. Column 1 reports the result of estimating (21) when $c = 0$, the standard approach in the literature. The elasticity is large, with a 1% drop in input tariffs producing a 1.05% increment in productivity. The magnitude is comparable to that estimated in Amiti and Konings (2007) and Brandt et al. (2017), but larger than that in Topalova and Khandelwal (2011). The coefficient on output tariffs is much smaller and positive. Because the introduction of c in the productivity estimation does not change estimates on output tariffs significantly and in a systematic fashion, we neglect it in the discussion that follows.

We now gradually introduce additional variables in the proxy function c^q to assess the relative impact of import intensity and the inventory-usage in changing the elasticity on input tariffs. Column 2 and 3 include both variables alone, respectively. In both cases we obtain a reduction of the coefficient of 18% and 14%, respectively. Column 4 includes both variables and now the elasticity drops significantly by 36% to -0.67. This can be interpreted as the fact that the mismeasurement is most important for firms that do both, increase their imports and hold more inventories. Column 5 reports the estimate

[45] The results we report below are similar if we use contemporaneous tariff levels.

[46] If standard errors are clustered at the level of variation of the tariffs (4-digit NIC industry - year), the coefficients on input tariffs of the baseline and robustness results continue to be significant at least at the 0.05 level.

when specifying c as in our baseline (11), that is, as a polynomial expansion of order 2 in m/z_{it} and s/q_{it}. The reduction is almost identical to the case of the previous column, with the coefficient going to -0.66.[47] In the last column, we regress the difference of both productivity, i.e. $\widehat{a}(c=0) - \widehat{a}(c)$, and regress it on the same right hand side of (21). The estimate of the difference is -0.39 and statistically different.[48] These results indicate that not accounting for the changing input costs significantly overestimates the effect of input tariff reductions on productivity.

Robustness

We now show that this result is robust to several alternative productivity estimation procedures, variable definitions and sample designs.

Specification of the Productivity Proxy function $h(\cdot)$ — In our baseline we specify the productivity proxy function (inverse of the material demand) as in (14). Alternatively, we could have included additional variables that presumably drive the material demand, such as input and output tariffs, importer status and industry and year fixed effects. In Table 9 we show that the reduction in the elasticity of productivity to input tariffs is robust to including those in $h(\cdot)$. Column 1 and 2 report the two estimates ($\ln\widehat{a}(c=0)/\ln\tau^{IN}$ and $\ln\widehat{a}(c)/\ln\tau^{IN}$) including of all of the aforementioned variables. The reduction is now of 41%. The finding is similar if we include tariffs and year and industry fixed effects (column 3 and 4) or only industry and year fixed effects (column 5 and 6). Column 7 and 8 report the result when excluding m/z and s/q from $h(\cdot)$. The reduction is almost identical as in our baseline.

Specification of the Productivity Process $g(\cdot)$ — In our baseline the process of unobserved productivity in (16) includes the linear terms of lagged productivity, lagged tariffs and lagged exporter status (see (18)). Table 10 reports the results under four alternative specifications of $g(\cdot)$. In columns 1 and 2 $g(\cdot)$ includes only lagged productivity; in columns 3 and 4 it includes lagged productivity and lagged tariffs; in columns 5 and 6 it includes lagged productivity and lagged exporter status; in columns 7 and 8 we consider a second order polynomial expansion of the baseline definition. In all cases the gap between

[47]Robustness results reported below are similar if we had used only the linear terms m/z_{it} and s/q_{it} in c. We prefer the polynomial of second order because of the results of model simulation in section 3.

[48]Results remain significant if instead we clustered at 4-digit industry - year level, the level of variation of the regressor.

the elasticity with and without the input cost control function is statistically significant and between 20% and 50%.

Production Function — Table 11 reports robustness to alternative specification of the production function and the factor share of the estimated input cost. In columns 1 and 2 we include power and fuels as an additional input to the production function; while in columns 3 and 4 we specify the production function to be translog.[49] The reductions in the elasticity remain significant and are 22% and 19%, respectively. In our baseline 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, we consider $\delta_i = \gamma_i/(\beta_l + \beta_k + \beta_q)$ 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, in the sense, that not necessarily the allocation of c across factors coincides with the factors shares of input quantities into production. Columns 5 and 6 of Table 11 report the results of the first case and columns 7 and 8 the results of the second case. In both cases, the results are identical to those of the baseline.

Identification of the Labor Coefficient — 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 $\mathbb{E}(\zeta_{it} l_{it}) = 0$. In Table 12 we consider two robustness checks to this assumption. First, in columns 1 and 2 we estimate the production function under the assumption that $\mathbb{E}(\zeta_{it} l_{i,t-1}) = 0$ so that labor adjusts freely. Second, we follow the approach of Levinsohn and Petrin (2003) and estimate the coefficient on labor, β_l, in the first stage. In both cases, the reduction remains significant and is of 35% in the first case and 24% in the second.

Various — Table 12 reports various robustness results in addition to the identification of the labor coefficient. Columns 5 and 6 show the results when deflating material usage with more disaggregate up to 4-digit industry specific price deflators. The bias in almost identical, indicating the importance of the heterogeneity within industries. In columns 7 and 8 we define inventories (S^{IG}) to be the average between the beginning- and end-of-the-year, instead of the end-of-the-year as in our baseline. This also does not affect our

[49] The precise equivalent of (12) under the translog production function is $y_{it} = \beta_l l_{it} + \beta_{ll} l_{it}^2 + \beta_{lq} l_{it} \tilde{q}_{it} + \beta_{lk} l_{it} k_{it} + \beta_k k_{it} + \beta_{kk} k_{it}^2 + \beta_{kq} k_{it} \tilde{q}_{it} + \beta_q \tilde{q}_{it} + \beta_q \tilde{q}_{it}^2 + \beta_{lkq} l_{it} k_{it} \tilde{q}_{it} - (\beta_q + \beta_{lq} + \beta_{kq} + \beta_{lkq}) c_{it} - \beta_{qq} c_{it}^2 + \omega_{it} + \varepsilon_{it}$.

baseline result. Finally, in columns 9 and 10 we control for the changes in the exchange rate interacted with a dummy of the lagged importer status.[50] Again, this does not affect our baseline result.

Sample of Firms and Period — Columns 1 to 6 investigate the importance of firm entry and exit in driving our results. Because our sample period spans over 13 years, there are few firms that are present in each year. Therefore we do not fully restrict the sample to be fully balanced but instead show that making it more restrictive does not change the results. In column 1 and 2 we restrict to include firms that are present in at least 8 years of the sample; in column 3 and 4 we require at least 10 years; and in columns 5 and 6 we include only firms that existed before 1991. In all three cases the difference in the elasticity remains large and slightly above our baseline result. In columns 7 and 8 we restrict the sample period to 1989-1997 and re-estimate the production function for this period. The elasticity in the case of $c = 0$ now drop to -0.60, similar to that in Topalova and Khandelwal (2011) who use this sample period. When including our control function, the elasticity drops to -0.30 but is insignificant. However, using the difference between $\widehat{a}(c = 0) - \widehat{a}(c)$ as the dependent variable in (21) is statistically significant.

Inspection of the Mismeasurement

Here we investigate first the effect of the variables included in the input cost control function on the difference between $\hat{a}(c = 0)$ and $\hat{a}(\hat{c})$; and second which firms and industries are driving the differential response of productivity to input tariffs under the two estimation procedures. Table 14 refers to the first. In columns 1 and 2 the dependent variable is $\hat{a}(c = 0) - \hat{a}(c)$ which we regress on the 5 variables (standarized) in our baseline definition of the input cost control function defined in (11) and the lagged input tariff. Column 1 includes no firm fixed effects while column 2 does. The coefficients on import intensity and its squared term are both positive and significant, suggesting that the bias is larger for firm that import more intensively. The coefficient on inventory-usage is only positive and significant in the case of its squared term.

Column 3 and 4 repeats this exercise using as the dependent variable the estimated input cost deflator, i.e. $\hat{c}$. Hence, the coefficients on can be interpreted as $\{\hat{\delta}_{nn'}\}$ in

[50] India's currency experimented with a continued devaluation throughout the sample period (see Figure B.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.

(11). Importantly, all coefficients except the interaction term are negative and significant, indicating that the estimated input cost deflator decreases with import intensity and inventory-usage. This is consistent with the mismeasurement of real material inputs being systematically understated when imports and the inventory-usage ratio rise as described in section 2. In terms of relative importance in driving the bias, these results indicate that the role of import intensity is slightly larger. Nonetheless, we should bear in mind that importing and inventories are closely related (See section 5.3).

Next, we examine which firms and industries are driving the reduction in the average response of productivity to input tariffs. Here, we focus on the heterogeneity in inventory holding intensity. To do so we drop the firm fixed from (21); interact lagged input tariffs with an indicator variable for the tercile of different distributions of the inventory-usage and set $\hat{a}(c=0)-\hat{a}(c)$ to be the dependent variable. Table 15 reports the results. Column 1 is the baseline average effect with firm fixed effects. When excluding firm fixed effects in column 2 the difference on the coefficient of lagged input tariffs doubles. In columns 3 we classify firms into their tercile of the distribution of s/q within 2-digit industries and year. In column 4 we do the same using a common distribution of all industries each year. The results show that the bias is larger for the second and much larger for the third tercile in the distribution. In fact, the average effect disappears for the lowest tercile in column 4. The fact that difference across terciles is larger in column 4 then in column 3 can be viewed as the fact that some of the variation is explained by industry effects. Therefore, in columns 5 and 6 we classify firms according to their industry and classify industries into terciles of the within 2-digit industries-year distribution of the industry level s/q and that of 1990, respectively. Column 5 shows that effect is much larger for firms in industries belonging to the third tercile. Column 6 shows that the average effect is almost entirely driven by firms belonging to industries in the third tercile of the industry level s/q distribution in 1990.

6 Dynamic Productivity Gains

Our baseline results documented that the average elasticity of productivity to input tariffs is 37% smaller when controlling for firm level input costs. Here we study how the bias behaved over different horizons. As argued in section 2, ordering and inventory holding costs are especially large when firm source internationally. Hence, the mismeasurement of firms' input costs becomes problematic precisely when firms change the source of their supplies. In that sense, it is well known that the trade responds gradually to trade liberalizations.[51] This section shows that the timing of the mismeasurement indeed aligns well with firms' sourcing adjustments.

6.1 Trade & Inventory Dynamics

First, we study the dynamic response of trade and inventories to the tariff reductions. To do so, we use the same firm level balance sheet data on imports of raw materials and estimate the dynamic response employing the local projection method in Jordà (2005). Precisely, we estimate the following equation:

$$\Delta_h y_{it} = \alpha_h^{IN} \Delta_h \tau_{jt}^{IN} + \alpha_h^{OUT} \Delta_h \tau_{jt} + D_{j_2,t} + u_{it} \tag{22}$$

where $\Delta_h y_{it}$ is defined as $y_{i,t+h} - y_{it}$ over the horizons $h \geq 0$. 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. These are the precise variables that we use as proxy variables of the firm-level input cost deflator in the production function estimation of section 4. Note that by taking changes we eliminate firm fixed effects. On the right hand side, we consider accumulated changes in tariffs over the same horizons h.[52] We include 2-digit sector-year fixed effects, $D_{j_2,t}$, to account for sector specific shocks. The inclusion of these fixed effects also allows us to interpret the remaining variation as probably not being captured by industry specific price indexes.[53]

The results of estimating (22) 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 measured imprecisely. Only after 3 years the trade elasticity becomes

[51] 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)). One important difference with these studies and the one here is that the former estimate elasticities using disaggregate product level trade and tariff data from customs data sets. Unfortunately, firm level HS-6 product import data are not available for India over the period studied here.

[52] 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.

[53] Around half of the price indexes are defined at the 2-digit NIC level, the rest is at 3- or 4-digit level. Including 4-digit time fixed effects would eliminate the variation from tariffs.

significant and large. It is around -9 and stays there. These trade elasticities are in the upper bound of the previous estimates.[54] 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 fully 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.

6.2 Productivity Dynamics

Next, we estimate the dynamic elasticity of productivity to input tariffs by considering the same local projection approach as above. Note that this equation is the same as the one used in the cross-sectional analysis (21), but in differences. For each $h = 1, ..., 5$ we estimate;

$$\Delta_h \hat{a}_{it}(c) = \lambda_h^{IN} \Delta_h \tau_{j,t-1}^{IN} + \lambda_h^{OUT} \Delta_h \tau_{j,t-1}^{OUT} + D_t + u_{it} \tag{23}$$

We estimate (23) for $\hat{a}(c = 0)$ and for the baseline $\hat{a}(c)$ defined in (11). The results are illustrated in Figure 6. The two elasticities are nearly indistinguishable in the first two years after the tariff change. This is when trade and inventories have both not yet responded strongly to the trade liberalization, as documented in section 5.3. But after three years, coinciding with the trade elasticity becoming significant and reaching its long run level, the two elasticities begin to diverge. While $\hat{a}(c = 0)$ further decreases, $\hat{a}(c)$ remains constant. After 5 years, when trade and the inventory-usage have settled, the difference between $\hat{a}(c = 0)$ and $\hat{a}(c)$ becomes significant. We conclude that the bias in the dynamic response of productivity to the trade liberalization is consistent with the timing of the trade adjustment, when the input cost mismeasurement unfolds.

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

7 Conclusions

Previous studies of the elasticity of input tariffs on firm level productivity have documented sizeable effects that are difficult to reconcile with firms' cost minimization prior to the trade reform. We revisit this result incorporating the fact that when firms expand their foreign sourcing, there are important changes in their input costs. When input tariffs drop, firms substitute towards lower variable, but higher ordering and inventory holding cost inputs. The use of aggregate price deflators in the estimation of productivity is ill suited to capture the heterogeneity in firms' input costs. We propose to control for firm level input costs that capture price differentials, ordering costs and inventory holding costs by including import intensity and the inventory usage in the estimation of productivity. When we apply the control function, the elasticity of productivity to input tariffs drops by 37% in the case of India's trade liberalization of the 1990s.

These findings illustrate that, without quantity data, it is important to account for the different margins of input cost in the evaluation of the firm performance. While this paper focused on the setting of trade liberalizations, similar mismeasurement might be consequential in the response to other trade shocks. For example, during large devaluations, productivity drops have been accompanied by large responses in inventories (Gopinath and Neiman (2014)). On the other hand, in this paper, we do not take a stand on whether the effects are driven by physical efficiency or markups, but the additional costs of engaging in international trade we refer to might as well be viewed as requiring higher per unit markups. An interesting avenue of future work is to incorporate the ordering and inventory holding costs described here and reassess the documented increase of markups after trade liberalizations (De Loecker et al. (2016), Brandt et al. (2017)).

Finally, this paper emphasizes that trade liberalizations affect multiple margins of the firms' sourcing decisions. Firms not only need to decide from where to source their inputs, but also their frequency and size. 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, especially in developing countries. In that sense, this paper offers a straightforward framework to analyze the productivity implications of such non-tariff trade barriers.

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Table 1: Summary Statistics Industries

	NIC 2-Digit Sector	N	Firms	Industries	Import Intensity$_{it}$	Inventory Usage$_{it}$	Input Tariff$_{1990}$	Input Tariff$_{2001}$
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: The values of import intensity and inventory-usage are averages over the full sample period, 1989-2002. Standard deviations are in the parentheses.

Table 2: Industry Level Import Facts in 1990 and 2001

		1989-1990				2001			
				$M/Z_i \mid M_i > 0$				$M/Z_i \mid M_i > 0$	
	NIC 2-Digit Sector	Firms	$M_i > 0$	Avg	Std. Dev.	Firms	$M_i > 0$	Avg	Std. Dev.
15	Food products and beverages	109	26%	0.06	0.13	394	28%	0.18	0.22
17	Textiles, apparel	133	49%	0.14	0.19	452	48%	0.22	0.24
21	Motor vehicles, trailers	36	86%	0.30	0.19	115	64%	0.26	0.21
24	Electrical machinery and communications	243	75%	0.19	0.17	759	64%	0.25	0.23
25	Fabricated metal products	47	89%	0.23	0.21	227	61%	0.17	0.17
26	Machinery and equipment	56	52%	0.10	0.11	142	47%	0.24	0.18
27	Rubber and plastic	132	73%	0.20	0.18	438	47%	0.25	0.24
29	Chemicals	118	72%	0.12	0.12	257	65%	0.16	0.16
31	Paper and paper products	85	89%	0.19	0.16	215	83%	0.27	0.25
34	Nonmetallic mineral products	85	73%	0.15	0.14	275	63%	0.18	0.20
	Total	1044	67%	0.18	0.17	3274	56%	0.22	0.22

Note: $M_i > 0$ denotes importing firms; $M/Z_i \mid M_i > 0$ denotes import intensity conditional on being an importer.

Table 3: Inventory Premium of Importers

Distribution Import Intensity	Firms	Import Intensity	Inventory Usage Ratio	Material Share
1^{st} Quartile	4,664	2%	0.26	66%
2^{nd} Quartile	4,664	9%	0.31	65%
3^{rd} Quartile	4,664	22%	0.34	65%
4^{th} Quartile	4,663	53%	0.41	67%
$+95^{th}$ Percentile	981	80%	0.49	67%

Note: This Table includes the 18,655 firm-year observations with positive imports of raw materials between 1989-2002 out of the 32,124 of our baseline sample. The inventory-usage is measured as the end of the period inventory level over the annual value of material usage.

Table 4: Calibration Model Simulations

Parameters			Moments	Data (India 2001)	Model
Annual dep rate	C^h	[35%, 40%]	Fraction importing	[28%, 83%]	[29%, 74%]
Ordering cost	κ_F	[0.95, 1.1]	Agg import share	[7%, 27%]	[6%, 16%]
Std dev. prod	σ^2_ω	0.5	Agg monthly S/Q	[0.8, 3.6]	[0.7, 1.9]
Persistence prod	ρ	0.5	CoV of sales	[0.70, 1.15]	[1.3, 4.0]

Note: The common parameters across all simulations are calibrated as: Discount rate $r = 0.06^{1/4}$, elasticity foreign-domestic inputs $\gamma = 2$; foreign quality advantage $\nu = 0.6$; material share $\beta_q = 0.6$.

Table 5: Productivity Elasticity to Tariffs - Model Simulations

Dep Var:	$\widehat{a}_{it}(y_{it}, q_{it}, c = 0)$	$\widehat{a}_{it}(\tilde{y}_{it}, \tilde{q}_{it}, c = 0)$	$\widehat{a}_{it}(\tilde{y}_{it}, \tilde{q}_{it}, c)$		
Input Tariffs	-0.45	-1.26	-0.58	-0.50	-0.46
Inventory-Usage	No	No	Linear	Poly 2	Poly 3
Import Intensity	No	No	Linear	Poly 2	Poly 3

Note: Total factor productivity a_{it} is calculated by using different measurements of output and material inputs and with or without the input cost control function in the estimation of productivity in (7). See section 3.2 for a full description of the variable defintion and estimation procedure.

Table 6: Inventories, Importer Premium and Tariffs

Dep. Var.: Inventory-Usage$_{it}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Used Raw Materials$_{it}$	-0.17***	-0.22***	-0.22***	-0.21***	-0.21***	-0.31***	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	
Importer$_{it}$		0.52***	0.37***	0.36***	0.35***	0.33***	
		(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	
Import Intensity$_{it}$			0.68***	0.66***	0.68***	0.66***	
			(0.06)	(0.06)	(0.06)	(0.06)	
Input Tariffs$_{jt}$				-5.05***	-5.47***	-4.67***	-6.32***
				(0.50)	(0.49)	(0.47)	(0.52)
Output Tariffs$_{jt}$					1.65***	1.51***	2.16***
					(0.21)	(0.19)	(0.22)
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: Estimates in column 6 are from equation (20). Other columns include all variables here indicated. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Heterogeneous Response of Inventories

Dep. Var.: Inventory-Usage$_{it}$	(1)	(2)	(3)	(4)
Used Raw Materials$_{it}$	-0.40***	-0.39***	-0.40***	
	(0.02)	(0.02)	(0.02)	
Importer$_{it}$	0.089***		0.091***	-0.047**
	(0.02)		(0.02)	(0.02)
Import Intensity$_{it}$	0.55***	0.83***	0.76***	0.69***
	(0.08)	(0.11)	(0.11)	(0.12)
Input Tariffs$_{jt}$	0.34	0.57	0.54	0.66
	(0.48)	(0.49)	(0.49)	(0.52)
Import Intensity$_{it}$ × Input Tariffs$_{jt}$		-1.29***	-1.36***	-0.99*
		(0.49)	(0.49)	(0.54)
Output Tariffs$_{jt}$	0.42***	0.43***	0.43***	0.43***
	(0.14)	(0.14)	(0.14)	(0.15)
Year FE	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Observations	27510	27510	27510	27510
Adjusted R^2	0.632	0.632	0.632	0.594

Note: Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Input Costs, Productivity and Tariffs - Baseline

Dep. Var:	$\widehat{a}_{it}(c)$							$\widehat{a}_{it}(c=0)-\widehat{a}_{it}(c)$
c includes	0	m/z_{it}	s/q_{it}	m/z_{it} & s/q_{it}	m/z_{it} & $(m/z_{it})^2$	s/q_{it} & $(s/q_{it})^2$	Baseline poly(2)	Baseline poly(2)
Input Tariff$_{j,t-1}$	-1.05***	-0.86**	-0.90***	-0.67***	-0.67***	-0.64***	-0.66***	-0.39***
	(0.21)	(0.40)	(0.22)	(0.22)	(0.22)	(0.22)	(0.23)	(0.09)
Output Tariff$_{j,t-1}$	0.11**	0.08	0.16***	0.18***	0.08	0.13**	0.15**	-0.03*
	(0.06)	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.02)
Reduction $\ln\widehat{a}/\ln\tau^{IN}$		18%	14%	36%	36%	39%	37%	
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.728	0.813	0.697	0.683	0.747	0.692	0.740	0.873

Note: All results are from estimating (21). $c = 0$ estimates a without including the input cost control function. m/z_{it} stands for import intensity, s/q_{it} for inventory-usage. The second to last column is our baseline definition of c as a second order polynomial expansion of m/z_{it} and s/q_{it}, defined in (11). The last column takes the difference in productivity estimates, $\widehat{a}_{it}(c = 0) - \widehat{a}_{it}(c)$ as the dependent variable. All other columns define c as indicated at the top of the column. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. If standard errors are clustered at the level of variation of the tariffs (4-digit NIC industry - year), all coefficients on input tariffs continue to be significant at least at the 0.05 level.

Table 9: Robustness - Productivity Proxy Function, $h(\cdot)$

	$h(\cdot,\tau^{IN}_{jt},\tau^{OUT}_{jt},D^m_{i,t-1},D_j,D_t)$		$h(\cdot,\tau^{IN}_{jt},\tau^{OUT}_{jt},D_j,D_t)$		$h(\cdot,D_j,D_t)$		$h(k_{it},l_{it},\tilde{q}_{it})$	
Dep. Var.: $\hat{a}_{it}(c)$	$c=0$	c poly(2)	$c=0$	c poly(2)	$c=0$	c poly(2)	$c=0$	c poly(2)
Input Tariffs$_{j,t-1}$	-1.00***	-0.59***	-1.26***	-0.66***	-1.00***	-0.60***	-1.05***	-0.69***
	(0.23)	(0.23)	(0.22)	(0.22)	(0.23)	(0.23)	(0.21)	(0.23)
Output Tariffs$_{j,t-1}$	0.16***	0.10*	0.15***	0.12**	-0.01	0.11**	0.11**	0.12**
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Reduction $\ln\hat{a}/\ln\tau^{IN}$		41%		48%		40%		34%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.694	0.723	0.696	0.750	0.801	0.732	0.728	0.716

Note: All results are from estimating (21) using alternative specifications of the productivity control function, $h(\cdot)$, in the estimation of productivity, defined as (14) in our baseline. $c = 0$ estimates a without including the input cost control function and c poly(2) uses our baseline definition of c as a second order polynomial expansion of m/z_{it} and s/q_{it}, defined in (11). See section 5.4 in the text for the description. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Robustness - Productivity Process, $g(\cdot)$

	$g(\omega_{i,t-1})$		$g(\omega_{i,t-1}, \tau^{OUT}_{j,t-1}, \tau^{IN}_{j,t-1})$		$g(\omega_{i,t-1}, D^x_{it})$		$g(\cdot)$ poly(2)	
Dep. Var.: $\hat{a}_{it}(c)$	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)
Input Tariffs$_{j,t-1}$	-1.04***	-0.49**	-0.97***	-0.64***	-1.05***	-0.52**	-0.97***	-0.76***
	(0.22)	(0.23)	(0.22)	(0.23)	(0.22)	(0.23)	(0.23)	(0.23)
Output Tariffs$_{j,t-1}$	0.12**	0.14**	0.09*	0.13**	0.12**	0.12**	0.13**	0.12**
	(0.05)	(0.06)	(0.05)	(0.06)	(0.05)	(0.06)	(0.05)	(0.06)
Reduction $\ln \hat{a}/\ln \tau^{IN}$		52%		34%		50%		22%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.719	0.746	0.736	0.741	0.709	0.751	0.705	0.752

Note: All results are from estimating (21) using alternative specifications of the autocorrelation process of productivity, $g(\cdot)$, in the estimation of productivity, defined as (16) in our baseline. $c = 0$ estimates a without including the input cost control function and c poly(2) uses our baseline definition of c as a second order polynomial expansion of m/z_{it} and s/q_{it}, defined in (11). See section 5.4 in the text for the description. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Robustness - Production Function

	Incl. Energy		Translog		C to all factors $\beta_k, \beta_l, \beta_q$		C to all factors, flexible	
Dep. Var.: $\hat{a}_{it}(c^q)$	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)
Input Tariffs$_{j,t-1}$	-0.87***	-0.68***	-1.00***	-0.81***	-1.05***	-0.67***	-1.05***	-0.67***
	(0.21)	(0.21)	(0.23)	(0.23)	(0.21)	(0.23)	(0.21)	(0.23)
Output Tariffs$_{j,t-1}$	0.15***	0.12**	0.15**	0.11*	0.11**	0.15**	0.11**	0.14**
	(0.05)	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Reduction $\ln \hat{a}/\ln \tau^{IN}$		22%		19%		37%		37%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	30646	30646	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.763	0.745	0.787	0.822	0.728	0.721	0.728	0.724

Note: All results are from estimating (21). Columns 1-4 use alternative specifications of the production function, y_{it}, in the estimation of productivity, defined as (8) in our baseline. Columns 5-8 use alternative specifications of the production function that distinguishes the mismeasurement from material inputs, defined as (12) in our baseline. $c = 0$ estimates a without including the input cost control function and c poly(2) uses our baseline definition of c as a second order polynomial expansion of m/z_{it} and s/q_{it}, defined in (11). See section 5.4 in the text for the description. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: Robustness - Various

Dep. Var.: $\hat{a}_{it}(c)$	Flexible Labor		Labor 1st Stage (LP)		Industry WPI		Average S^{IG}		Exchange Rate	
	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)
Input Tariffs$_{j,t-1}$	-1.09***	-0.71***	-0.93***	-0.71***	-0.99***	-0.61***	-1.05***	-0.64***	-1.00***	-0.64***
	(0.22)	(0.23)	(0.23)	(0.23)	(0.22)	(0.23)	(0.21)	(0.22)	(0.21)	(0.23)
Output Tariffs$_{j,t-1}$	0.15***	0.15**	0.038	0.11**	0.080	0.12**	0.11**	0.11**	0.11**	0.15**
	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Importer$_{i,t-1}$									-0.21**	-0.061
									(0.09)	(0.10)
Xrate$_t$× Importer$_{i,t-1}$									0.07**	0.02
									(0.03)	(0.03)
Reduction $\ln \hat{a}/\ln \tau^{IN}$		35%		24%		38%		39%		36%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	31304	31304	31304	31304	31304	31304	31304	31304	31304	31304
Adjusted R^2	0.713	0.741	0.725	0.727	0.736	0.757	0.728	0.758	0.728	0.740

Note: All results are from estimating (21). $c = 0$ estimates a without including the input cost control function and c poly(2) uses our baseline definition of c as a second order polynomial expansion of m/z_{it} and s/q_{it}, defined in (11). See section 5.4 in the text for the description. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: Robustness - Sample of Firms and Period

Dep. Var.: $\hat{a}_{it}(c)$	8+ Years in Sample		10+ Years in Sample		Exist Before 1991		1989-1997	
	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)
Input Tariffs$_{j,t-1}$	-1.02***	-0.61**	-0.90***	-0.49*	-1.00***	-0.58**	-0.60***	-0.30
	(0.23)	(0.24)	(0.24)	(0.25)	(0.25)	(0.27)	(0.20)	(0.22)
Output Tariffs$_{j,t-1}$	0.11*	0.15**	0.12*	0.15**	0.12*	0.14**	0.05	-0.01
	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.05)	(0.06)
Reduction $\ln \hat{a}/\ln \tau^{IN}$		40%		46%		42%		50%
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	23599	23599	17493	17493	14314	14314	15913	15913
Adjusted R^2	0.724	0.741	0.738	0.762	0.759	0.783	0.803	0.807

Note: All results are from estimating (21). $c = 0$ estimates a without including the input cost control function and c poly(2) uses our baseline definition of c as a second order polynomial expansion of m/z_{it} and s/q_{it}, defined in (11). See section 5.4 in the text for the description. Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 14: Inspection of the Bias - Variables in c

	$\widehat{a}_{it}(c=0) - \widehat{a}_{it}(c)$		$\widehat{c}$	
Std. Import Intensity$_{it}$	0.072***	0.068***	-0.11***	-0.099***
	(0.02)	(0.01)	(0.02)	(0.01)
Std. Import Intensity$^2_{it}$	0.068***	0.047***	-0.090***	-0.075***
	(0.02)	(0.01)	(0.02)	(0.01)
Std. Inventory-Usage$_{it}$	0.000	0.000	-0.037***	-0.022***
	(0.01)	(0.00)	(0.01)	(0.01)
Std. Inventory-Usage$^2_{it}$	0.028***	0.015***	-0.076***	-0.043***
	(0.01)	(0.00)	(0.01)	(0.01)
Std. Import Intensity$_{it}\times$ Inventory-Usage$_{it}$	-0.001	0.005	0.018**	0.003
	(0.01)	(0.00)	(0.01)	(0.01)
Input Tariff$_{j,t-1}$	-0.79***	-0.43***		
	(0.19)	(0.09)		
Constant	0.080**	0.019	0.086***	0.086***
	(0.03)	(0.01)	(0.00)	(0.00)
Firm FE		✓		✓
Year FE	✓	✓	✓	✓
Observations	31952	31128	31952	31128
Adjusted R^2	0.031	0.879	0.024	0.859

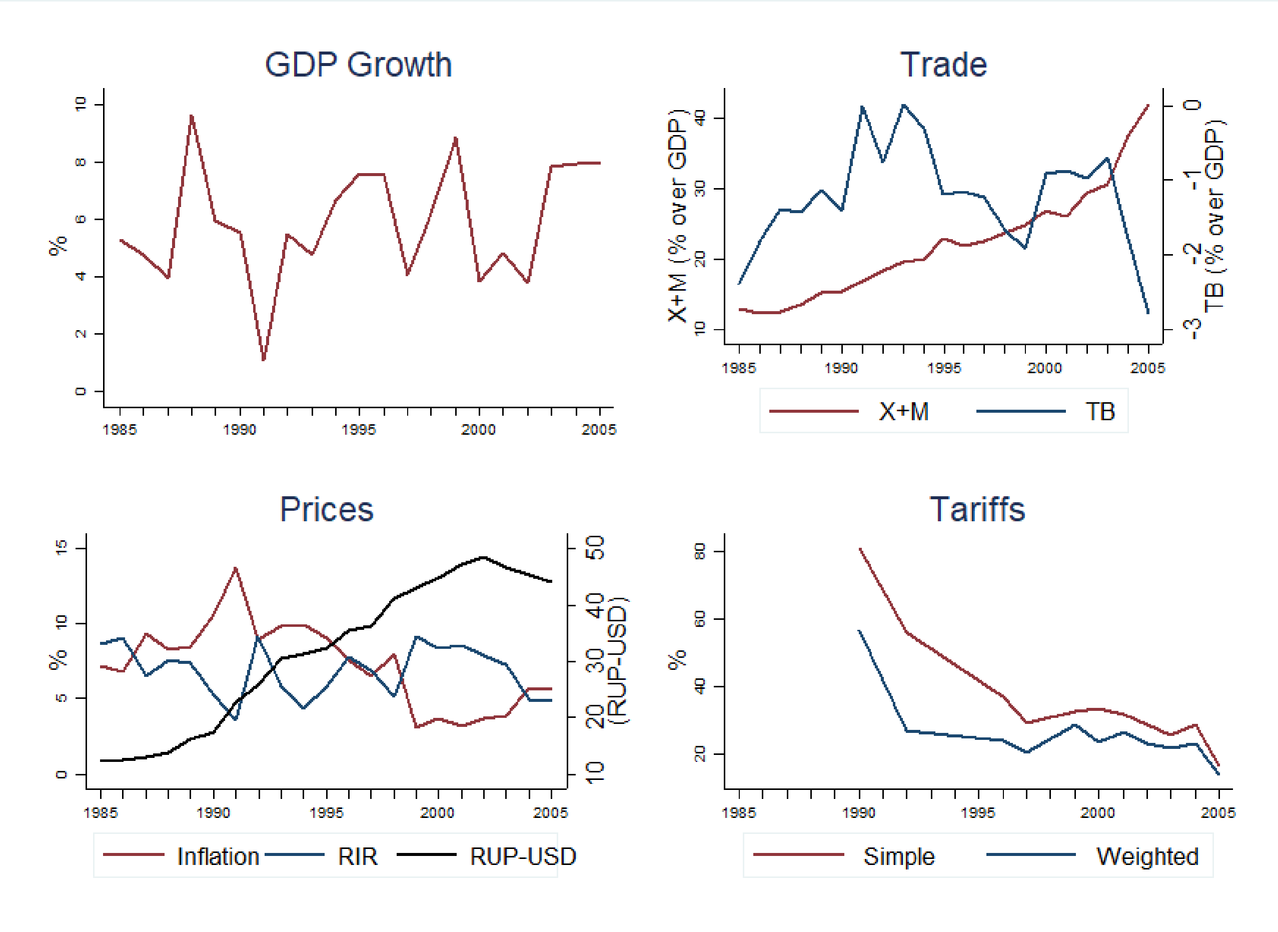
Note: Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15: Inspection of the Bias - Distribution

Dep. Var.: $\widehat{a}_{it}(c=0) - \widehat{a}_{it}(c)$			Firm's s/q Distribution		Industry's s/q Distribution	
	Average		by NIC2-Year	by Year	by NIC-2-Year	in 1990
$\tau^{IN}_{j,t-1}$	-0.39***	-0.70***	-0.37**	-0.18	-0.53***	0.10
	(0.09)	(0.18)	(0.17)	(0.16)	(0.15)	(0.12)
$\mathbf{1}\{i \in 2/3\} \times\tau^{IN}_{j,t-1}$			-0.29***	-0.46***		
			(0.07)	(0.07)		
$\mathbf{1}\{i \in 3/3\} \times\tau^{IN}_{j,t-1}$			-0.70***	-0.97***		
			(0.08)	(0.09)		
$\mathbf{1}\{i \in 2/3\} \times\tau^{IN}_{j,t-1}$					0.027	-0.12*
					(0.05)	(0.06)
$\mathbf{1}\{i \in 3/3\} \times\tau^{IN}_{j,t-1}$					-0.91***	-1.49***
					(0.08)	(0.13)
Firm FE	✓					
Year FE	✓	✓	✓	✓	✓	✓
Observations	31304	32124	32124	32124	32124	31438
Adjusted R^2	0.873	0.031	0.040	0.053	0.071	0.146

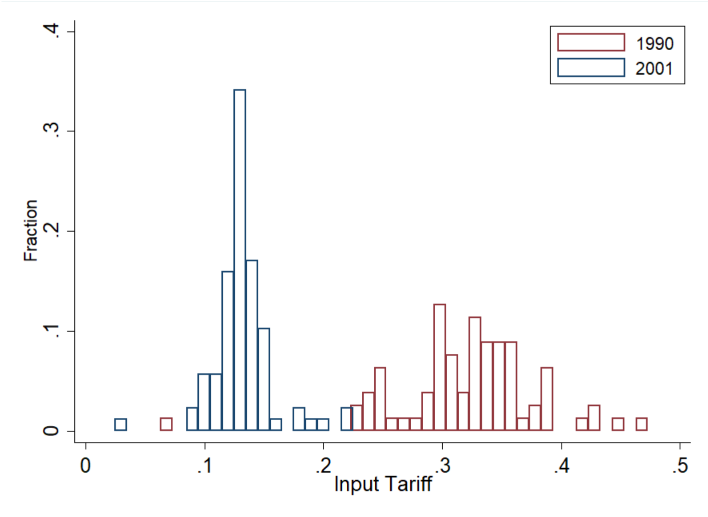
Note: Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1: Macroeconomic Context of India's Trade liberalization



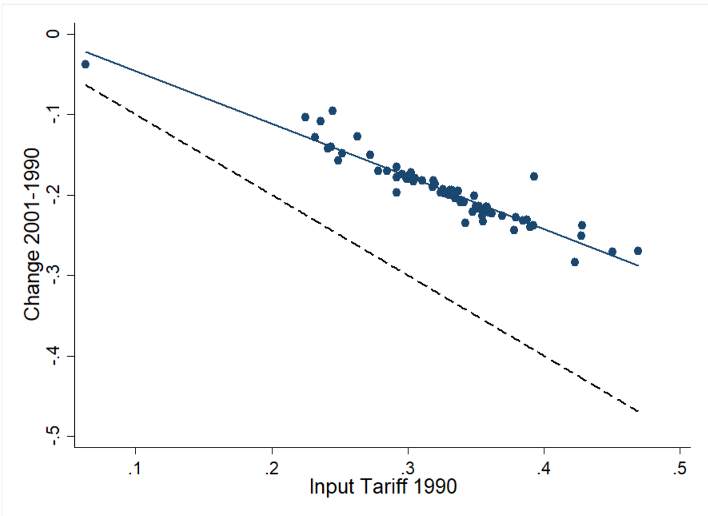
Note: Data is from The World Bank Development Indicators.

Figure 2: Input Tariff Distributions in 2001 and 1990



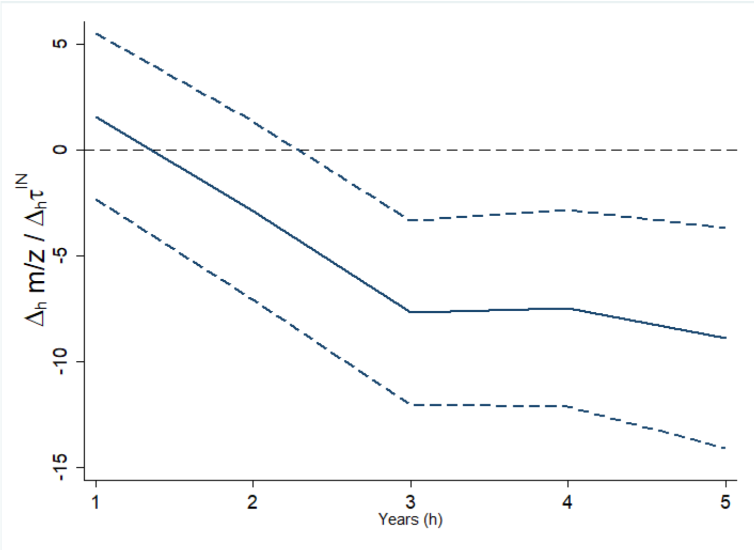
Note: This figure plots the distribution of India's input tariffs at the 4-digit industry level. We can see a marked shifting of the distribution to the left as well as the reduction in the variation in tariffs across industries.

Figure 3: Changes in Input Tariff by Initial Level



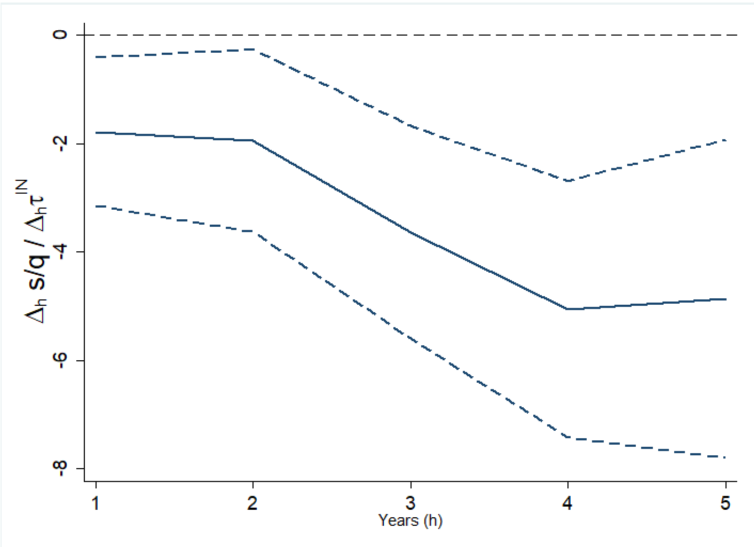
Note: The correlation between the level of input tariffs in 1990 and the change until 2001 is -0.6. The dashed grey line has a slope of -1 for comparison.

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



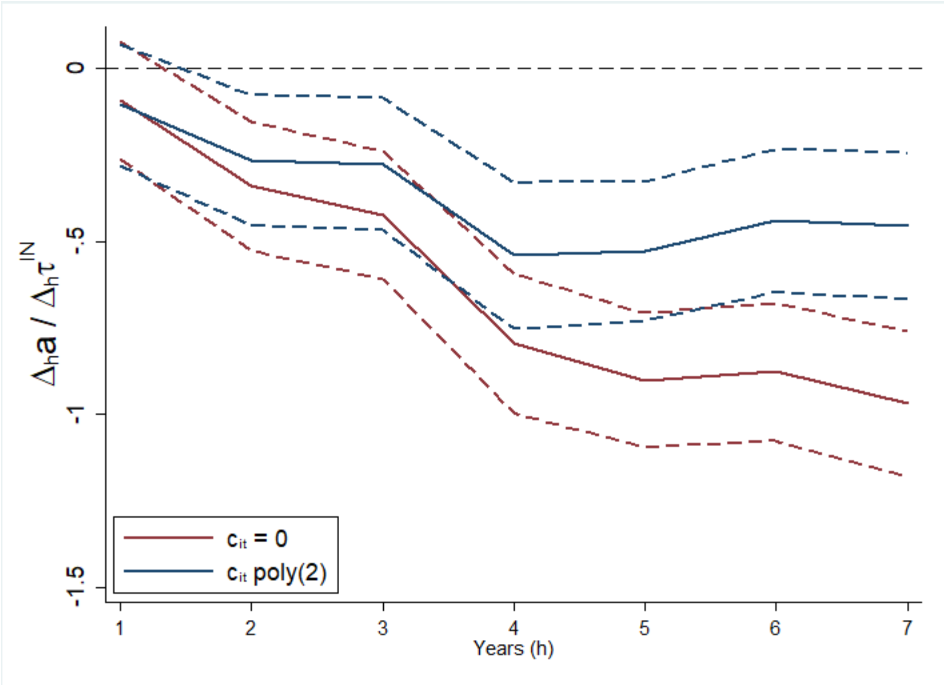
Note: Estimates for each year correspond to the results of estimating (22) for $h = 1, ..., 5$ with $y = m/z_{it}$. The dashed lines are the 68% confidence interval or one standard error.

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



Note: Estimates for each year correspond to the results of estimating (22) for $h = 1, ..., 5$ with $y = s/q_{it}$. 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 $\Delta_h a(c = 0)$ to $\Delta_h \tau^{IN}$ and the blue line is the dynamic response when a is estimated controlling for input costs with the baseline specification of c^q in (11). Estimates for each year correspond to the results of estimating (23) for $h = 1, ..., 7$ with the two productivities. The dashed lines are the 68% confidence interval or one standard error.

Appendix

A Tables

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

Dep. Var.: Inventory-Usage$_{it}$	(1)	(2)	(3)	(4)	(5)	(6)
Used Raw Materials$_{it}$	-0.31***	-0.31***	-0.34***	-0.31***	-0.25***	-0.38***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Importer$_{it}$	0.33***	0.34***	0.51***	0.31***	0.24***	0.35***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)
Import Intensity$_{it}$	0.66***	0.66***	0.65***	0.69***	0.64***	0.68***
	(0.06)	(0.06)	(0.06)	(0.07)	(0.08)	(0.05)
Input Tariffs$_{jt}$	-4.67***	-4.26***	-5.54***	-3.83***	-4.26***	-4.01***
	(0.47)	(0.42)	(0.38)	(0.46)	(0.60)	(0.45)
Output Tariffs$_{jt}$	1.51***	1.39***	0.56***	1.23***	1.21***	1.21***
	(0.19)	(0.17)	(0.17)	(0.20)	(0.24)	(0.18)
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 (20). Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Inventories & Tariffs - Variables

Dep. Var.:	(1) s/q_{it}	(2) s_{it}^{IG}	(3) s_{it}^{IG}/y_{it}	(4) s_{it}^{RM}/q_{it}^{RM}	(5) s/q_{it}	(6) s/q_{it}
Used Raw Materials$_{it}$	-0.31***	0.69***		-0.27***		
	(0.01)	(0.01)		(0.01)		
Sales$_{it}$			-0.24***			-0.22***
			(0.01)			(0.01)
Purchases Raw Materials$_{it}$					-0.27***	
					(0.01)	
Importer$_{it}$	0.33***	0.33***	0.35***	0.38***	0.32***	0.25***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Import Intensity$_{it}$	0.66***	0.66***	0.64***	0.83***	0.66***	0.69***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Input Tariffs$_{jt}$	-4.67***	-4.67***	-2.13***	-4.41***	-4.88***	-6.00***
	(0.47)	(0.47)	(0.45)	(0.55)	(0.47)	(0.51)
Output Tariffs$_{jt}$	1.51***	1.51***	0.67***	1.43***	1.59***	1.99***
	(0.19)	(0.19)	(0.19)	(0.20)	(0.20)	(0.21)
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 (20). Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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

Dep. Var.: Inventory-Usage$_{it}$	(1)	(2)	(3)	(4)
Used Raw Materials$_{it}$	-0.40***	-0.39***	-0.40***	
	(0.02)	(0.02)	(0.02)	
Importer$_{it}$	0.089***		0.091***	-0.047**
	(0.02)		(0.02)	(0.02)
Import Intensity$_{it}$	0.55***	0.83***	0.76***	0.69***
	(0.08)	(0.11)	(0.11)	(0.12)
Input Tariffs$_{jt}$	0.34	0.57	0.54	0.66
	(0.48)	(0.49)	(0.49)	(0.52)
Import Intensity$_{it}$ × Input Tariffs$_{jt}$		-1.29***	-1.36***	-0.99*
		(0.49)	(0.49)	(0.54)
Output Tariffs$_{jt}$	0.42***	0.43***	0.43***	0.43***
	(0.14)	(0.14)	(0.14)	(0.15)
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 (20). Standard errors, clustered at firm level, are reported in the parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

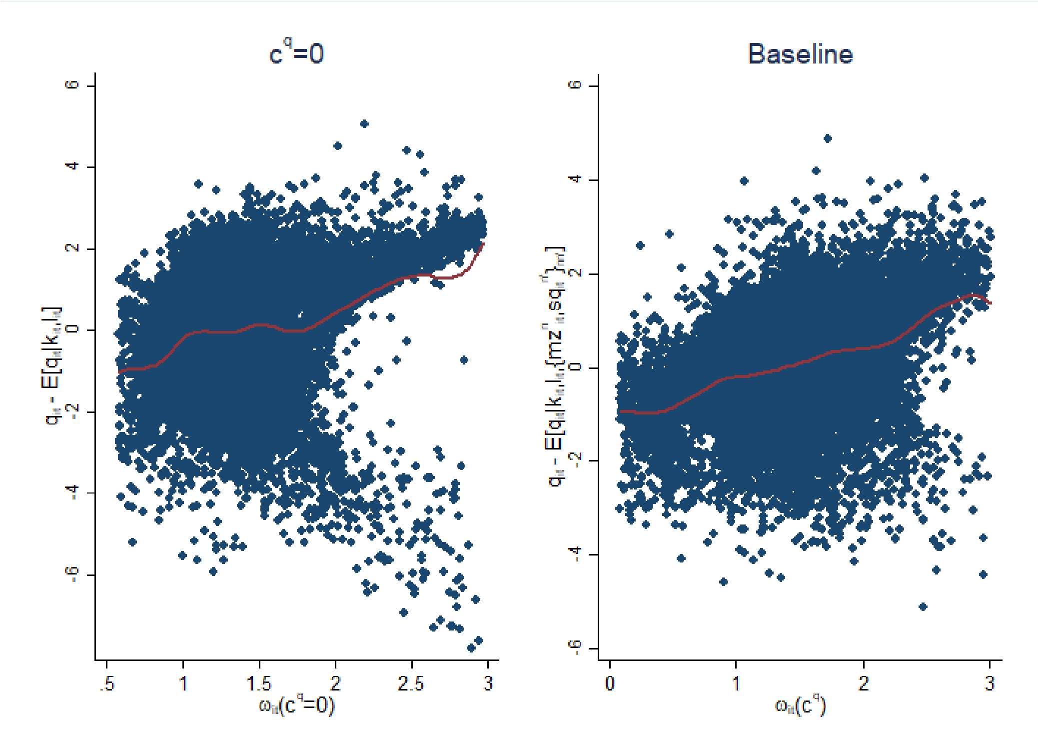
Table A.4: Output Elasticities

	2-Digit NIC Sector	$\hat{\beta}_l$		$\hat{\beta}_k$		$\hat{\beta}_q$	
		$c = 0$	c poly(2)	$c = 0$	c poly(2)	$c = 0$	c poly(2)
15	Food products and beverages	0.48	0.46	0.08	0.02	0.39	0.54
		(0.10)	(0.11)	(0.08)	(0.03)	0.21)	(0.09)
17	Textiles, apparel	0.22	0.16	0.11	0.08	0.70	0.71
		(0.06)	(0.03)	(0.05)	(0.03)	(0.22)	(0.04)
21	Motor vehicles, trailers	0.24	0.28	0.06	0.09	0.84	0.66
		(0.16)	(0.08	0.20)	(0.12)	(0.51)	(0.16)
24	Electrical machinery and communications	0.36	0.31	0.15	0.10	0.56	0.57
		(0.15)	(0.08)	(0.05)	(0.06	0.32)	(0.09)
25	Fabricated metal products	0.26	0.25	0.09	0.08	0.63	0.65
		(0.07)	(0.10)	(0.07)	(0.07)	(0.17)	(0.12)
26	Machinery and equipment	0.35	0.24	0.46	0.43	0.30	0.55
		(0.14)	(0.08)	(0.08)	(0.15	0.22)	(0.15)
27	Rubber and plastic	0.19	0.18	0.09	0.08	0.75	0.72
		(0.02)	(0.04)	(0.02)	(0.02)	(0.03)	(0.06)
29	Chemicals	0.35	0.26	0.09	0.09	0.54	0.65
		(0.06)	(0.09)	(0.03)	(0.04)	(0.07)	(0.08)
31	Paper and paper products	0.24	0.27	0.12	0.10	0.66	0.69
		(0.04)	(0.15)	(0.03)	(0.08)	(0.05)	(0.15)
34	Nonmetallic mineral products	0.23	0.20	0.09	0.11	0.66	0.59
		(0.04)	(0.12)	(0.03)	(0.04)	(0.04)	(0.15)
	Average	0.29	0.26	0.09	0.11	0.60	0.63

Note: Coefficients are calculated as the mean over all bootstrap repetitions. Standard deviations (not standard errors) are reported in the parentheses.

B Figures

Figure B.1: Monotonicity Condition of Material Usage and Productivity



Note: The two graphs plot the estimated anticipated productivity (ω_{it}) and the difference between the log of material usage ($\tilde{q}_{it}$) and the linear prediction of material usage by capital and labor on the left ($\mathbb{E}[\tilde{q}_{it}|k_{it}, l_{it}]$) plus the inventory-usage and import intensity on the right ($\mathbb{E}[q_{it}|k_{it}, l_{it}, \{mz_{it}^{n} \times sq_{it}^{n'}\}_{nn'}]$). The red line is the local polynomial. In both cases, the material usage is on average mostly increasing over the range of productivity. If anything the relationship is stronger including our material cost deflators (right panel). However, the strict monotonicity clearly fails in both cases. The sample is the baseline including the 14 industries. Results for each industry separately can be provided by request.