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Prices, Markups and Trade Reform

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ABSTRACT

This paper examines how prices, markups and marginal costs respond to trade liberalization. We develop a framework to estimate markups from production data with multi-product firms. This approach does not require assumptions on the market structure or demand curves faced by firms, nor assumptions on how firms allocate their inputs across products. We exploit quantity and price information to disentangle markups from quantity-based productivity, and then compute marginal costs by dividing observed prices by the estimated markups. We use India's trade liberalization episode to examine how firms adjust these performance measures. Not surprisingly, we find that trade liberalization lowers factory-gate prices and that output tariff declines have the expected pro-competitive effects. However, the price declines are small relative to the declines in marginal costs, which fall predominantly because of the input tariff liberalization. The reason for this incomplete cost pass-through to prices is that firms offset their reductions in marginal costs by raising markups. Our results demonstrate substantial heterogeneity and variability in markups across firms and time and suggest that producers benefited relative to consumers, at least immediately after the reforms.

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1 Introduction

Trade reforms have the potential to deliver substantial benefits to economies by forcing a more efficient allocation of resources. A large body of theoretical and empirical literature has analyzed the mechanisms behind this process. When trade barriers fall, aggregate productivity rises as less productive firms exit and the remaining firms expand (e.g., Melitz (2003) and Pavcnik (2002)) and take advantage of cheaper or previously unavailable imported inputs (e.g., Goldberg et al. (2010a) and Halpern et al. (2011)). Trade reforms have also been shown to reduce markups (e.g., Levinsohn (1993) and Harrison (1994)). Based on this evidence, we should expect trade reforms to exert downward pressure on firm prices. However, we have little direct evidence on how prices respond to liberalization because they are rarely observed during trade reforms. We fill this gap by developing a unified framework to estimate jointly markups and marginal costs from production data, and examine how prices, and their underlying markup and cost components, adjust during India’s comprehensive trade liberalization.

Our paper makes three main contributions. First, we develop a unified framework to estimate markups and marginal costs of multi-product firms across a broad set of manufacturing industries. Since these measures are unobserved, we must impose some structure on the data. However, our approach does not require assumptions on consumer demand, market structure or the nature of competition common in industrial organization studies. This flexibility is particularly appealing in settings when one wants to infer the full distribution of markups across firms and products over time in different manufacturing sectors. Since prices are observed, we can directly recover marginal costs from the markup estimates. Our approach is quite general and since data containing this level of detail are becoming increasingly available, this methodology is useful to researchers studying other countries and industries. The drawback of this approach is that we are unable to perform counterfactual simulations since we do not explicitly model consumer demand and firm pricing behavior.

The second and key contribution of our study is towards the methodology to estimate production functions. In order to infer markups, the proposed approach requires estimates of production functions. Typically, these estimates have well-known biases if researchers use revenue rather than quantity data. Estimates of “true” productivity (or marginal costs) are confounded by demand shocks and markups, and these biases may be severe (see Foster et al. (2008)). De Loecker (2011) demonstrates that controlling for demand shocks substantially attenuates the productivity increases in response to trade reforms in the European Union textile industry. That paper addresses the bias arising from unobserved output prices (the so-called output price bias) by introducing a CES demand system in the analysis. In contrast to that approach, we address the output price-bias by estimating a quantity-based production function using data that contain the prices and quantities of firms’ products over time. The focus on a quantity-based production function highlights the need for the estimation to address two additional biases that have not received much attention in the literature: the bias stemming from the unobserved allocation of inputs across products within multi-product firms and the bias stemming from unobserved input prices (or the use of (quality)

differentiated inputs) by firms - the so-called input price bias. Our study contributes an approach to address these biases.

Third, existing studies that have analyzed the impact of trade reforms on markups have focused exclusively on the competitive effects from declines in output tariffs (e.g., Levinsohn (1993) and Harrison (1994)). Comprehensive reforms also lower tariffs on imported inputs and previous work, particularly on India, has emphasized this aspect of trade reforms (e.g., see Goldberg et al. (2009)). These two tariff reductions represent distinct shocks to domestic firms. Lower output tariffs increase competition by changing the residual demand that firms face. Conversely, firms benefit from lower costs of production when input tariffs decline. It is important to account for both channels of liberalization to understand the overall impact of trade reforms on prices and markups. In particular, declines in markups depend on the extent to which firms pass these cost savings to consumers, the pass-through being influenced by both the market structure and nature of demand. For example, in models with monopolistic competition and CES demand, markups are constant and so by assumption, pass-through of tariffs on prices is complete. Arkolakis et al. (2012) demonstrate that several of the influential trade models assume constant markups and by doing so, abstract away from the markup channel as a potential source of gains from trade. This is the case in Ricardian models that assume perfect competition, such as Eaton and Kortum (2002), and models with monopolistic competition such as Krugman (1980) and its heterogeneous firm extensions like Melitz (2003). There are models that can account for variable markups by imposing some structure on demand and market structure.¹ While these studies allow for richer patterns of markup adjustment, the empirical results on markups and pass-through ultimately depend on the underlying parametric assumptions imposed on consumer demand and nature of competition. Ideally, we want to understand how trade reforms affect markups without having to rely on explicit parametric assumptions of the demand systems and/or market structures, which themselves may change with trade liberalization.

The structure of our analysis is as follows. We use production data to infer markups by exploiting the optimality of firms' variable input choices. Our approach is based on Hall (1988) and De Loecker and Warzynski (2012), but we extend their methodology to account for multi-product firms and to take advantage of observable price data and physical quantity of products. The key assumption we need to infer markups is that firms minimize cost; then, markups are the deviation between the elasticity of output with respect to a variable input and that input's share of total revenue. We obtain this output elasticity from estimates of production functions across many industries. As noted above, in contrast to many studies, we utilize physical quantity data rather than revenues to estimate the production functions.² This alleviates the concern that the production function estimation is contaminated by prices, yet presents different challenges that we discuss in detail in Section 3. Most importantly, using physical quantity data forces us to conduct the analysis at

¹See Goldberg (1995), Bernard et al. (2003), Goldberg and Verboven (2005), Atkeson and Burstein (2008), Melitz and Ottaviano (2008), Feenstra and Weinstein (2010), Nakamura and Zerom (2010), Edmonds et al. (2011), Goldberg and Hellerstein (2013), Arkolakis et al. (2012), Mayer et al. (2014) and Atkin and Donaldson (2014).

²Foster et al. (2008) also use quantity data in their analysis of production functions, but they focus on a set of homogeneous products.

the product level since without a demand system to aggregate across products, prices and physical quantities are only defined at the product level.

The approach we propose calls for an explicit treatment of multi-product firms. We show how to exploit data on single-product firms along with a sample selection correction to obtain consistent estimates of the production functions. The benefit of using single-product firms at the production function estimation stage is that it does not require assumptions on how firms allocate inputs across products, something we do not observe in our data.³ This approach assumes that the *physical* relationship between inputs and outputs is the same for single- and multi-product firms that manufacture the same product. That is, a single-product firm uses the same technology to produce rickshaws as a multi-product firm that produces rickshaws and cars. While this assumption may appear strong, it is already implicitly employed in all previous work that pools data across single- and multi-product firms (e.g., Olley and Pakes (1996) or Levinsohn and Petrin (2003)). Importantly, the assumption of the same physical production structure does not rule out economies of scope, which can operate through higher (factor-neutral) productivity of multi-product firms, the spreading of fixed costs across multiple products, or lower input prices for multi-product firms (as long as they are not related to input quantities). Once we estimate the production functions from the single-product firms, we show how to back out allocation of inputs across products within a multi-product firm. We obtain the markups for each product manufactured by firms by dividing the output elasticity of materials by the materials share of total revenue.⁴ Finally, we divide prices by the markups to obtain marginal costs.

The estimation of the production function provides plausible results and highlights the importance of addressing the input price bias. We also observe that firms have lower markups and higher marginal costs on products that are farther from their core competency, a finding consistent with recent heterogeneous models of multi-product firms. Foreshadowing the impact of the trade liberalizations, we find that changes in marginal costs are not perfectly reflected in changes in prices because of variable markups (i.e., incomplete pass-through).

Our main results focus on how prices, marginal costs, and markups adjust during India's trade liberalization. As has been discussed extensively in earlier work, the nature of India's reform provides an identification strategy that alleviates the standard endogeneity concerns associated with trade liberalization. Perhaps not surprisingly, we observe price declines during the reform period, but these declines appear modest relative to the size of the reform. On average, prices fall 18 percent despite average output tariff declines of 62 percentage points. Marginal costs, however, decline on average by 35 percent due primarily to input tariff liberalization; this finding is consistent with earlier

³Suppose a firm manufactures three products using raw materials, labor and capital. To our knowledge, no dataset covering manufacturing firms reports information on how much of each input is used for each product. One way around this problem is to assume input proportionality. For example, Foster et al. (2008) allocate inputs based on products' revenue shares. Their approach is valid under perfect competition or the assumption of constant markups across all products produced by a firm. While these assumptions may be appropriate for the particular homogenous good industries they study, we study a broad class of differentiated products where these assumptions may not apply. Moreover, our study aims to estimate markups without imposing such implicit assumptions.

⁴For multi-product firms, we use the estimated input allocations in the markup calculation.

work demonstrating the importance of imported inputs in India's trade reform. The predominant force driving down marginal costs are lower input tariffs reducing the costs of imported inputs, rather than output tariffs reducing X-inefficiencies.⁵ Since our prices decompose exactly into their underlying cost and markup components, we can show that the reason the relatively large decline in marginal costs did not translate to equally large price declines was because markups increased: on average, the trade reform raised relative markups by 17 percent. The results imply that firms offset the cost declines from input tariff reductions by raising markups, and the net effect is that the reform has an attenuated impact on prices. The increases in markups do not imply that the trade reforms caused firms to collude or engage in less competitive behavior. Rather, the results simply show that prices do not respond fully to cost, a finding that has been studied extensively in the exchange rate literature and is consistent with any model with variable markups. Finally, we observe that firms' ability to raise markups even further is mitigated by the pro-competitive impact of output tariff declines, particularly for those firms with very high initial markups. Our analysis is based on data representative of larger firms, so our results are representative of these larger firms.

Our results suggest that the most likely beneficiaries of the trade liberalization in the short-run are domestic Indian firms who benefit from lower production costs while simultaneously raising markups. The short-run gains to consumers appear small, especially considering that we observe factory-gate prices rather than retail prices. However, the additional short-run profits accrued to firms may have spurred innovation in Indian manufacturing, particularly in the introduction of many new products, that benefit consumers in the long run. These new products accounted for about a quarter of overall manufacturing growth (see Goldberg et al. (2010b)). In earlier work, we showed that the new product introductions were concentrated in sectors with disproportionately large input tariff declines that allowed firms access to new, previously unavailable imported materials (see Goldberg et al. (2010a)). In the present paper, we find that firms with larger increases in average markups were more likely to introduce new products, which suggests that higher profits may have financed the development of new products that contributed to long run gains to consumers. A more detailed investigation of this channel is beyond the scope of the present paper.

In addition to the papers discussed earlier, our work is related to a wave of recent papers that focus on productivity in developing countries, such as Bloom and Van Reenen (2007) and Hsieh and Klenow (2009). The low productivity in the developing world is often attributed to lack of competition (see Bloom and Van Reenen (2007) and Bloom and Van Reenen (2010)) or the presence of policy distortions that result in a misallocation of resources across firms (Hsieh and Klenow (2009)). Against this background, it is natural to ask whether there is any evidence that an increase in competition or a removal of distortions reduces production costs. India's reforms are an excellent context to study these questions because of the nature of the reform and the availability of detailed data. Trade protection is a policy distortion that distorts resource allocation. Limited competition benefits some firms relative to others, and the high input tariffs are akin to the capital

⁵The relative importance of input and output tariffs is consistent with Amiti and Konings (2007) and Topalova and Khandelwal (2011) who find that firm-level productivity changes in Indonesia and India, respectively, were predominantly driven by input tariff declines.

distortions examined by Hsieh and Klenow (2009). Our results suggest that the removal of barriers on inputs lowered production costs, so the reforms did indeed deliver gains in the form of lower production costs. However, the overall picture is more nuanced as firms do not appear to pass the entirety of the cost savings to consumers in the form of lower prices. Our findings highlight the importance of jointly studying changes in prices, markups and costs to understand the full distributional consequences of trade liberalization.

The remainder of the paper is organized as follows. In the next section, we provide a brief overview of India’s trade reform and the data used in the analysis. In Section 3 we lay out the general empirical framework that allows us to estimate markups, and marginal costs. Section 3.1 presents the theoretical framework, Section 3.2 presents the empirical methodology to estimate the production function and discusses identification, and Section 3.3 explains the process to recover the allocation of inputs across products for multi-product firms. Section 4 presents the results and Section 5 concludes.

2 Data and Trade Policy Background

We first describe the Indian data since it dictates our empirical methodology. We also describe key elements of India’s trade liberalization that are important for our identification strategy. Given that the Indian trade liberalization has been described in a number of papers (including several by a subset of the present authors), we keep the discussion of the reforms brief.

2.1 Production and Price data

We use the Prowess data that is collected by the Centre for Monitoring the Indian Economy (CMIE). Prowess includes the usual set of variables typically found in firm-level production data, but has important advantages over the Annual Survey of Industries (ASI), India’s manufacturing census. First, unlike the repeated cross section in the ASI, Prowess is a panel that tracks firm performance over time. Second, the data span India’s trade liberalization from 1989-2003. Third, Prowess records detailed product-level information for each firm. This enables us to distinguish between single-product and multi-product firms, and track changes in firm scope over the sample period. Fourth, Prowess collects information on quantity and sales for each reported product, so we can construct the prices of each product a firm manufactures. These advantages make Prowess particularly well-suited for understanding the mechanisms of firm-level adjustments in response to trade liberalizations that are typically hidden in other data sources, and deal with measurement issues that arise in most studies that estimate production functions.

Prowess enables us to track firms’ product mix over time because Indian firms are required by the 1956 Companies Act to disclose product-level information on capacities, production and sales in their annual reports. As discussed extensively in Goldberg et al. (2010b), several features of the database give us confidence in its quality. Product-level information is available for 85 percent of the manufacturing firms, which collectively account for more than 90 percent of Prowess’ manufacturing

output and exports. Since product-level information and overall output are reported in separate modules, we can cross check the consistency of the data. Product-level sales comprise 99 percent of the (independently) reported manufacturing sales. We refer the reader to Appendix C and Goldberg et al. (2010a,b) for a more detailed discussion of the data.

The definition of a product is based on the CMIE’s internal product classification. There are 1,400 products in the sample for estimation.⁶ Table 1 reports basic summary statistics by two-digit NIC (India’s industrial classification system) sector. As a comparison, the U.S. data used by Bernard et al. (2010), contain approximately 1,500 products, defined as five-digit SIC codes across 455 four-digit SIC industries. Thus, our definition of a product is similar to earlier work that has focused on the U.S. Table 2 provides a few examples of products available in our data set. In our terminology, we will distinguish between “sectors” (which correspond to two-digit NIC aggregates), “industries” (which correspond to four-digit NIC aggregates) and “products” (the finest disaggregation we observe); we emphasize that since the “product” definition is available at a highly disaggregated level, unit values are plausibly interpreted as “prices” in our application.

The data also have some disadvantages. Unlike Census data, the CMIE database is not well suited for understanding firm entry and exit. However, Prowess contains mainly medium large Indian firms, so entry and exit is not necessarily an important margin for understanding the process of adjustment to increased openness within this subset of the manufacturing sector.⁷

We complement the production data with tariff rates from 1987 to 2001. The tariff data are reported at the six-digit Harmonized System (HS) level and were compiled by Topalova (2010). We pass the tariff data through India’s input-output matrix for 1993-94 to construct input tariffs. We concord the tariffs to India’s national industrial classification (NIC) schedule developed by Debroy and Santhanam (1993). Formally, input tariffs are defined as $\tau_{it}^{\text{input}} = \sum_k a_{ki} \tau_{kt}^{\text{output}}$, where $\tau_{kt}^{\text{output}}$ is the tariff on industry k at time t , and a_{ki} is the share of industry k in the value of industry i .

2.2 India’s Trade Liberalization

A key advantage of our approach is that we examine the impact of openness by relying on changes in trade costs induced by a large-scale trade liberalization. India’s post-independence development strategy was one of national self-sufficiency and heavy government regulation of the economy. India’s trade regime was amongst the most restrictive in Asia, with high nominal tariffs and non-tariff barriers. In response to a balance-of-payments crisis, India launched a dramatic liberalization of the economy as part of an IMF structural adjustment program in August 1991. An important part of this reform was to abandon the extremely restrictive trade policies it had pursued since independence.

Several features of the trade reform are crucial to our study. First, the external crisis of 1991,

⁶We have fewer products than in Goldberg et al. (2010b) because we require non-missing values for quantities and revenues rather than just a count of products, and drop small sectors that do not have enough observations to implement the methodology.

⁷Firms in Prowess account for 60 to 70 percent of the economic activity in the organized industrial sector and comprise 75 percent of corporate taxes and 95 percent of excise duty collected by the Government of India (CMIE).

which came as a surprise, opened the way for market oriented reforms (Hasan et al. (2007)).⁸ The liberalization of the trade policy was therefore unanticipated by firms in India and not foreseen in their decisions prior to the reform. Moreover, reforms were passed quickly as sort of a “shock therapy” with little debate or analysis to avoid the inevitable political opposition (see Goyal (1996)). Industries with the highest tariffs received the largest tariff cuts implying that both the average and standard deviation of tariffs across industries fell.

While there was significant variation in the tariff changes across industries, Topalova and Khandelwal (2011) show that tariff changes through 1997 were uncorrelated with pre-reform firm and industry characteristics such as productivity, size, output growth during the 1980s and capital intensity. The tariff liberalization does not appear to have been targeted towards specific industries and appears relatively free of usual political economy pressures until 1997 (which coincides with an election that changed political power). We estimate the production function and markups on the full sample, but restrict our analysis of the trade reform to the 1989-1997 period when trade policy did not respond to pre-existing industry- or firm-level trends. We again refer the reader to previous publications that have used this trade reform for a detailed discussion (Topalova and Khandelwal (2011); Topalova (2010); Sivadasan (2009); Goldberg et al. (2010a,b)).

3 Methodology: Recovering Markups and Marginal Costs

This section describes the framework to estimate markups and marginal costs using product- and firm-level production data. Section 3.1 presents the theoretical framework and explicitly states the assumptions required to implement the approach. The computation of markups and marginal costs requires estimates of production function coefficients and information about the allocation of inputs across products. Section 3.2 describes the methodology to estimate the production function and identification. Once the production function parameters are estimated, Section 3.3 explains how we recover the allocation of inputs across products for multi-product firms. In section 3.4 we discuss how we compute markups and marginal costs. Section 3.5 comments on the assumptions required to implement our methodology.

3.1 Theoretical Framework

Consider a production function for a firm f producing a product j at time t :

$$Q_{fjt} = F_{jt}(\mathbf{V}_{fjt}, \mathbf{K}_{fjt})\Omega_{ft} \quad (1)$$

where Q is physical output, \mathbf{V} is a vector of variable inputs that the firm can freely adjust and \mathbf{K} is a vector of fixed inputs that face adjustment costs. The firm’s productivity is denoted Ω_{ft} . A firm

⁸Some commentators (e.g., Panagariya (2008)) noted that once the balance of payments crisis ensued, market-based reforms were inevitable. While the general direction of the reforms may have been anticipated, the precise changes in tariffs were not. Our empirical strategy accounts for this shift in broad anticipation of the reforms, but exploits variation in the sizes of the tariff cuts across industries.

produces a discrete number of products J_{ft} . Collect the inputs into a vector $\mathbf{X} = \{\mathbf{V}, \mathbf{K}\}$. Let W_{fjt}^v denote the price of a variable input v and W_{fjt}^k denote the price of a dynamic input k , with $v = \{1, \dots, V\}$ and $k = \{1, \dots, K\}$.

We begin by characterizing conceptual assumptions necessary to estimate markups and marginal costs for multi-product firms. We refer to these assumptions as conceptual because they are independent of the particular data and setting. Implementing the approach requires additional assumptions dictated by particular features of our data and our focus on India's trade reforms (e.g., functional form and identification assumptions), and we describe these in the next section. The approach requires the following assumptions:

Assumption 1: The production technology is product-specific. Our notation reflects this assumption. The production function $F(\cdot)$ is indexed by product j . This assumption implies that a single-product firm and a multi-product firm that produce the same product have the same production technology, although their productivities Ω_{ft} might differ.

Assumption 2: $F_{jt}(\cdot)$ is continuous and twice differentiable w.r.t. at least one element of \mathbf{V}_{fjt} , and this element of \mathbf{V}_{fjt} is a static (i.e., freely adjustable or variable) input in the production of product j . This assumption restricts the technology so that the firm can adjust its output quantity by changing a particular variable input.⁹ Furthermore, this assumption implies that firm cost minimization involves at least one static first order condition with respect to a variable input of production.

Assumption 3: Hicks-neutral productivity Ω_{ft} is log-additive and firm-specific. This assumption implies that a multi-product firm has the same productivity Ω_{ft} in the production of all its products.¹⁰ This assumption follows the tradition of modeling productivity in the multi-product firm literature in this manner (e.g., Bernard et al. (2011)). For single-product firms, this assumption is of course redundant.

Assumption 4: Expenditures on all variable and fixed inputs are attributable to products. This assumption implies that we can always write the expenditure on input X attributable to product j as $W_{fjt}^X X_{fjt} = \tilde{\rho}_{fjt} \sum_j \left(W_{fjt}^X X_{fjt} \right)$ where W_{fjt}^X is the price for input X with $X \in \mathbf{X}$, and $\tilde{\rho}_{fjt}$ is the share of input expenditures attributable to product j with the restriction that $\sum_j \tilde{\rho}_{fjt} = 1$. Note that $\tilde{\rho}_{fjt}$ is not observed in the data. Assumption 4 allows for economies (or diseconomies) of scope in costs of production; we discuss this distinction below in Section 3.5.

⁹Assumption 2 rules out a fixed proportion technology (e.g., Leontief) in *all* variable inputs. The assumption seems reasonable at the level of aggregation of our data. We observe total labor, capital and intermediate inputs at the firm level, and so there is ample room for firms to substitute, say, workers for capital while keeping output constant.

¹⁰In principle, we can allow for $F_{jt}(\mathbf{V}_{fjt}, \mathbf{K}_{fjt}, \Omega_{fjt})$ to derive a theoretical expression for markups. However, assumption 3 is required to estimate markups for multi-product firms.

Assumption 5: The state variables of the firm are

$$\mathbf{s}_{ft} = \{J_{ft}, \mathbf{K}_{f,j=1,t}, \dots, \mathbf{K}_{f,J_{ft},t}, \Omega_{ft}, \mathbf{G}_f, \mathbf{r}_{fjt}\}$$

The state variables include the number of products produced (J_{ft}), the dynamic inputs for all products (\mathbf{K}_{fjt}), productivity (Ω_{ft}), location information (\mathbf{G}_f), and all payoff relevant serially correlated variables, such as tariffs and the firm's export status (EXP_{ft}), which we collect in \mathbf{r}_{fjt} .

Assumption 6: Firms minimize short-run costs taking output quantity and input prices \mathbf{W}_{fjt} at time t as given. Firms face a vector of variable input prices $W_{fjt}^v = W_t^v(\nu_{fjt}, \mathbf{G}_f, \mathbf{a}_{fjt-1})$, which depends on the quality ν_{fjt} of product j , exogenous factors \mathbf{G}_f (e.g., geography), and firm/product-level actions \mathbf{a}_{fjt-1} taken prior to time t . The latter can capture pre-negotiated input prices through contracts, for example, as long as the contracts do not specify input prices as a function of input quantities. The important assumption is that a firm's variable input price does not depend on input quantity. This assumption rules out static sources of market power in input markets. We discuss this assumption in more detail at the end of this subsection.

We consider the firm's cost minimization problem conditioning on state variables. From assumptions 2 and 6, firms minimize costs with respect to variable inputs. Assumptions 4 and 6 imply that costs are separable across products since a firm's product mix is a dynamic choice and pre-determined at time t when variable inputs are chosen. Hence, we can minimize costs product-by-product for multi-product firms.

The associated Lagrangian function for any product j at time t is:

$$\begin{aligned} \mathcal{L}(\mathbf{V}_{fjt}, \mathbf{K}_{fjt}, \lambda_{fjt}) &= \sum_{v=1}^V W_{fjt}^v V_{fjt}^v + \sum_{k=1}^K W_{fjt}^k K_{fjt}^k \\ &+ \lambda_{fjt} [Q_{fjt} - Q_{fjt}(\mathbf{V}_{fjt}, \mathbf{K}_{fjt}, \Omega_{ft})] \end{aligned} \quad (2)$$

The first order condition for any variable input V^v used on product j , is

$$\frac{\partial \mathcal{L}_{fjt}}{\partial V_{fjt}^v} = W_{fjt}^v - \lambda_{fjt} \frac{\partial Q_{fjt}(\cdot)}{\partial V_{fjt}^v} = 0, \quad (3)$$

where the marginal cost of production at a given level of output is λ_{fjt} since $\frac{\partial \mathcal{L}_{fjt}}{\partial Q_{fjt}} = \lambda_{fjt}$. Rearranging terms and multiplying both sides by $\frac{V_{fjt}^v}{Q_{fjt}}$, provides the following expression:

$$\frac{\partial Q_{fjt}(\cdot)}{\partial V_{fjt}^v} \frac{V_{fjt}^v}{Q_{fjt}} = \frac{1}{\lambda_{fjt}} \frac{W_{fjt}^v V_{fjt}^v}{Q_{fjt}}. \quad (4)$$

The left-hand side of the above equation represents the elasticity of output with respect to variable input V_{fjt}^v (the "output elasticity"). Define the markup μ_{fjt} as $\mu_{fjt} \equiv \frac{P_{fjt}}{\lambda_{fjt}}$.

This cost-minimization condition can be rearranged to express the markup for each product j

as:

$$\mu_{fjt} = \theta_{fjt}^v \left(\frac{P_{fjt} Q_{fjt}}{W_{fjt}^v V_{fjt}^v} \right) = \theta_{fjt}^v (\alpha_{fjt}^v)^{-1} \quad (5)$$

where θ_{fjt}^v denotes the output elasticity on variable input V^v and α_{fjt}^v is the share of expenditure on input V^v allocated to product j in the total sales of product j . This expression forms the basis for our approach to compute markups. To compute the markup, we need the output elasticity on V^v for product j , and the share of the input's expenditure allocated to product j in the total sales of product j , α_{fjt}^v .

The expression for the markup in (5) looks similar to the one derived in De Loecker and Warzynski (2012) with one *crucial* difference: all variables are indexed by j . This seemingly small distinction has significant ramifications for the analysis and precludes us from using the existing approach in De Loecker and Warzynski (2012) to obtain the subcomponents of (5). De Loecker and Warzynski (2012) focus on firm-level markups and implement the conventional production function methodology using revenue data. Because of their focus and data, they do not need to confront the challenges posed by multi-product firms. Specifically, the firm-specific expenditures shares are directly observed in their data and the output elasticity is obtained by estimating a firm-level production function using deflated revenues. In contrast, our framework utilizes product-specific information on quantities and prices. This forces us to conduct the analysis at the product-level because aggregation to the firm-level is not possible without an explicit model of market demand.

The focus on products rather than firms calls for an explicit treatment of multi-product firms. In a multi-product setting, *both* components in equation (5) are unobserved. In contrast to a single-product firm setting, we must estimate the output elasticity separately for each product manufactured by each firm. Furthermore, the product-specific input expenditure shares α_{fjt}^v cannot be calculated from the data because firms do not report the input expenditure allocations $\tilde{\rho}_{fjt}$.¹¹ Our framework, presented below, confronts these two challenges by proposing a methodology for estimating production functions that explicitly deals with multi-product firms and allows one to impute the input expenditure allocations across the products of a multi-product firm.

An additional advantage of focusing on products rather than firms is that once we derive estimates of product-level markups, we can calculate marginal costs using information on product-level prices, which are observed directly in the data:

$$mc_{fjt} = \frac{P_{fjt}}{\mu_{fjt}}. \quad (6)$$

A brief discussion of the assumptions underlying the analysis is in order. Assumptions 1-5 have been explicitly or implicitly assumed throughout the literature estimating production functions.¹² For example, Assumption 1 is made implicitly whenever researchers pool single- and multi-product firm data to estimate production functions, which is almost always the case. The only difference is

¹¹We are unaware of any data set that provides this information for all inputs.

¹²See Akerberg et al. (2006) for an overview of this literature.

that the standard approach uses firm-level deflated sales and expenditure data; this practice does not force the researcher to confront multi-product firms in the data since the analysis is conducted at the firm level. Our framework strictly nests this approach, but since we use price data, and because prices are only defined at the product level (unless one is willing to make additional assumptions on demand that will allow aggregation to the firm level), we must specify physical production functions at the *product* level. We therefore explicitly state the assumptions that underlie the treatment of multi-product firms (Assumptions 1, 3 and 4).

Variants of Assumption 4 have been invoked in the few studies that have addressed the price bias in production function estimation (e.g., Foster et al. (2008) and De Loecker (2011)). Foster et al. (2008) allocate input expenditures according to revenue shares, while De Loecker (2011) allocates them based on the number of products. These variants are considerably stronger than, and are strictly nested within, Assumption 4. Relaxing these input allocation assumptions is one of the methodological contributions of this paper.

The product-by-product short-run cost minimization with respect to variable inputs in (2) follows from Assumptions 2, 4 and 6. Assumption 2 assures the existence of a variable input and is essential for our approach. If all inputs are dynamic, we can still estimate the production function, but we cannot derive markups using the approach we described above. However, the assumption that there is at least one factor of production that the firm can freely adjust over the period of a year (we have annual production data) is both plausible and standard in empirical work.

Our framework allows for economies (or diseconomies) of scope. While physical synergies in production are ruled out by Assumption 1, other forms of economies (or diseconomies) of scope are consistent with Assumptions 1 and 4. Economies of scope can operate through the Hicks-neutral productivity shocks Ω_{ft} , by spreading of the fixed costs associated with dynamic inputs (e.g., capital) across multiple products¹³, and/or through pre-negotiated firm-level contracts for input prices W_{fjt}^v , as long as these input prices do not depend on quantity of inputs. We discuss economies of scope in more detail in Section 3.5.

Finally, an important assumption we maintain throughout the analysis is that input prices do not depend on input quantities (Assumption 6). While restrictive, this assumption is more general than the one employed in almost all production function studies, in which it is assumed that all firms face the same input prices (in contrast, we allow for input prices to differ across firms because of locational differences and/or quality differentiation). If firms have monopsony power in input markets, Assumption 6 will be violated. In this case, one can show that our approach will tend to understate the *level* of markups. However, the approach can still be used to trace and explain *changes* in markups, as long as there are no contemporaneous changes in firms' monopsony power, or, even if there are such changes, as long as changes in firms' monopsony power are uncorrelated with trade policy changes. Appendix D provides a detailed discussion of the conditions under which our approach is valid in the case of monopsony power.¹⁴

¹³That is, $J_{ft}^{-1} \sum_j W_{fjt}^k K_{fjt}$ falls as the number of products increases.

¹⁴In principle, one could make the argument that trade policy might lead to exit of smaller, less productive firms, which might give monopsony power to the remaining firms in the market. In practice, we do not observe firm exit in

In sum, our approach to recover estimates of markups and marginal costs requires estimates of the parameters of the production function $F_{jt}(\cdot)$ at the product level and the input allocations $\tilde{\rho}_{fjt}$ across products within each multi-product firm. Section 3.2 discusses the production function estimation method and the identification strategy we employ in order to obtain the output elasticities for both single- and multi-product firms.

3.2 Estimation

We take logs of equation (1) and allow for log-additive measurement error and/or unanticipated shocks to output (ϵ_{fjt}). Log output is given by: $q_{fjt} = \ln(Q_{fjt} \exp(\epsilon_{fjt}))$. Letting \mathbf{x}_{fjt} be the vector of (log) physical inputs, $\mathbf{x}_{fjt} = \{\mathbf{v}_{fjt}, \mathbf{k}_{fjt}\}$, and ω_{ft} be $\ln(\Omega_{ft})$, we obtain:

$$q_{fjt} = f_{jt}(\mathbf{x}_{fjt}; \boldsymbol{\beta}) + \omega_{ft} + \epsilon_{fjt}. \quad (7)$$

By writing the production function in terms of physical output rather than revenue, we exploit separate information on quantities and prices that are available in the data. The use of physical output in equation (7) eliminates concerns of a price bias that arises if output is constructed by deflating firm revenues by an industry-level price index.¹⁵

Unobserved productivity ω_{ft} potentially leads to well known simultaneity and selection biases. These two biases have been the predominant focus of the production function estimating literature and we follow the insights of Olley and Pakes (1996), Levinsohn and Petrin (2003), and Akerberg et al. (2006) in addressing them. Note that if we theoretically had data on the physical inputs ($\mathbf{v}_{fjt}, \mathbf{k}_{fjt}$) for all products, these existing approaches to estimating production functions would in principle suffice to obtain consistent estimates of the production function coefficients $\boldsymbol{\beta}$.

In reality, no dataset records product-specific inputs, so estimating equation (7) requires dealing with two additional issues: (a) we do not observe input allocations across products in multi-product firms; and (b) we observe industry-wide deflated firm-level input expenditures rather than firm-level input quantities. The latter is not merely a measurement problem because firms typically rely on differentiated inputs to manufacture differentiated products, so physical input and output are not readily comparable across firms.

To understand the implications of these two issues for estimation, let $\tilde{\mathbf{x}}_{ft}$ denote the (observed) vector of deflated input expenditures, deflated by a sector-specific price index. From Assumption 4, product-level input quantities, x_{fjt} , for each input x relate to firm-level expenditures as follows:

$$x_{fjt} = \rho_{fjt} + \tilde{x}_{ft} - w_{fjt}^x \quad (8)$$

where $\rho_{fjt} = \ln \tilde{\rho}_{fjt}$ is the (log) share of firm input expenditures allocated to product j and w_{fjt}^x de-

our sample, so we do not consider such a scenario as a likely explanation for our empirical results. We have explored heterogeneity in our results by identifying business groups in our sample who may have some degree of monopsony power, but we do not find differential effects with respect to the impacts of tariffs on their prices, markups and marginal costs (results available upon request).

¹⁵For a detailed discussion, see De Loecker (2011) and Foster et al. (2008).

notes the deviation of the unobserved (log) firm-product-specific input price from the (log) industry-wide input price index.¹⁶ By substituting this expression for physical inputs into equation (7) and defining \mathbf{w}_{fjt} as the vector of log firm-product-specific input prices, we obtain:¹⁷

$$q_{fjt} = f_{jt}(\tilde{\mathbf{x}}_{fjt}; \boldsymbol{\beta}) + A_t(\rho_{fjt}, \tilde{\mathbf{x}}_{fjt}, \boldsymbol{\beta}) + B_t(\mathbf{w}_{fjt}, \rho_{fjt}, \tilde{\mathbf{x}}_{fjt}, \boldsymbol{\beta}) + \omega_{ft} + \epsilon_{fjt} \quad (9)$$

Compared to equation (7), there are two additional unobserved terms in (9). First, the term $A_t(\cdot)$ that arises from the unobserved product-level input allocations ρ_{fjt} and second, the term $B_t(\cdot)$ that captures unobserved firm-product-specific input prices \mathbf{w}_{fjt} . The exact form of terms $A(\cdot)$ and $B_t(\cdot)$ depends on the functional form of $f(\cdot)$. Both terms depend on the vector of coefficients $\boldsymbol{\beta}$, the input expenditures $\tilde{\mathbf{x}}_{fjt}$, and the unobserved product-level input allocation shares ρ_{fjt} . It is evident from (9) that even after controlling for the unobserved productivity ω_{ft} using standard estimation techniques, the presence of the terms $A(\cdot)$ and $B(\cdot)$ leads to biased production function coefficients since both terms are correlated with the deflated input expenditures $\tilde{\mathbf{x}}_{fjt}$. We refer to the bias arising from the term $A(\cdot)$ as the “input allocation” bias and the bias arising from $B(\cdot)$ as the “input price” bias. The methodology we develop in this subsection addresses these biases.

Neither the “input allocation” nor the “input price” bias have received much attention in the literature on production function estimation to date because the standard practice regresses deflated sales on deflated expenditures at the firm level.¹⁸ De Loecker and Goldberg (2014) discuss the conditions under which these biases interact so as to produce reasonable estimates. But although such estimates may look plausible, this does not imply that the coefficients are consistent estimates of the production function. Failing to correct these biases traces the elasticity of sales with respect to input expenditures, but that elasticity is not useful in our approach because equation (5) requires the elasticity of output quantities with respect to input quantities.

To deal with these biases, we proceed in four steps. Subsection 3.2.1 explains how the estimation addresses the unobserved input allocation bias. Subsection 3.2.2 explains how to address the bias arising from unobserved input prices. Subsection 3.2.3 explains our treatment of the unobserved productivity shock and selection correction. Subsection 3.2.4 explains the moment conditions and further elaborates on identification and estimation. The first two steps are new to the literature on production function estimation; the last two steps build on existing work.

¹⁶We allow for multi-product firms to face different input prices in the production of their various products. Accordingly, the input prices w are indexed by both f and j . This would be the case if a multi-product firm manufactured products of different qualities that relied on inputs of different qualities; see subsection 3.2.2 for a discussion of the relationship between output and input quality.

¹⁷To simplify notation, we will always use \mathbf{w}_{fjt} to denote the deviations of firm-product-specific input prices from industry input price indexes. Similarly, from now on, we will use the term “firm input prices” to denote firm-specific deviations from industry averages.

¹⁸Katayama et al. (2009) is the only study to our knowledge that acknowledges the existence of the input price bias

3.2.1 Unobserved Input Allocations: The Use of Single-Product Firms

Assumptions 1 and 4 imply that a firm f 's technology used to produce product j is independent of the other products manufactured by the firm. This also implies that a multi-product firm uses the same technology as a single-product firm producing the same product.¹⁹ We can therefore rely on single-product firms to estimate the product-level production function in (9), without having to address the unobserved input allocations in multi-product firms. For single-product firms, $A(\cdot) = 0$ because by definition, $\tilde{\rho}_{fjt} = 1$. Since estimation is based on the single-product sample, we omit the product subscript j for the remainder of the exposition of the estimation algorithm.

Equation (9) simplifies to:

$$q_{ft} = f_t(\tilde{\mathbf{x}}_{ft}; \boldsymbol{\beta}) + B_t(\mathbf{w}_{ft}, \tilde{\mathbf{x}}_{ft}, \boldsymbol{\beta}) + \omega_{ft} + \epsilon_{ft}. \quad (10)$$

The approach of using the single-product firm estimates to infer the production function coefficients for all firms raises the concern that the estimates may suffer from a selection bias since we rely only on single-product firms in the estimation. The selection bias arises if firms' choice to add a second product and become multi-product depends on the unobserved firm productivity ω_{ft} and/or firms' input use. Our estimation procedure utilizes the selection correction insights from Olley and Pakes (1996) to address this potential selection bias in two ways. First, we use an unbalanced panel that consists of firms that are single-product *at a given point in time*. At time t , the unbalanced panel includes both firms who always remain single-product firms and those that manufacture a single product at t but add additional products at a later date. This feature of the sample is important since many firms start off as single-product firms and add products during our sample. The use of the unbalanced panel fully addresses the non-random event that a firm becomes a multi-product producer based on unobserved productivity ω_{ft} .²⁰ Second, to account for the possibility that the productivity threshold determining the transition of a firm from single- to multi-product status is correlated with production inputs (in particular, capital), we additionally apply a sample selection correction procedure. We describe the details of the sample selection correction procedure in subsection 3.2.3.²¹

As the notation in (10) indicates, it is in principle possible to estimate separate production functions by year. In practice, our sample is not large enough to allow for time-varying production functions. Therefore, the production function we take to the data is not indexed by t . We consider

¹⁹For example, imagine a single-product firm produces a t-shirt using a particular technology, and another single-product firm produces carpets using a different combination of inputs. We assume that a multi-product firm that manufactures both products will use each technology on its respective product, rather than some third technology.

²⁰This non-random event of adding a second product results in a sample selection issue analogous to the non-random exit of firms discussed in Olley and Pakes (1996). In their context, Olley and Pakes (1996) are concerned about the left tail of the productivity distribution; here, a balanced panel of single-product firms would censor the right tail of the productivity distribution. The use of the unbalanced panel of single-product firms improves upon this selection problem.

²¹Firms in our sample very rarely drop products, so we do not observe the reverse transition from multi- to single-product status. We refer the reader to Goldberg et al. (2010b) for a detailed analysis of product adding and dropping in our data. Unlike Olley and Pakes (1996), we are also not concerned with firm exit. Firm exit is rare in our data because Prowess covers the medium and large firms in India.

three inputs in the (deflated) input expenditure vector $\tilde{\mathbf{x}}_{ft}$: labor (\tilde{l}), intermediate inputs (\tilde{m}) and capital (\tilde{k}). It is clear from equation (10) that we still need to correct for the term related to unobserved firm-specific input price variation, $B(\mathbf{w}_{ft}, \tilde{\mathbf{x}}_{ft}, \boldsymbol{\beta})$ and the unobserved firm-level productivity (ω_{ft}) in order to obtain consistent estimates of the production function parameters $\boldsymbol{\beta}$, and hence the output elasticities that are used to compute markups and marginal costs. We turn to these issues next.

3.2.2 Unobserved Input Prices

The treatment of unobserved input prices is important for two reasons. First, we need to control for them in $B(\mathbf{w}_{ft}, \tilde{\mathbf{x}}_{ft}, \boldsymbol{\beta})$ in equation (10) to recover consistent estimates of the production function parameters $\boldsymbol{\beta}$.²² Second, the input demand equation that is used to control for productivity ω_{ft} naturally depends on input prices (see next subsection 3.2.3).

In our framework (see Assumption 6), firm-specific input price variation can arise through exogenous variation in input prices across local input markets (G_f) and/or variation in input quality (ν_{ft}).²³ This implies that two firms in the same industry that produce in the same location only face the exact same input prices if they buy the exact same input quality. We propose an approach to control for unobserved input price variation across firms using information on observables, particularly (but not exclusively) output prices. The intuition is that output prices contain information about input prices. For example, using data from Colombia that uniquely record price information for both inputs and outputs, Kugler and Verhoogen (2011) document that producers of more expensive products also use more expensive inputs.

We provide a formal model that rationalizes our approach to control for input prices in Appendix A. We show that in a large class of models of consumer demand and imperfect competition used in the Industrial Organization and International Trade literatures, we can proxy for unobserved input prices using a function of the firm’s output price, market share, and product dummies. Here, we sketch the main argument and provide the economic intuition underlying our empirical strategy.

The main premise is that manufacturing high quality products requires high quality inputs, and that high quality inputs are expensive. We further assume *complementarity* in input quality: manufacturing high quality products requires combining high quality materials with high quality labor and capital. This is a common assumption in the literature and underlies ‘O-Ring’-type theories of production (e.g., Kremer (1993), Verhoogen (2008) and Kugler and Verhoogen (2011)). This complementarity implies that the prices of *all* inputs facing a firm can be expressed as a function of a single index of product quality. Appendix A shows that input prices are an increasing function of product quality in this setting. Accordingly, we can control for input price variation across firms using differences in output quality across firms.

²²This subsection considers single-product firms since we use only these firms to estimate the production functions, but all relationships described below also apply to multi-product firms (in which case all relevant variables should be indexed by j).

²³We abstract from lagged action variables \mathbf{a}_{ft-1} , since we do not have rich enough data to measure these (e.g., past contracts specifying input prices independent of quantities).

Given that input prices are an increasing function of input quality, which is an increasing function of output quality, we can use the variables proxying for output quality (i.e., output price, market share and product dummies) to proxy for input prices. Formally, we write input prices w_{ft}^x as a function of output quality ν_{ft} and firm location \mathbf{G}_f .²⁴

$$w_{ft}^x = w_t(\nu_{ft}, \mathbf{G}_f). \quad (11)$$

This expression for input prices generalizes Assumption 6 to all inputs. Under the assumption of input quality complementarity, the unobserved input price variation across all inputs can be captured by a single control function.

Using the results from Appendix A we get:

$$w_{ft}^x = w_t(p_{ft}, \mathbf{ms}_{ft}, \mathbf{D}_f, \mathbf{G}_f, EXP_{ft}), \quad (12)$$

where p_{ft} is the output price of the firm, \mathbf{ms}_{ft} is a vector of market shares, \mathbf{D}_f captures the vector of product dummies, and EXP_{ft} denotes the export status of a firm.²⁵ It is important to note that our approach to control for unobserved input quality does not assume that products are only vertically differentiated. It allows for horizontal differentiation, but horizontal differentiation is costless. In contrast, differentiation along the vertical dimension requires higher quality inputs that have higher input prices. This assumption is common in trade models (e.g., Verhoogen (2008) and Khandelwal (2010)). Moreover, because we model output quality as a flexible function of output prices, market share, and product dummies, the approach does not commit to a particular demand function since it encompasses a large class of demand models used in the literature. For example, in a purely vertical differentiation model, there is a one-to-one mapping between product quality and product prices, so output prices perfectly proxy for quality; in this case, one would not require controls for market share or product characteristics. In the simple logit model, quality is a function of output prices and market shares (see Khandelwal (2010) for a detailed exposition). In more general models, such as the nested logit or random coefficients models, quality is a function of additional variables, such as product characteristics, conditional market shares, etc. While product characteristics usually cannot be observed in firm-level data, product dummies accommodate these more general demand specifications as in Berry (1994). Finally, using output prices as a proxy for quality does not imply that we assume complete pass-through of input to output prices; the degree of pass-through is dictated by the (unspecified) underlying demand and market structure and by the firm behavioral assumptions. Accordingly, the approach is consistent with *any* degree of pass-through between input and output prices.

²⁴We remind the reader that we have defined the input price w_{ft}^x for input x as the deviation of the actual input price from the relevant input price index (i.e., the weighted industry mean), and therefore $w_{ft}^x = 0$ for the producer paying exactly the (weighted) average \bar{w}_t^x . Formally $w_{ft}^x = w_{ft}^{x*} - \bar{w}_t^x$, where $*$ denotes the actual input price faced by firm f for its product j at time t .

²⁵We include the export status of a firm to allow for market demand conditions to differ from the domestic market. In our data we do not observe the product-destination trade flows for each firm. Otherwise this information could be included here.

The final step is to substitute the input price control function from (12) into the expression for w_{ft} in $B(\mathbf{w}_{ft}, \tilde{\mathbf{x}}_{ft}, \boldsymbol{\beta})$ in equation (10), we get:

$$B(\mathbf{w}_{ft}, \tilde{\mathbf{x}}_{ft}, \boldsymbol{\beta}) = B((p_{ft}, \mathbf{ms}_{ft}, \mathbf{D}_f, \mathbf{G}_f, EXP_{ft}) \times \tilde{\mathbf{x}}_{ft}^c; \boldsymbol{\beta}, \boldsymbol{\delta}) \quad (13)$$

A few words on notation are in order. The function $B(\cdot)$ is different from the input price function $w(\cdot)$ as described in equation (12). The function $B(\cdot)$ depends on the input prices w_{ft} and will therefore take as arguments the elements of $w(\cdot)$. However, it also contains interactions of the input prices (w_{ft}) with the vector of deflated input expenditures $\tilde{\mathbf{x}}_{ft}$. We use the notation $\tilde{\mathbf{x}}_{ft}^c$ to highlight the fact that the input price term $w(\cdot)$ enters also by itself, without being interacted with the input expenditures $\tilde{\mathbf{x}}_{ft}$, and thus we include a constant term: $\tilde{\mathbf{x}}_{ft}^c = \{1, \tilde{\mathbf{x}}_{ft}\}$. The notation highlights that the use of the input price control function requires us to estimate an additional parameter vector $\boldsymbol{\delta}$ alongside the production function parameters $\boldsymbol{\beta}$.

3.2.3 Unobserved Productivity and Selection Correction

The only remaining source of potential bias in (10) is the unobserved firm-level productivity ω_{ft} . Firms' choices of inputs and number of products are in part affected by this (to the econometrician) unobserved productivity, potentially leading to simultaneity and selection bias in estimation. We control for unobserved productivity ω_{ft} in (10) using a control function based on a static input demand equation. In addition, we implement a selection correction for the potential selection bias stemming from the use of single-product firms in the estimation procedure, discussed in subsection 3.2.1. We describe both procedures here.

We follow the literature on production function estimation, as initiated by Olley and Pakes (1996) and extended by Levinsohn and Petrin (2003), and control for unobserved productivity ω_{ft} in (10) using a static input demand equation. The materials demand function in our setting will take as arguments all state variables of the firm noted in Assumption 5, including productivity, and all additional variables that affect a firm's demand for materials. These include firm location (\mathbf{G}_f), output prices (p_{ft}), product dummies (\mathbf{D}_f), market shares (\mathbf{ms}_{ft}), input prices ($w_t(\cdot)$), the export status of a firm (EXP_{ft}) and the input (τ_{it}^{input}) and output tariffs ($\tau_{it}^{\text{output}}$) that the firm faces on the product it produces. From (12) input prices are themselves a function of output price, market share and product dummies²⁶, so materials demand is given by:

$$\tilde{m}_{ft} = m_t(\omega_{ft}, \tilde{k}_{ft}, \tilde{l}_{ft}, \mathbf{G}_f, p_{ft}, \mathbf{D}_f, \mathbf{ms}_{ft}, EXP_{ft}, \tau_{it}^{\text{input}}, \tau_{it}^{\text{output}}). \quad (14)$$

We collect all the variables determining intermediate input demand, except for the input expenditures and unobserved productivity, in $\mathbf{z}_{ft} = \{\mathbf{G}_f, p_{ft}, \mathbf{D}_f, \mathbf{ms}_{ft}, EXP_{ft}, \tau_{it}^{\text{input}}, \tau_{it}^{\text{output}}\}$. The number of products (J_{ft}) is omitted from the set of state variables since the sample we use for

²⁶Note that we consider (log) intermediate input expenditure, defined as the sum (in logs) of the intermediate input demand and the input price. This implies that the materials expenditure function $\tilde{m}_t(\cdot)$ takes as arguments the same variables as the physical materials demand function $m_t(\cdot)$: $m_{ft} = m_t(w_{ft}^m, \cdot)$ and $\tilde{m}_{ft} = m_t(\cdot) + w_{ft}^m = \tilde{m}_t(w_{ft}^m, \cdot)$, where w_{ft}^m is the input price.

estimation contains only single-product firms. The subscript i on the tariff variables denotes an industry to indicate that tariffs vary at a higher level of aggregation than products. Inverting (14) gives our control function for productivity:²⁷

$$\omega_{ft} = h_t(\tilde{\mathbf{x}}_{ft}, \mathbf{z}_{ft}). \quad (15)$$

Our approach also encompasses a selection correction to address the potential selection bias stemming from the use of only single-product firms in the estimation discussed in subsection 3.2.1. The selection bias arises if a firm’s choice to add a second product and become a multi-product firm depends on unobserved firm productivity ω_{ft} in equation (10) and/or the firm’s input use. Following Olley and Pakes (1996), who address the selection bias due to plant exit in their setting, we model the probability that a firm continues to produce one product non-parametrically as a function of the firm’s productivity forecast and all state variables \mathbf{s}_{ft} .

The underlying model behind our sample selection correction is one where the number of products manufactured by firms increases with productivity. Several multi-product firm models generate this correlation, with Mayer et al. (2014) matching our setup most closely. In that model, the number of products a firm produces is an increasing step function of the firms’ productivity. Firms have a productivity draw which determines their core product. Conditional on entry, the firm produces this core product and incurs an increasingly higher marginal cost of production for each additional product it manufactures. This structure generates a competence ladder that is characterized by a set of cutoff points, each associated with the introduction of an additional product.²⁸

The cutoff point relevant to our sample selection procedure is the one associated with the introduction of a *second* product. We denote this cutoff by $\bar{\omega}_{ft}$. Firms with productivity that exceeds $\bar{\omega}_{ft}$ are multi-product firms that produce two (or more) products while firms below $\bar{\omega}_{ft}$ remain single-product producers and are included in the estimation sample.

If the threshold $\bar{\omega}_{ft}$ is independent of the right-hand side variables in the production function in equation (10), there is no selection bias and we obtain consistent estimates of production function coefficients (as long as we use the unbalanced panel of single product firms, i.e., the sample of firms that are single-product at any point in time, but may become multi-product in the future). A bias arises when the threshold is a function of capital and/or labor. For example, it is possible that even conditional on productivity, a firm with more capital finds it easier to finance the introduction of

²⁷As discussed in Olley and Pakes (1996), the proxy approach does not require knowledge of the market structure for the input markets; it simply states that input demand depends on the firm’s state variables and variables affecting input demand. By using a static control to proxy for productivity, we do not have to revisit the underlying dynamic model and prove invertibility when modifying Olley and Pakes (1996) for our setting to include additional state variables (e.g., tariffs). See De Loecker (2011) and Akerberg et al. (2006) for an extensive discussion. A recent literature has discussed alternative estimation procedures that do not rely on this inversion. In the absence of shocks to output ϵ_{ft} , this can be accomplished without any extra assumptions. However, these shocks end up being important, especially when estimating physical output production functions where they absorb unit fixed effects.

²⁸Alternative models such as Bernard et al. (2010) introduce firm-product-specific demand shocks that generate product switching (e.g., product addition and dropping) in each period. We avoid this additional complexity since product dropping is not a prominent feature of our data (Goldberg et al. (2010b)). Moreover, in Section 4 we find strong support that firms’ marginal costs are lower on their core competent products (products that have higher sales shares).

an additional product; or, a firm that employs more workers may have an easier time expanding into new product lines. In these cases, firms with more capital and/or labor are less likely to be single-product firms, even conditional on productivity, and this generates a negative bias in the capital and labor coefficients.

To address the selection bias, we allow the threshold $\bar{\omega}_{ft}$ to be a function of the state variables \mathbf{s}_{ft} and the firm's information set at time \mathcal{I}_{t-1} (we assume the decision to add a product is made in the previous period). The selection rule requires that the firm make its decision to add a product based on a forecast of these variables in the future. Define an indicator function χ_{ft} to be equal to 1 if the firm remains single-product (SP) and 0 otherwise. The selection rule can be written as:

$$\Pr(\chi_{ft} = 1) = \Pr[\omega_{ft} \leq \bar{\omega}_{ft}(\mathbf{s}_{ft}) | \bar{\omega}_{ft}(\mathbf{s}_{ft}), \omega_{ft-1}] \quad (16)$$

$$\begin{aligned} &= \kappa_{t-1}(\bar{\omega}_{ft}(\mathbf{s}_{ft}), \omega_{ft-1}) \\ &= \kappa_{t-1}(\tilde{\mathbf{x}}_{ft-1}, i_{ft-1}, \mathbf{z}_{ft-1}) \\ &\equiv SP_{ft} \end{aligned} \quad (17)$$

Note that the variables included in \mathbf{z} are a subset of the state variables that appear in \mathbf{s} (the latter include the dynamic inputs that are part of $\tilde{\mathbf{x}}$). We use the fact that the threshold at t is predicted using the firm's state variables at $t-1$, the accumulation equation for capital, and $\omega_{ft} = h_t(\tilde{\mathbf{x}}_{ft}, \mathbf{z}_{ft})$ from equation (15) to arrive at the last equation.²⁹ As in Olley and Pakes (1996), we have two different indexes of firm heterogeneity, the productivity and the productivity cutoff point. Note that $SP_{ft} = \kappa_{t-1}(\omega_{ft-1}, \bar{\omega}_{ft})$ and therefore $\bar{\omega}_{ft} = \kappa_{t-1}^{-1}(\omega_{ft-1}, SP_{ft})$.

3.2.4 Productivity Process, Moment Conditions, and Identification

To estimate the parameter vectors β and δ , we follow Akerberg et al. (2006) and form moments based on the innovation in the productivity shock ξ_{ft} . We consider the following law of motion for productivity:

$$\omega_{ft} = g(\omega_{ft-1}, \tau_{it-1}^{\text{output}}, \tau_{it-1}^{\text{input}}, EXP_{ft-1}, SP_{ft}) + \xi_{ft}. \quad (18)$$

The tariff variables and export dummy are included in the law of motion to account for the fact that trade policy and exporting *may* affect productivity. As De Loecker (2013) shows, if one expects these variables to have an effect on productivity, then the theoretically consistent treatment is to include them directly in the law of motion. Otherwise, their omission may lead to biased production function coefficients. Of course, the fact that these variables are allowed to have an impact on productivity does not mean that they will in fact have an effect. It is entirely possible that the empirical estimates indicate that the trade variables have no effect on productivity. Hence, including trade variables in the law of motion does not assume a particular result regarding the

²⁹The accumulation equation for capital is: $K_{ft} = (1 - \delta)K_{ft-1} + I_{ft-1}$, where δ is the depreciation rate of capital. This specification takes into account that firms hire and/or fire workers based on their labor force at time $t-1$ and their forecast of future demand and costs captured by \mathbf{z} and ω . So all variables entering the nonparametric function $\kappa_{t-1}(\cdot)$ help predict the firm's employment at time t .

effects of tariffs or exporting on productivity.

Trade related variables are expected to affect productivity both through exporting and importing channels. For example, a large literature suggests “learning by exporting” effects. Likewise, trade economists have postulated that a reduction in output tariffs that exposes firms to intensified import competition may lead to reduction in X-inefficiencies and adoption of better management practices. In this case, output tariff reductions may lead to productivity improvements. On the input side, input tariff reductions may lead to the import of new, previously unavailable intermediate products, which will lead to increases in productivity (see Halpern et al. (2011) for a formalization of this argument). We emphasize that the specification we adopt for the law of motion for productivity in equation (18) *allows* for these mechanisms to generate productivity improvements, but by no means assumes the result. The inclusion of the probability that a firm remains single-product in the next period SP_{ft} in the law of motion addresses the selection correction from equation (16).

To form moments based on the innovation in the productivity shock in (18), one needs to express the productivity ω_{ft} as a function of data and parameters. Plugging the expressions for the input price correction from (13) and for unobserved productivity from (15) into the production function equation (10), we get:

$$q_{ft} = \phi_t(\tilde{\mathbf{x}}_{ft}, \mathbf{z}_{ft}) + \epsilon_{ft}, \quad (19)$$

Estimation of (19) enables one to get rid of unanticipated shocks and/or measurement error ϵ_{ft} . We note that although the variables proxying for input prices (see equation (12)) also enter the input demand equation in equation (15), this has no implications for the identification of the production function parameters. The only purpose of the first stage estimation is to purge the output quantity data from unanticipated shocks and/or measurement error (i.e., purge ϵ_{ft} in equation (10)).³⁰ For example, output prices (p_{ft}) enter this first stage both to control for unobserved productivity and input price differences, but we do not need to distinguish between them when forecasting output. Note that even if we observed (quality-corrected) input prices, we would still include output prices and the function $\phi_t(\cdot)$ would reflect this.

The first stage of the estimation in (19) yields an estimate of predicted output $\hat{\phi}_{ft}$.³¹ One can then express productivity ω_{ft} as a function of data and parameters. In particular, using equations (10), (13) and (19) we have:

$$\omega_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) = \hat{\phi}_{ft} - f(\tilde{\mathbf{x}}_{ft}; \boldsymbol{\beta}) - B((p_{ft}, \mathbf{ms}_{ft}, \mathbf{D}_f, \mathbf{G}_f, EXP_{ft}) \times \tilde{\mathbf{x}}^c_{ft}; \boldsymbol{\delta}), \quad (20)$$

where the last term, the function $B(\cdot)$, represents the input price control function.³²

³⁰We could set $\epsilon_{ft} = 0$; in this case, we no longer need to invert the input demand function to control for unobserved productivity. However, we feel that the input demand specification addresses first-order empirical issues with the data: measurement error in output and differences in units across products within sectors, which are absorbed by unit fixed effects in the first stage.

³¹In practice we approximate the function $\phi_t(\cdot)$ with a third-order polynomial in all its elements, with the exception of product dummies. We add the product dummies linearly to avoid having to estimate all cross terms. This seems innocuous since the first stage R^2 is very close to one.

³²We approximate $B(\cdot)$ with a flexible third-order polynomial. At this point the reader might find it useful to consider a special case of a Cobb-Douglas production function and a vertical differentiation model of consumer

It is important to note that even though the input expenditures $\tilde{\mathbf{x}}_{ft}$ enter both the production function $f(\cdot)$ and the input price control function $B(\cdot)$, the coefficients of the production function $\boldsymbol{\beta}$ are identified because $\tilde{\mathbf{x}}_{ft}$ enter the input price control function in (13) only interacted with input prices, or put differently, the input expenditures do not enter the input price function $w(\cdot)$ in (12). This identification insight does not rest on any functional form assumptions; it results from the fact that the control function for quality, and hence input prices, rests on the demand side alone and hence does not include input expenditures.

The main parameters of interest to compute markups are the vector of production function coefficients $\boldsymbol{\beta}$. However, from (13), note that the parameter vector $\boldsymbol{\delta}$ allows us to identify the input prices: after we have estimated $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$, we can recover the input prices from equation (12).³³

To estimate the parameter vectors $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$, we form moments based on the innovation in the productivity shock ξ_{ft} in law of motion in equation (18). We use (20) to project $\omega_{ft}(\cdot)$ on the elements of $g(\cdot)$ to obtain the innovation ξ_{ft} as a function of the parameters $\xi_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta})$:

$$\xi_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) = \omega_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) - E\left(\omega_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) \mid \omega_{ft-1}(\boldsymbol{\beta}, \boldsymbol{\delta}), \tau_{it-1}^{\text{output}}, \tau_{it-1}^{\text{input}}, EXP_{ft-1}, SP_{ft}\right) \quad (21)$$

The moments that identify the parameters are:

$$E(\xi_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) \mathbf{Y}_{ft}) = 0, \quad (22)$$

where \mathbf{Y}_{ft} contains lagged materials, current capital and labor, and their higher order and interaction terms, as well as lagged output prices, lagged market shares, lagged tariffs, and their appropriate interactions with the inputs.

This method identifies the production function coefficients by exploiting the fact that current shocks to productivity will immediately affect a firm's materials choice while labor and capital do not immediately respond to these shocks; moreover, the degree of adjustment can vary across firms and time. These moments that rely on adjustment costs in inputs are by now standard in this literature. In our context, we assume that firms freely adjust materials and treat capital and labor as dynamic inputs that face adjustment costs. In other settings, one may choose to treat labor as a flexible input. Since materials are the flexible input, we use lagged materials when we construct moments.³⁴

We use lagged output prices, market shares, and tariffs and their interactions with appropriately lagged inputs to form additional moment conditions to identify jointly the production function coefficients $\boldsymbol{\beta}$ and the coefficients $\boldsymbol{\delta}$ capturing the input price variation. For example, the parameter related to the output price is identified off the moment $E(\xi_t p_{t-1}) = 0$; this moment condition is based on the insight that current prices do react to productivity shocks, so we need to use lagged

demand. In this special case equation (20) reduces to: $\omega_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) = \phi_{ft} - \tilde{\mathbf{x}}'_{ft} \boldsymbol{\beta} - \Gamma w_t(p_{ft}; \boldsymbol{\delta})$, where Γ denotes the returns to scale parameter. Please see Appendix B for details.

³³In other words, we specify the function $w(\cdot)$ and therefore the $\boldsymbol{\delta}$ parameters are a function of both the production function coefficients $\boldsymbol{\beta}$, and the parameters in $w(\cdot)$.

³⁴In our setting, input tariffs are serially correlated and since they affect input prices, input prices are serially correlated over time, creating a link between current and lagged intermediate input usage.

output prices which exploit the serial correlation of prices.

We estimate the model using a GMM procedure on a sample of firms that manufacture a single product for at least three consecutive years.³⁵ We choose three years since the moment conditions require at least two years of data because of the lagged values; we add an additional (third) year to allow for potential measurement error in the precise timing of a new product introduction. We discuss the timing assumptions further in subsection 3.5.2. In principle, one could run the estimation separately for each product. In practice, our sample size is too small to allow estimation at the product level, so we estimate (10) at the two-digit sector level.³⁶

Estimation of equation (10) requires choosing a functional form for f . We adopt a translog specification because of its flexibility.³⁷ Specifically, the translog offers the advantage that it generates output elasticities that are not constant over time and across firms (though the production coefficients are constrained to be the same across years and firms); hence, large firms can have different elasticities than small firms. The exact functional form for $f(\cdot)$ does not generate any identification results. The crucial assumption is that productivity enters in a log-additive fashion (Assumption 3 in Section 3.1).

Finally, the standard errors on the coefficients are obtained using block-bootstrapping, where we draw an entire firm time series. Since our ultimate objective is to estimate the impact of the trade reforms on markups and marginal costs, we correct the standard errors of the regressions in Section 4 by block-bootstrapping over our entire empirical procedure.

3.3 Recovering Input Allocations

As shown in equations (5) and (6), computing markups and marginal costs requires the product-specific output elasticity and product-specific revenue shares on a variable input (in our case, materials). We obtain the output elasticity from the estimation outlined in Section 3.2 based on single-product firms, but we do not know the product-specific revenue shares of inputs for multi-product firms. Here, we show how to compute the input allocations across products of a multi-product firm in order to construct α_{fjt}^M .

From Assumption 6, recall that $\rho_{fjt} = \ln\left(\frac{W_{fjt}^X X_{fjt}}{X_{ft}}\right) \forall X \in \{V, K\}$, is product j 's input cost share. We solve for ρ_{fjt} in multi-product firms as follows. We first eliminate unanticipated shocks and measurement error from the product-level output data by following the same procedure as in the first stage of our estimation routine for the single-product firms in (19). We project q_{fjt} on the exact same variables used in the first stage of the estimation procedure, $\hat{q}_{fjt} \equiv E(q_{fjt} | \phi_t(\tilde{\mathbf{x}}_{ft}, \mathbf{z}_{ft}))$, which allows us to eliminate any measurement error and unanticipated shocks to output from the recorded output data.

³⁵We follow the procedure suggested by Wooldridge (2009) that forms moments on the joint error term $(\xi_{ft} + \epsilon_{ft})$.

³⁶This follows the standard practice in the literature where production functions are estimated at the industry level. For example, see Levinsohn and Petrin (2003).

³⁷The translog production function is $q_{ft} = \beta_l l_{ft} + \beta_{ll} l_{ft}^2 + \beta_k k_{ft} + \beta_{kk} k_{ft}^2 + \beta_m m_{ft} + \beta_{mm} m_{ft}^2 + \beta_{lk} l_{ft} k_{ft} + \beta_{lm} l_{ft} m_{ft} + \beta_{mk} m_{ft} k_{ft} + \beta_{lmk} l_{ft} m_{ft} k_{ft} + \omega_{ft}$.

Given the aforementioned assumptions that productivity is firm-specific and log-additive and that inputs are divisible across products, we can rewrite the production function as:

$\hat{q}_{fjt} = f(\tilde{\mathbf{x}}_{ft}, \hat{\boldsymbol{\beta}}, \hat{w}_{fjt}, \rho_{fjt}) + \omega_{ft}$, and recover $\left\{ \{\rho_{fjt}\}_{j=1}^J, \omega_{ft} \right\}$ using:

$$\hat{q}_{fjt} - f_1(\tilde{\mathbf{x}}_{ft}, \hat{\boldsymbol{\beta}}, \hat{w}_{fjt}) = f_2(\tilde{\mathbf{x}}_{ft}, \hat{w}_{fjt}, \rho_{fjt}) + \omega_{ft} \quad (23)$$

$$\sum_j \exp(\rho_{fjt}) = 1, \quad (24)$$

where f_1 and f_2 depend on the functional form of the production function and the input prices \hat{w}_{fjt} for each product j are computed based on the input price function (12). In other words, to recover the input allocations ρ_{fjt} , we separate the production function into a component f_1 that captures all terms that do not depend on ρ_{fjt} and a component f_2 that collects all terms that involve ρ_{fjt} . Because the input allocation shares have to sum up to 1 across all products in a multi-product firm, this yields a system of $J_{ft} + 1$ equations (where J_{ft} is the number of products produced by firm f at time t) in $J_{ft} + 1$ unknowns (the J_{ft} input allocations ρ_{fjt} and ω_{ft}) for each firm-year pair.

Let $\hat{w}_{fjt} = \hat{q}_{fjt} - f_1(\tilde{\mathbf{x}}_{ft}, \hat{\boldsymbol{\beta}}, \hat{w}_{fjt})$. Applying our translog functional form to (23), we obtain:

$$\hat{w}_{fjt} = \omega_{ft} + \hat{a}_{fjt}\rho_{fjt} + \hat{b}_{fjt}\rho_{fjt}^2 + \hat{c}_{fjt}\rho_{fjt}^3 \quad (25)$$

The terms \hat{a}_{ft} , \hat{b}_{ft} , and \hat{c}_{ft} are functions of the estimated parameter vector $\hat{\boldsymbol{\beta}}$ and the estimated input price correction \hat{w}_{fjt} .³⁸

For each year, we obtain the firm's productivity and input allocations, the $J + 1$ unknowns $(\omega_{ft}, \rho_{f1t}, \dots, \rho_{fJt})$, by solving a system of $J + 1$ equations:

$$\hat{w}_{f1t} = \omega_{ft} + \hat{a}_{f1t}\rho_{f1t} + \hat{b}_{f1t}\rho_{f1t}^2 + \hat{c}_{f1t}\rho_{f1t}^3 \quad (26)$$

$$\dots \quad (27)$$

$$\hat{w}_{fJt} = \omega_{ft} + \hat{a}_{fJt}\rho_{fJt} + \hat{b}_{fJt}\rho_{fJt}^2 + \hat{c}_{fJt}\rho_{fJt}^3 \quad (28)$$

$$\sum_{j=1}^J \exp(\rho_{fjt}) = 1, \quad \exp(\rho_{fjt}) \leq 1 \quad \forall fjt \quad (29)$$

This system imposes the economic restriction that each input share can never exceed one and they must together sum up to one across products in a firm. We numerically solve this system for each firm in each year.

³⁸For the translog, these terms are

$$\begin{aligned} \hat{a}_{ft} &= \hat{\beta}_k + \hat{\beta}_l + 3\hat{w}_{fjt}^2\hat{\beta}_{lmk} + \tilde{l}_{ft} \left(\hat{\beta}_{lk} + 2\hat{\beta}_{lu} + \hat{\beta}_{lm} + \tilde{k}_{ft}\hat{\beta}_{lmk} + \tilde{m}_{ft}\hat{\beta}_{lmk} - 2\hat{w}_{fjt}\hat{\beta}_{lmk} \right) + \hat{\beta}_m + \tilde{k}_{ft} \left(2\hat{\beta}_{kk} + \hat{\beta}_{lk} + \tilde{m}_{ft}\hat{\beta}_{lmk} \right) \\ &\quad + \tilde{k}_{ft} \left(-2\hat{w}_{fjt}\hat{\beta}_{lmk} + \hat{\beta}_{mk} \right) + \hat{w}_{fjt} \left(-2\hat{\beta}_{kk} - 2\hat{\beta}_{lk} - 2\hat{\beta}_{lu} - 2\hat{\beta}_{lm} - 2\hat{\beta}_{mk} - 2\hat{\beta}_{mm} \right) + \tilde{m}_{ft} \left(\hat{\beta}_{lm} - 2\hat{w}_{fjt}\hat{\beta}_{lmk} + \hat{\beta}_{mk} + 2\hat{\beta}_{mm} \right) \\ \hat{b}_{ft} &= \hat{\beta}_{kk} + \hat{\beta}_{lk} + \hat{\beta}_{lu} + \hat{\beta}_{lm} + \hat{\beta}_{lmk}\tilde{k}_{ft} + \hat{\beta}_{lmk}\tilde{l}_{ft} + \hat{\beta}_{lmk}\tilde{m}_{ft} - 3\hat{w}_{fjt}\hat{\beta}_{lmk} + \hat{\beta}_{mk} + \hat{\beta}_{mm} \\ \hat{c}_{ft} &= \hat{\beta}_{lmk} \end{aligned}$$

3.4 Markups and Marginal Costs

We can now apply our framework to compute markups and marginal costs using the estimates of the production function coefficients (β) and the input allocations (ρ). We calculate the markup for each product-firm pair f, j in each time period t using:

$$\hat{\mu}_{fjt} = \hat{\theta}_{fjt}^M \frac{P_{fjt} Q_{fjt}}{\exp(\hat{\rho}_{fjt}) \tilde{X}_{ft}^M}, \quad (30)$$

where $\hat{\theta}_{fjt}^M = \theta(\hat{\beta}, \tilde{\mathbf{x}}_{ft}, \hat{w}_{fj}, \hat{\rho}_{fjt})$ and \tilde{X}_{ft}^M denotes the firm's expenditure on materials.

The product-specific output elasticity for materials $\hat{\theta}_{fjt}^M$ is a function of the production function coefficients and the materials allocated to product j . Hence, it can be easily computed once the allocation of inputs across products has been recovered.³⁹ Marginal costs mc_{fjt} are then recovered by dividing price by the relevant markup according to equation (6).

Note that both markups and marginal costs are estimates since they depend on the estimated production function coefficients and the input cost allocation parameters, which are estimates themselves since they depend on the production function coefficients. Hence, the only source of uncertainty in our markup (and marginal cost) estimates comes from using estimated coefficients (the production function coefficients $\hat{\beta}$ and the input price correction coefficients $\hat{\delta}$). We account for the measurement error in these variables when we estimate the reduced form regressions in Section 4 by bootstrapping over the entire procedure. We execute the following steps in sequence: 1) estimate the production function, 2) recover the input allocations, 3) calculate markups (marginal costs), and 4) project markups and costs on trade policy variables. We then repeat this procedure 500 times, using bootstrapped (with replacement) samples that keep the sample size equal to the original sample size. This allows us to compute the bootstrapped standard error on the trade policy coefficients in Section 4.

3.5 Discussion

In addition to the conceptual assumptions discussed in Section 3.1, the actual implementation of the approach requires a set of assumptions to accommodate limitations of the data. Some of these limitations are specific to our data set (for example, we do not have information on physical labor units and wages, but only the wage bill) and may be of little general relevance. But other limitations are present in every firm-level data set and will need to be addressed by any study using such data. To our knowledge, no dataset reports the allocation of input expenditures across products in multi-product firms or contains the complete information on the firm-specific input prices (including firm-specific price of capital). The additional assumptions we impose are needed in order to deal with these features of the data. Apart from measurement issues, the assumptions we employ also address challenges that arise from product differentiation.

³⁹The expression for the materials output elasticity for product j at time t is: $\hat{\theta}_{fjt}^M = \hat{\beta}_m + 2\hat{\beta}_{mm}m_{fjt} + \hat{\beta}_{lm}l_{fjt} + \hat{\beta}_{mk}k_{fjt} + \hat{\beta}_{lmk}l_{fjt}k_{fjt}$. As before, to obtain the physical inputs, we rely on our estimates of the input prices \hat{w}_{fjt} and the input allocation shares $\hat{\rho}_{fjt}$.

In this section we discuss these additional assumptions and our identification strategy. We start by discussing the way we deal with the unobserved input allocations in multi-product firms.

3.5.1 The Use of Single-Product Firms: Economies of Scope and Relationship to Cost Function Estimation

This subsection expands on the discussion of economies of scope in our setting and relates it to discussion of economies of scope in the cost function literature. Our approach does not rule out economies (or diseconomies) of scope, which may be important for multi-product firms. Panzar (1989) defines economies of scope in terms of cost. Baumol et al. (1983) speak of economies of scope in production if the cost function is sub-additive: $c_{ft}(q_1, q_2) \leq c_{ft}(q_1) + c_{ft}(q_2)$ where $c_{ft}(\cdot)$ is a firm's cost curve. While our framework rules out differences in the production technology between single- and multi-product firms, it allows for economies of scope through cost synergies. The main sources of such economies are the possibility that multi-product firms have higher Hicks-neutral productivity than single-product firms (potentially because of differences in management practices or organizational structures) and the multiproduct firms' ability to spread their fixed costs across multiple products.

An alternative way of explaining the assumptions underlying our approach is to express them in terms of the cost function rather than the production function. A multi-product firm faces the short-run cost function, written in a general form as:

$$C(\mathbf{Q}) = \Phi(\Omega)C(\mathbf{Q}, \mathbf{W}, \beta) + F(\iota(\mathbf{Q})) \quad (31)$$

where C denotes the total costs for a firm producing a vector of outputs \mathbf{Q} , $\Phi(\Omega)$ denotes the impact of factor-neutral productivity on costs, \mathbf{W} denotes a vector of input prices, F are the fixed costs (which would be zero in long-run cost function), and $\iota(\cdot)$ is an indicator that takes the value of 1 if a firm produces a particular product in the vector \mathbf{Q} and is zero otherwise. The assumption we impose is that the function $C(\mathbf{Q}, \mathbf{W}, \beta)$ is the same across single- and multi-product firms. However, costs between the two types of firms can still differ because of: 1) factor-neutral productivity differences reflected in $\Phi(\Omega)$; 2) (in the short run) the amortization of fixed costs F across more products for multi-product firms. A third possibility is that factor prices \mathbf{W} differ across the two types of firms because of pre-negotiated contracts; such differences are consistent with our assumptions regarding input prices as long as the contracts do not specify input prices as a function of input quantity.

We emphasize that we allow for economies of scope rather than assuming it. For example, our results could find no productivity differences between single- and multi-product firms, or find that multi-product firms are less productive implying diseconomies of scope. Likewise, finding economies of scope in the range of our data does not imply existence of economies of scope over any range of products produced by a firm; it is possible that economies of scope switch to diseconomies once a firm reaches a certain number of products. This paper does not attempt to provide a theory of multi-product firms. We simply point out that our approach does not *a priori* rule out economies

or diseconomies of scope in the range of our data.

The representation of the cost function in (31) raises the natural question of why we do not exploit the duality between production and cost function and estimate a multi-product cost function. The main reason for focusing on the production function is that we do not have information on wages and the firm-specific user cost of capital, which are required to estimate a cost function. Furthermore, a multi-product cost function estimation would require additional identification assumptions in order to deal with the endogeneity of multiple product outputs on the right-hand side. Finally, even if one could come up with such identification assumptions, the product portfolios in our particular context are not stable. While Indian firms very rarely drop products, they often add products during this period (see Goldberg et al. (2010b)). These frequent additions require explicitly modeling a firm’s decision to add a particular product (in contrast, our approach requires us to model only the change from single- to multi-product status). Given these challenges, the approach to estimate production functions from single-product firms while accounting for the potential selection bias is an appealing alternative.

3.5.2 Control Function for Input Prices and Timing Assumptions

This subsection explains how the control function for input prices, the law of motion for productivity and the timing assumptions allow us to identify the coefficients. Recall that the identification strategy involves two control functions for the two unobservables: input prices and productivity:

$$w_{ft} = w_t(p_{ft}, \mathbf{ms}_{ft}, \mathbf{D}_f, \mathbf{G}_f, EXP_{ft}) \quad (32)$$

$$\omega_{ft} = g(\omega_{ft-1}, \tau_{it-1}^{\text{output}}, \tau_{it-1}^{\text{input}}, EXP_{ft-1}, SP_{ft}) + \xi_{ft}. \quad (33)$$

While ω_{ft} enters the production function (10) linearly, the input prices enter non-linearly as part of the term $B(\cdot)$. By substituting the input price control function into the expression for w , we get equation (13).

First, note that we make use of the input price control function in the first stage of the estimation, when we purge the data from the noise ϵ . At this stage, we use materials as a proxy for productivity. Given that materials demand depends on input prices, it is important to control for the input prices using the control function specified above. However, the first stage has no implications for the identification of the production function coefficients; its sole purpose is to net out ϵ .

Next, consider the identification of the production function coefficients β and the coefficients associated with the input price correction term δ . These are identified off our timing assumptions. To review these assumptions, we assume that materials are a freely adjustable input and hence they will be correlated with contemporaneous productivity. Similarly, output prices will be correlated with current productivity. In contrast, capital and labor are dynamic inputs. Therefore, they will be uncorrelated with the productivity innovation ξ_{ft} . We rely on these assumptions to form moment conditions.

There are two remaining identification issues that need to be discussed. First, as we noted earlier,

the term $B(\cdot)$ will in general include input expenditures $\tilde{\mathbf{x}}_{ft}$. This raises the question of whether the production coefficients β are identified. They are identified because the input expenditures $\tilde{\mathbf{x}}_{ft}$ enter the input price term $B(\cdot)$ *only through interaction* with the input prices. It is because of the complexity of the translog that $\tilde{\mathbf{x}}_{ft}$ appear in $B(\cdot)$ through interactions with input prices. In a Cobb-Douglas specification, the input expenditures do not appear in $B(\cdot)$. In fact, under a constant returns to scale Cobb-Douglas production function the input correction term $B(\cdot)$ simplifies to $w(\cdot)$.⁴⁰

The second question is how the coefficients on variables that enter both the law of motion for productivity and the input price control function are identified. One example of such a variable is the export dummy. The law of motion for productivity includes a dummy for exporting in $t - 1$, while it is also included in the input price control. The answer is that these coefficients are again identified off timing assumptions. We assume that productivity responds with a lag to changes in a firm’s environment, since it plausibly takes time for a firm to take the actions required to increase its efficiency (e.g., hiring better managers, adopting better management practices, changing organizational structure, importing new intermediate inputs, etc.). Accordingly, variables that may influence a firm’s productivity, such as tariffs or exporting, enter with a lag in the law of motion of productivity. In contrast, output and input prices respond immediately to changes in the economic environment. Accordingly, the variables included in the input price control function enter with their current values. As noted earlier, it is precisely because these variables enter with their current values that we face an identification problem; the current values will be correlated with ξ_{ft} since by assumption they respond to contemporaneous shocks. It is this potential correlation that leads us to form moment conditions based on the lags, and not the current values, of the corresponding variables (the vector \mathbf{Y}_{ft} contains *lagged* output prices, *lagged* market shares, etc.).

4 Empirical Results

4.1 Output Elasticities, Marginal Costs and Markups

In this subsection, we present the output elasticities recovered from the production function estimation procedure. We describe how failing to correct for input price variation or account for the selection bias affects the parameters. Finally, we present and discuss our markup and marginal cost estimates.

The output elasticities are reported in Table 3.⁴¹ The nice feature of the translog is that unlike in a Cobb-Douglas production function, output elasticities can vary across firms (and across products within firms). We report both the average and standard deviation of the elasticities across sectors, and the final column reports the returns to scale. We note that a few sectors appear to have low returns to scale, but these are driven by outliers; Table 4 reports median output elasticities which

⁴⁰See Appendix B for details of the special case of Cobb-Douglas.

⁴¹The output elasticity for capital and labor are defined analogous to the materials elasticity reported in Footnote 39.

are generally larger than the averages. Since the returns to scale vary across firms, it is possible for many firms in a sector to have increasing returns to scale, while the estimate of the industry-average returns to scale is close to one. At the firm level, 70 percent of the sample exhibits increasing returns to scale.

The left panel of Table 5 repeats the production function estimation without implementing the correction for the unobserved input price variation discussed in subsection 3.2.2. The uncorrected procedure yields nonsensical estimates of the production function. For example, the output elasticities and returns to scale are sometimes negative, very low or very high. These results are to be expected given that we estimate a quantity-based production function using deflated input expenditures, i.e., we relate physical output to input expenditures. It is clear that failing to account for input price variation yields distorted estimates. To understand the source of the distortion, consider the following concrete example from our data: in 1995, Ashnoor Textile Mills and Delight Handicrafts Palace sold 71,910 and 67,000,000 carpets, respectively. Ashnoor, however, had about three times higher input expenditures and three times higher revenues. It is easiest to understand the implications of this example for the estimates using a Cobb-Douglas specification. A quantity production function estimation that ignores input price variation would result in very large and negative output elasticities (more input expenditures result in lower quantity for Ashnoor). In the more general translog specification, it is impossible to sign this bias because there are three inputs which interact in complicated ways with each other and input prices, but it is clear that one needs to correct for input price variation across firms. By introducing the input price control, we are effectively comparing output quantities to input quantities, and the resulting output elasticities then look reasonable.

The importance of the input price correction is not apparent in the earlier literature, which traditionally estimates a Cobb-Douglas specification of the form: $q + p = \tilde{x}\beta + \tilde{\omega}$. This specification relates deflated sales to deflated expenditures and implies that $\tilde{\omega} = \omega + p - w(\cdot)$. That is, the unobserved productivity measure includes both (unobserved) output price p and (unobserved) input prices w . If one does not control for either output or input price variation (the typical practice in this literature until recently), there is no apparent problem as the two price biases tend to work in opposite directions.⁴² This leads to output elasticities that appear plausible without immediately calling for a correction.⁴³ Of course, this does not mean that the two biases exactly cancel each other, so the final estimates will generally still be biased.

The right panel of Table 5 presents the mean output elasticities from an estimation of the production function that does not include the sample selection correction described in Section 3.2.3. The coefficients change slightly when the selection correction is not implemented. The stability of the coefficient estimates with and without selection correction for the unbalanced panel suggests that the use of the unbalanced panel of single-product firms (which includes firms that are always

⁴²See De Loecker and Goldberg (2014) for a detailed discussion of this issue.

⁴³In fact, when we estimate a firm-level revenue-based production function using the standard control function approach, we obtain production function coefficients that look similar to the previous literature (results available upon request).

single-product and firms that ultimately transition to a multi-product status) likely alleviates most of the concerns about the selection bias. This is consistent with the findings in Olley and Pakes (1996).

The markups are reported in Table 6. The mean and median markups are 2.24 and 1.18, respectively, but there is considerable variation across sectors and across products and firms within sectors. Some firms report markups below one for individual products, but multi-product firms maximize profits across products, so they may lose money on some products while being profitable on others. To get a better sense of the plausibility of our estimates, we aggregate the product-level markups to the firm level using the share of sales as weights. The firm-level markups are below one for only about 15 percent of the sample and the median firm-level markup is 1.43. In fact, we find a strong positive (and statistically significant) relationship between firm markups and reported accounting profits, measured as operating profits divided by total sales (results available upon request). Importantly, for our main results below, we rely on *changes* in markups over time by exploiting variation within firm-product pairs rather than variation in levels across firms.

The methodology provides measures of markups and marginal costs without *a priori* assumptions on the returns to scale. The estimates show that many firms are characterized by increasing returns to scale, so we expect to observe an inverse relationship between a product’s marginal cost and quantity produced. Accordingly, another way to assess the plausibility of the measures is to plot marginal costs against production quantities in Figure 1 (we de-mean each variable by product-year fixed effects in order to facilitate comparisons across firms). The figure shows indeed that marginal costs vary inversely with production quantities. The left panel of the figure shows that quantities and markups are positively related indicating that firms producing more output also enjoy higher markups (due to their lower marginal costs).

We also examine how markups and marginal costs vary across products within a firm. Our analysis here is guided by the recent literature on multi-product firms. Our correlations are remarkably consistent with the predictions of this literature, especially with those of Eckel and Neary (2010) and the multi-product firm extension of Melitz and Ottaviano (2008) developed by Mayer et al. (2014). A key assumption in these models is that multi-product firms each have a “core competency”. The core product has the lowest (within a firm) marginal cost. For the other products, marginal costs rise with a product’s distance from the core competency. Mayer et al. (2014) assume a linear demand system which implies that firms have non-constant markups across products. Furthermore, firms have their highest markups on their “core” products with markups declining as they move away from their main product. Figure 2 provides evidence supporting these implications. They plot the de-meaned markups and marginal costs against the sales share of the product within each firm (markups and marginal costs are de-meaned by product-year and firm-year fixed effects in order to make these variables comparable across products within firms). Marginal costs rise as a firm moves away from its core competency while the markups fall. In other words, the firm’s most profitable product (excluding any product-specific fixed costs) is its core product. Despite not imposing any assumptions on the market structure and demand system in our estimation, these correlations are

remarkably consistent with the predictions from the multi-product firm literature.

4.2 Pass-Through

Foreshadowing the results in the next subsection, we also find evidence of imperfect pass-through of costs on prices because of variable markups. This subsection explains how we estimate pass-through.

Consider the identity that decomposes the (log) price of a firm f producing product j into its two subcomponents: (log) marginal cost, $\ln mc_{fjt}$, and (log) markup, $\ln \mu_{fjt}$:

$$\ln P_{fjt} = \ln mc_{fjt} + \ln \mu_{fjt} \quad (34)$$

This identity can also be written as:

$$\ln P_{fjt} = \ln \mu_{fj} + \ln mc_{fjt} + (\ln \mu_{fjt} - \ln \mu_{fj}) \quad (35)$$

where $\ln \mu_{fj}$ is the (time-invariant) average (log) markup for this particular firm-product pair and $(\ln \mu_{fjt} - \ln \mu_{fj})$ is the deviation of the markup from its average. If markups are constant, then the last term becomes zero. This is the case of complete pass-through: a proportional change in marginal cost is passed entirely to prices. If markups are variable, then marginal costs are correlated with the term in parenthesis and pass-through is incomplete. For example, if the price elasticity of demand is increasing in price, then an increase in marginal cost (which will tend to raise the price) will lead to an increase in the price elasticity of demand and a decrease in the markup. In this case, the marginal cost is negatively correlated with the (variable) markup and the pass-through of a marginal cost change onto price is below one. This correlation between marginal costs and markups is *not* an econometric issue since the equation above is an identity. Rather, it is a correlation dictated by economic theory: any model that implies variable markups will also imply a correlation between marginal cost and markup and result in incomplete pass-through.

To understand the implications of variable markups and incomplete pass-through in our setting, first consider the hypothetical case where marginal cost can be measured exactly. Suppose we run the following pass-through regression:

$$\ln P_{fjt} = a_{fj} + \zeta \ln mc_{fjt} + \varepsilon_{fjt} \quad (36)$$

where a_{fj} is a firm-product fixed effect. In this setup, the error term ε_{fjt} has a structural interpretation. It reflects the deviation of the actual markup in period t from the average (i.e., it corresponds to $(\ln \mu_{fjt} - \ln \mu_{fj})$).

If markups are constant, then we would expect to find that $\zeta = 1$ and $\varepsilon_{fjt} = 0$ (i.e., an exact fit). The firm-product fixed effect a_{fj} would accurately measure the constant markup and the coefficient ζ would measure the pass-through of marginal cost to price which would be complete ($\zeta = 1$). The deviation of the actual markup from the average, ε_{fjt} , would be zero if markups were constant. Of course, in reality we would never get an exact fit of the regression line. But as long as ε_{fjt} captures

random variation in price (due for example to recording errors) that is orthogonal to the marginal cost, we would estimate complete pass-through.

If markups are variable, then the error term ε_{fjt} will be correlated with the marginal cost $\ln mc_{fjt}$.⁴⁴ We again emphasize that this correlation is dictated by theory and not by econometrics. If the price elasticity facing the firm is increasing in price, then a marginal cost increase will lead to a price increase, which will raise the price elasticity and lower the markup. Hence, ε_{fjt} and $\ln mc_{fjt}$ will be negatively correlated and the pass-through coefficient ζ will be below one. This is the case of incomplete pass-through.

When observing marginal cost, the coefficient ζ reflects markup variability and pass-through. There would be no need to instrument for marginal costs. In fact, instrumenting marginal costs is conceptually incorrect because the correlation between marginal costs and the structural error of the regression (i.e., the markup) is precisely what the coefficient ζ is supposed to capture. However, in our application (and almost every other empirical study), we only observe an estimate of marginal cost, $\ln \widehat{mc}_{fjt} = \ln mc_{fjt} + \sigma_{fjt}$. The pass-through regression becomes

$$\ln P_{fjt} = a_{fj} + \zeta \ln \widehat{mc}_{fjt} + (\varepsilon_{fjt} - \zeta \sigma_{fjt}) = a_{fj} + \zeta \ln \widehat{mc}_{fjt} + u_{fjt} \quad (37)$$

Measurement error results in a downward bias in the pass-through coefficient ζ leading us to conclude, potentially erroneously, that pass-through is incomplete. We therefore require instruments to address measurement error in marginal costs. It is important to note that in this setting, instruments must be uncorrelated with the measurement error, σ_{fjt} . However, we do not require that they are uncorrelated with the part of the error term that reflects the deviation in markup, ε_{fjt} . Indeed, such a condition would be inconsistent with the exercise which is precisely to measure the correlation between marginal cost and markup, that is the correlation between \widehat{mc}_{fjt} and ε_{fjt} .

We instrument for marginal cost in equation (37) with input tariffs and lagged marginal cost. Both variables are certainly correlated with marginal cost. The former should be uncorrelated with the measurement error in our marginal cost estimate, but input tariffs do not vary at the firm level. The advantage of lagged marginal cost is that it varies at the firm-product-year level. Although lagged marginal costs contain measurement error, we have no reason to expect this measurement error to be serially correlated.

Table 7 presents the pass-through results from estimating (37).⁴⁵ OLS results are reported in column 1, and the coefficient is 0.360. The second column instruments marginal costs with both lagged marginal cost and input tariffs, and consistent with measurement error, the IV estimate increases. The coefficient rises to 0.427 and is statistically significant. In case one is concerned about first-order serial correlation in measurement error, the third column uses input tariffs and two-period lagged marginal cost as the instruments, and the IV estimate is now 0.572. Thus, the results seem robust to the use of alternative instruments and consistently point to low pass-through.

⁴⁴Variable markups can be generated in many different ways through various combinations of market structure, firm behavior and demand function. See Goldberg and Hellerstein (2013) for a discussion.

⁴⁵As noted in Section 3.4, we report bootstrap standard errors.

This imperfect pass-through means that shocks to marginal costs, for example shocks from trade liberalization, do not lead to proportional changes in factory-gate prices because of changes in markups. We examine this markup adjustment in detail in the subsequent section.

4.3 Prices, Markups and Trade Liberalization

We now examine how prices, markups and marginal costs adjusted as India liberalized its economy. As discussed in Section 2, we restrict the analysis to 1989-1997 since tariff movements after this period appear correlated with industry characteristics.

We begin by plotting the distribution of raw prices in 1989 and 1997 in Figure 3. Here, we include only firm-product pairs that are present in both years, and we compare the prices over time by regressing them on firm-product pair fixed effects and year dummies and plotting the residuals. As before, we remove outliers in the bottom and top 3rd percentiles. This comparison of the same firm-product pairs over time exploits the same variation as our regression analysis below. The figure shows that the distribution of (real) prices did not change much between 1989 and 1997. This might at first be a surprising result given nature of India’s economic reforms during this period that were designed to reduce entry barriers and increase competition in the manufacturing sector. As a first pass, the figure suggests that prices did not move much despite the reforms.

Of course, the figure includes only firm-product pairs that are present at the beginning and end of the sample, and summarizes aggregate trends, thereby not controlling for sector-specific factors that could influence prices beyond the trade reforms. We use the entire sample and control for macroeconomic trends in the following specification:⁴⁶

$$p_{fjt} = \lambda_{fj} + \lambda_{st} + \lambda_1 \tau_{it}^{\text{output}} + \eta_{fjt}. \quad (38)$$

We exploit variation in prices and output tariffs within a firm-product over time through the firm-product fixed effects (λ_{fj}) and control for macroeconomic fluctuations through sector-year fixed effects λ_{st} . Since the trade policy measure varies at the industry level, we cluster our standard errors at this level.⁴⁷ We report the price regression with just year fixed effects in column 1 of Table 8. The coefficient on the output tariff is positive implying that a 10 percentage point decline is associated with a small-1.29 percent-decline in prices.⁴⁸ Between 1989 and 1997, output tariffs fall on average by 62 percentage points; this results in a precisely estimated average price decline of 8 percent ($=62*0.129$). This is a small effect of the trade reform on prices and it is consistent with the raw distributions plotted in Figure 3. The basic message remains the same if we control more flexibly for trends with sector-year fixed effects in column 2. The results imply that the average

⁴⁶One could try to capture the net impact of tariff reforms using the effective rate of protection measure proposed by Corden (1966). However, this measure is derived in a setting with perfect competition and an infinite export-demand and import-supply elasticities which imply perfect pass-through. As we show below, these assumptions are not satisfied in our setting, so that the concept of the “effective rate of protection” is not well defined in our case.

⁴⁷Recall from Section 2 that tariffs vary at a 4-digit level, while sector is defined as a 2-digit industry.

⁴⁸Our result is consistent with Topalova (2010) who finds that a 10 percentage point decline in output tariffs results in a 0.96 percent decline in wholesale prices in India during this period.

decline in output tariffs led to a 10 (=62*.161) percent relative drop in prices.

These results show that although the trade liberalization led to lower factory-gate prices, the decline is more modest than we would have expected given the magnitude of the tariff declines. Since earlier studies (Goldberg et al. (2010a), Topalova and Khandelwal (2011)) have emphasized the importance of declines in input tariffs in shaping firm performance, we separate the effects of output tariffs and input tariffs on prices. Output tariff liberalization reflects primarily an increase in competition, while the input tariff liberalization should provide access to lower cost (and more variety of) inputs. We run the analog of the regression in (38), but separately include input and output tariffs:

$$p_{fjt} = \lambda_{fj} + \lambda_{st} + \lambda_1 \tau_{it}^{\text{output}} + \lambda_2 \tau_{it}^{\text{input}} + \eta_{fjt}. \quad (39)$$

The results are shown in column 1 of Table 9.⁴⁹ There are two interesting findings that are important for understanding how trade affects prices in this liberalization episode. First, there is a positive and statistically significant coefficient on output tariffs. This result is consistent with the common intuition that increases in competitive pressures through lower output tariffs will lead to price declines. The effect is traditionally attributed to reductions in markups and/or reductions in X-inefficiencies within the firm. The point estimates imply that a 10 percentage point decline in output tariffs results in a 1.49 percent decline in prices. On the other hand, the coefficient on input tariffs is small and noisy. Holding input tariffs fixed and reducing output tariffs, we would observe a precisely estimated decline in prices. Overall, average output tariffs and input tariffs fall by 62 and 24 percentage points, respectively, and using the point estimates in column 1, this implies that prices fall on average by 18.1 percent (a decline that is statistically significant).

We use the estimates of markups and costs to examine the mechanisms behind these moderate changes in factory-gate prices. We begin by plotting the distribution of markups and costs in Figure 4. Like Figure 3, this figure considers only firm-product pairs that appear in both 1989 and 1997. The figure indicates that between 1989 and 1997, the marginal cost distribution shifted left indicating an efficiency gain. However, this marginal cost decline is offset by a corresponding rightward shift in the markup distribution. Since (log) marginal costs and (log) markups exactly sum to (log) prices, the net effect results in little changes to prices. Hence, the raw data point towards imperfect pass-through of cost declines to prices. As before, these patterns are only suggestive and presented only for illustrative purposes, given that the figures do not condition on the policy and other changes that took place over this period.

We re-run specification (39) using marginal costs and markups as the dependent variables to formally analyze these relationships. Since prices decompose exactly to the sum of marginal costs and markups, the coefficients in columns 2 and 3 sum to their respective coefficients in column 1 in Table 9. We first focus on marginal costs regressions reported in column 2. The coefficient on

⁴⁹The regressions exclude outliers in the top and bottom 3rd percent of the markup distribution. We trim to ensure that the results are not driven by outliers. Nevertheless, the results are robust (e.g., magnitudes change slightly but statistical significance is unaffected) to alternative trims (e.g, the top and bottom 1st) and to not trimming at all (results are available upon request).

output tariffs is statistically insignificant, suggesting that marginal costs are insensitive to output tariff liberalization. However, the coefficient on input tariffs is both positive and large in magnitude. This is strong evidence that improved access to cheaper and more variety of imported inputs results in large cost declines. The final row of Table 9 reports the average effect on marginal costs using the average declines in input and output tariffs. On average, marginal costs fell 35.2 percent.

This magnitude of the marginal costs decline is sizable and would translate to larger prices declines if markups are constant. However, Figure 4 suggests that markups rose during this period, and in column 3 of Table 9, we directly examine how input and output tariffs affected markups. The coefficient on input tariffs is large and negative implying that input tariff liberalization resulted in higher markups. The results indicate that firms offset the beneficial cost reductions from improved access to imported inputs by raising markups. The overall effect, taking into account the average declines in input and output tariffs between 1989 and 1997, is that markups, on average, increased by 17.0 percent. This increase offsets about half of the average decline in marginal costs, and as a result, the overall effect of the trade reform on prices is moderated.⁵⁰

Although tempting, it is misleading to draw conclusions about the pro-competitive effects of the trade reform from the markup regressions in column 3 of Table 9. The reason is that one needs to control for impacts of output tariff liberalization on marginal costs in order to isolate pro-competitive effects. For example, if output tariffs affect costs through changes in X-inefficiencies, firms may adjust markups in response to these cost changes. The simultaneous effects that tariffs have on both costs and markups make it difficult to identify pro-competitive effects of the reform based on specification in column 3.

To isolate pro-competitive effects, we need to control for simultaneous shocks to marginal costs. We do this by re-running the markup regression but controlling flexibly for marginal costs. Conditioning on marginal costs, the output tariff coefficient isolates the direct pro-competitive effect of the trade liberalization on markups. We report the results in Table 10.⁵¹ Indeed, the coefficient on output tariffs in column 1 is positive and significant; this provides direct evidence that output tariff liberalization exerted pro-competitive effects on markups. The way to interpret the results in column 1 is to consider the markups on two products in different industries. Conditional on any (potentially differential) impact of the trade reforms on their respective costs, the product in the industry that experiences a 10 percentage point larger decline in output tariffs will have a 1.25 percent relative decline in markups.⁵² Column 2 instruments marginal costs to account for measurement error (see discussion in Section 4.2) with input tariffs and a second-order polynomial in lag marginal costs, and the coefficient declines but remains statistically significant. This analysis demonstrates

⁵⁰These results are robust to controlling for other contemporaneous policy changes in India, e.g., delicensing (results available upon request).

⁵¹To control for marginal costs as flexibly as possible, we use a second-order polynomial for marginal costs and suppress these coefficients in Table 10. We find very similar results if we simply include marginal costs as the only control (results are available upon request).

⁵²In unreported results, we include input tariffs in the regression. As discussed earlier, input tariffs should affect markups *only through* the imperfect transmission of their impact on costs through improved access to imported inputs. Once we control for marginal costs, input tariffs should have *no* effect on markups and that is what we find.

that although India’s trade reform led to large cost reductions leading firms to respond by raising markups. Once we control for these cost effects, output tariff reductions do exert pro-competitive effects by putting downward pressure on markups.

The pro-competitive effects might differ across products. For example, output tariffs may exert more pressure on products with high markups prior to the reform. We explore this heterogeneity by creating a time-invariant indicator for firm-product pairs in the top decile of their industry’s markup distribution in the first year that a product-pair is observed in the data. We interact output tariffs with this indicator to allow for differential effects of output tariffs on markups for these high markup products. The results are reported in column 3 of Table 10. The table shows a very strong effect of output tariffs on these high markup products: a 10 percentage point decline in output tariffs leads to a 1.04 percent fall in markups for products initially below the 90th percentile in the markup distribution. For high markup products, the same policy reform results in an additional 4.40 percent decline in markups. In short, once we control for the incomplete pass-through of costs, output tariffs reduce markups and these reductions are substantially more pronounced on products with initially high markups. We observe similar patterns when we account for measurement error in marginal costs by instrumenting in column 4.

4.4 Interpretation of Results: Variable Markups and Incomplete Pass-through

Our results call for a nuanced evaluation of the effects of the Indian trade liberalization on markups. While we do find evidence that the tariff reductions have pro-competitive effects, especially at the right tail of the markup distribution, our results suggest that the most significant effect of the reforms is to reduce costs to producers. Due to variable markups, cost reductions are not passed through completely to consumers.

This last finding raises the question of why prices do not fully respond to cost reductions. Our results here relate to a voluminous literature on price rigidities and incomplete pass-through in macroeconomics and international macroeconomics. While this literature has focused primarily on exchange rate pass-through, its findings are equally relevant to tariff reductions given that exchange rate and tariff changes have similar effects on firm profits. Structural approaches within this literature explain incomplete pass-through through a combination of demand side and market structure assumptions. As discussed in Section 4.2, there is a large class of potential models (i.e., combinations of demand side and market structure assumptions) that can generate this phenomenon. Incomplete pass-through requires the demand elasticity perceived by the firm to be rising in price, so any model that delivers a demand elasticity increasing in price will also deliver incomplete pass-through. For example, this pattern can be generated in a setting with a linear consumer demand and monopolistic competition as in Melitz and Ottaviano (2008). Alternatively, one could assume CES preferences and Cournot (e.g., Atkeson and Burstein (2008)), or nested logit and Bertrand (e.g., Goldberg (1995) or Goldberg and Verboven (2005)); or random coefficients and Bertrand (e.g., Goldberg and Hellerstein (2013) or Nakamura and Zerom (2010)). Which assumptions are appropriate depends on the industry under investigation. Against this background, the advantage

of our approach is precisely the fact that it establishes the existence of incomplete pass-through and explores its implications for trade policy without committing to a particular structure. Such structure may be defensible in the context of Industrial Organization case studies which rely on a careful study of the industry under consideration and its institutional setting to inform their assumptions. But it is less defensible in the context of an analysis of the entire Indian manufacturing sector that includes many heterogeneous industries, each likely characterized by different demand and market conditions. Our study demonstrates that variable markups generate incomplete cost pass-through in many different sectors, but it cannot answer the question of which fundamentals in each case generate variable markups. To answer this last question, one would need to impose more structure along the lines of the aforementioned studies, yet doing so would undermine the fundamental rationale and advantage of our approach.

Our results suggest that the trade reforms benefited producers relatively more than consumers, at least in the short run. However, this does not necessarily imply that the reform lowered consumer welfare, especially in the long run. There is an active literature studying the relationship between competition, firm profitability and innovation (e.g., see Aghion et al. (2005)). In Goldberg et al. (2010a), we show that firms introduced many new products—accounting for about a quarter of output growth—during this period. If the cost reductions (and associated markup increases) induced by the trade reform spurred this product growth, the benefits to consumers are potentially substantially larger. We also observe a positive correlation between changes in firm markups and product introductions (results available upon request).⁵³ This suggests that firms used the input tariff reductions and associated profit increases to finance the development of new products, implying potential long-term gains to consumers. A complete analysis of this mechanism and the impact on welfare lies beyond the scope of this current paper.

5 Conclusion

This paper examines the adjustment of prices, markups and marginal costs in response to trade liberalization. We take advantage of detailed price and quantity information to estimate markups from quantity-based production functions. Our approach does not require any assumptions on the market structure or demand curves that firms face. This feature of our approach is important in our context since we want to analyze how markups adjust to trade reforms without imposing *ex ante* restrictions on their behavior. An added advantage of our approach is that since we observe firm-level prices in the data, we can directly compute firms' marginal costs once we have estimates of the markups.

Estimating quantity-based production functions for a broad range of differentiated products introduces new methodological issues that we must confront. We propose an identification strategy based on estimating production functions on single-product firms. The advantage of this approach

⁵³These findings are consistent with Peters (2012) who develops a model with imperfect competition that generates heterogeneous markups which determine innovation incentives.

is that we do not need to take a stand on how inputs are allocated across products within multi-product firms. We also demonstrate how to correct for a bias that arises when researchers do not observe input price variation across firms, an issue that becomes particularly important when estimating quantity-based production functions.

The large variation in markups suggests that trade models that assume constant markups may be missing an important channel when quantifying the gains from trade. Furthermore, our results highlight the importance of analyzing the effects of both output and input tariff liberalization. We observe large declines in marginal costs, particularly due to input tariff liberalization. However, prices do not fall by as much. This imperfect pass-through occurs because firms offset the cost declines by raising markups. Conditional on marginal costs, we find pro-competitive effects of output tariffs on markups. Our analysis is based on data representative of larger firms, so our results are representative of these larger firms. Our results suggest that trade liberalization can have large, yet nuanced effects, on marginal costs and markups. Understanding the welfare consequences of these results using models with variable markups is an important topic for future research.

Our results have broader implications for thinking about the trade and productivity across firms in developing countries. The methodology produces quantity-based productivity measures that can be compared with revenue-based productivity measures. Hsieh and Klenow (2009) discuss how these measures can inform us about distortions and the magnitude of misallocation within an economy. Importantly, our methodology can deliver quantity-based productivity measures purged of substantial variation in markups across firms, which potentially improves upon our understanding of the role of misallocation in generating productivity dispersion. We leave the analysis of the role of misallocation on the distribution of these performance measures for future research.

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Tables and Figures

Table 1: Summary Statistics

Sector	Share of Sample		Single-Product	
	Output (1)	All Firms (2)	Firms (3)	Products (4)
15 Food products and beverages	10%	300	137	135
17 Textiles, Apparel	9%	331	196	78
21 Paper and paper products	3%	76	59	32
24 Chemicals	25%	462	216	483
25 Rubber and Plastic	5%	149	102	83
26 Non-metallic mineral products	6%	119	88	60
27 Basic metals	17%	232	142	101
28 Fabricated metal products	2%	76	55	45
29 Machinery and equipment	7%	171	83	186
31 Electrical machinery, communications	6%	95	55	102
34 Motor vehicles, trailers	9%	62	40	95
Total	100%	2,073	1,173	1,400

Notes: Table reports summary statistics for the sample. The first column reports the share of output by sector in 1995. Columns 2 and 3 report the number of firms and number of single-product firms manufacturing products in the sector in 1995. Column 4 reports the number of products over the full sample, 1989-2003.

Table 2: Example of Sector, Industry and Product Classifications

Examples of Industries, Sectors and Products	
NIC Code	Description
27	Basic Metal Industries (Sector <i>s</i>)
2710	Manufacture of Basic Iron & Steel (Industry <i>i</i>)
130101010000	Pig iron
130101020000	Sponge iron
130101030000	Ferro alloys
130106040800	Welded steel tubular poles
130106040900	Steel tubular structural poles
130106050000	Tube & pipe fittings
130106100000	Wires & ropes of iron & steel
130106100300	Stranded wire
2731	Casting of iron and steel (Industry <i>i</i>)
130106030000	Castings & forgings
130106030100	Castings
130106030101	Steel castings
130106030102	Cast iron castings
130106030103	Maleable iron castings
130106030104	S.G. iron castings
130106030199	Castings, nec

Notes: This table is replicated from Goldberg et al. (2010b). For NIC 2710, there are a total of 111 products, but only a subset are listed in the table. For NIC 2731, all products are listed in the table.

Table 3: Average Output Elasticities, by Sector

Sector	Observations in	Labor	Materials	Capital	Returns to
	Production				Scale
	Function				
	Estimation				
	(1)	(2)	(3)	(4)	(5)
15 Food products and beverages	774	0.20 [0.13]	0.67 [0.20]	0.23 [0.05]	1.10 [0.07]
17 Textiles, Apparel	1,574	0.13 [0.06]	0.77 [0.09]	0.14 [0.08]	1.04 [0.14]
21 Paper and paper products	470	0.25 [0.16]	0.65 [0.16]	0.02 [0.10]	0.92 [0.09]
24 Chemicals	1,552	0.22 [0.07]	0.73 [0.05]	0.17 [0.07]	1.11 [0.07]
25 Rubber and Plastic	705	0.13 [0.23]	0.67 [0.31]	0.09 [0.28]	0.89 [0.67]
26 Non-metallic mineral products	632	0.25 [0.34]	0.43 [0.22]	0.02 [0.43]	0.70 [0.66]
27 Basic metals	947	0.11 [0.20]	0.70 [0.18]	0.06 [0.20]	0.86 [0.41]
28 Fabricated metal products	392	0.05 [0.35]	0.50 [0.34]	-0.03 [0.34]	0.52 [1.01]
29 Machinery and equipment	702	0.32 [0.16]	0.57 [0.06]	0.34 [0.15]	1.24 [0.19]
31 Electrical machinery & communications	761	0.08 [0.17]	0.64 [0.24]	0.02 [0.15]	0.74 [0.47]
34 Motor vehicles, trailers	386	0.44 [0.59]	0.55 [0.25]	0.46 [0.63]	1.45 [1.19]

Notes: Table reports the output elasticities from the production function. The first column reports the number of observations for each production function estimation. Columns 2-4 report the average estimated output elasticity with respect to each factor of production for the translog production function for all firms. Standard deviations of the output elasticities are reported in brackets. The 5th column reports the average returns to scale, which is the sum of the preceding three columns.

Table 4: Median Output Elasticities, by Sector

Sector	Returns			
	Labor (1)	Materials (2)	Capital (3)	to Scale (4)
15 Food products and beverages	0.20	0.69	0.23	1.11
17 Textiles, Apparel	0.13	0.75	0.13	1.01
21 Paper and paper products	0.25	0.66	0.04	0.93
24 Chemicals	0.21	0.73	0.16	1.10
25 Rubber and Plastic	0.18	0.75	0.14	1.06
26 Non-metallic mineral products	0.29	0.46	0.14	0.84
27 Basic metals	0.14	0.72	0.09	0.97
28 Fabricated metal products	0.15	0.63	0.09	0.88
29 Machinery and equipment	0.32	0.57	0.33	1.18
31 Electrical machinery & communications	0.12	0.69	0.06	0.93
34 Motor vehicles, trailers	0.36	0.50	0.39	1.24

Notes: Table reports the median output elasticities from the production function. Columns 2-4 report the median estimated output elasticity with respect to each factor of production for the translog production function for all firms. The 5th column reports the median returns to scale.

Table 5: Output Elasticities, Input Price Variation and Sample Selection

Sector	Estimates without Correcting for Input Price Variation				Estimates without Correcting for Sample Selection			
	Labor (1)	Materials (2)	Capital (3)	Returns to Scale (4)	Labor (1)	Materials (2)	Capital (3)	Returns to Scale (4)
15 Food products and beverages	0.66	0.21	1.71	2.62	0.19	0.64	0.24	1.05
17 Textiles, Apparel	-0.02	0.58	-0.05	0.41	0.12	0.75	0.13	1.01
21 Paper and paper products	0.03	-0.09	-0.19	-0.48	0.27	0.62	0.03	0.92
24 Chemicals	0.71	0.67	-0.74	0.57	0.21	0.75	0.15	1.11
25 Rubber and Plastic	0.03	0.02	0.13	0.38	0.19	0.76	0.11	1.04
26 Non-metallic mineral products	0.27	0.30	0.92	1.43	0.24	0.48	0.18	0.90
27 Basic metal	-0.27	0.92	0.02	0.85	0.12	0.74	0.12	0.99
28 Fabricated metal products	-1.28	-0.67	2.18	0.26	0.16	0.65	0.08	0.90
29 Machinery and equipment	0.05	0.22	-0.21	0.29	0.29	0.56	0.34	1.15
31 Electrical machinery, communicati	-1.49	-0.08	0.31	-0.26	0.08	0.76	0.05	0.97
34 Motor vehicles, trailers	0.02	-0.46	1.63	0.84	0.26	0.53	0.31	1.07

Notes: The left table reports the median output elasticities from production function estimations that do not account for input price variation. The right panel reports the median output elasticities from production function estimations that do not account for sample selection.

Table 6: Markups, by Sector

Sector	Markups	
	Mean	Median
15 Food products and beverages	1.56	1.09
17 Textiles, Apparel	1.48	1.22
21 Paper and paper products	1.08	0.98
24 Chemicals	1.97	1.25
25 Rubber and Plastic	2.45	1.31
26 Non-metallic mineral products	3.22	1.51
27 Basic metals	2.57	1.11
28 Fabricated metal products	2.73	1.10
29 Machinery and equipment	1.93	1.00
31 Electrical machinery, communications	3.82	1.30
34 Motor vehicles, trailers	5.06	1.16
Average	2.24	1.18

Notes: Table displays the mean and median markup by sector for the sample 1989-2003. The table trims observations with markups that are above and below the 3rd and 97th percentiles within each sector.

Table 7: Pass-Through of Costs to Prices

	Log Price _{ijt}		
	(1)	(2)	(3)
Log Marginal Cost _{ijt}	0.360 ***	0.427 ***	0.572 **
	0.042	0.084	0.251
Observations	21,122	15,887	12,232
Within R-squared	0.30	0.25	0.09
Firm-Product FEs	yes	yes	yes
Instruments	-	yes	yes
First-Stage F-test	-	59	7

Notes: The dependent variable is (log) price. Column 1 is an OLS regression on log marginal costs. Column 2 instruments marginal costs with input tariffs and lag marginal costs. Column 3 instruments marginal costs with input tariffs and two-period lag marginal costs. The regressions exclude outliers in the top and bottom 3rd percent of the markup distribution. All regressions include firm-product fixed effects. The regressions use data from 1989-1997. The standard errors are bootstrapped and are clustered at the firm level. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 8: Prices and Output Tariffs, Annual Regressions

	Log Prices _{fit}	
	(1)	(2)
Output Tariff _{it}	0.129 **	0.161 ***
	0.058	0.055
Within R-squared	0.00	0.02
Observations	21,122	21,122
Firm-Product FEs	yes	yes
Year FEs	yes	no
Sector-Year FEs	no	yes
Overall Impact of Trade Liberalization	-8.0 **	-10.0 ***
	3.6	3.4

Notes: The dependent variable is a firm-product's (log) price. Column 1 includes year fixed effects and Column 2 includes sector-year fixed effects. The regressions exclude outliers in the top and bottom 3rd percent of the markup distribution. All regressions include firm-product fixed effects and use data from 1989-1997. Standard errors are clustered at the industry level. The final row uses the average 62% decline in output tariffs from 1989-1997 to compute the mean and standard error of the impact of trade liberalization on prices. That is, for each column the mean impact is equal to the $-0.62 \cdot 100 \cdot \{\text{coefficient on output tariffs}\}$. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 9: Prices, Costs and Markups and Tariffs

	Log Prices _{ijt}	Log Marginal Cost _{ijt}	Log Markup _{ijt}
	(1)	(2)	(3)
Output Tariff _{it}	0.149 ***	0.084	0.065
	0.056	0.085	0.077
Input Tariff _{it}	0.372	1.253 **	-0.881 *
	0.303	0.523	0.489
Within R-squared	0.02	0.01	0.01
Observations	21,122	21,122	21,122
Firm-Product FEs	yes	yes	yes
Sector-Year FEs	yes	yes	yes
Overall Impact of Trade Liberalization	-18.1 **	-35.2 ***	17.0
	7.3	12.8	11.8

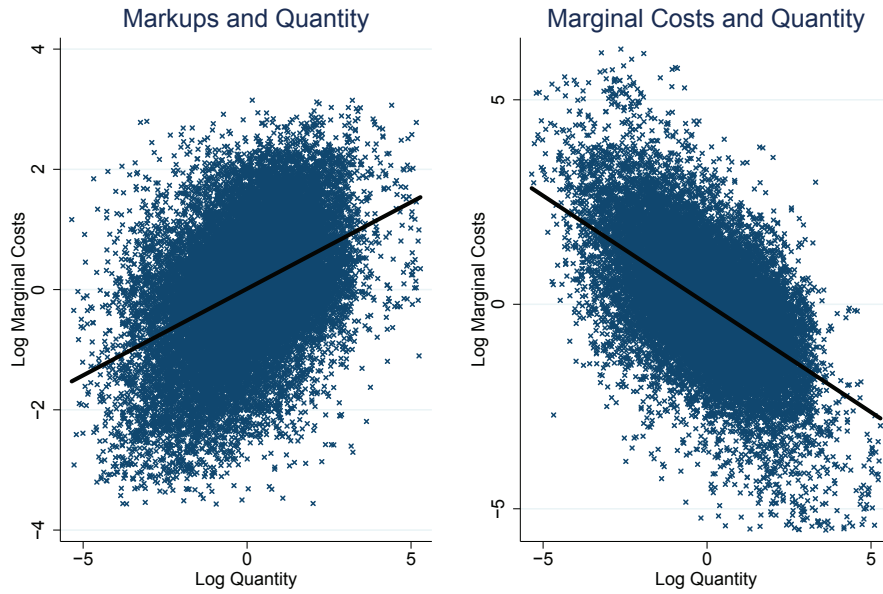
Notes: The dependent variable is noted in the columns. The sum of the coefficients from the markup and marginal costs regression equals their respective coefficient in the price regression. The regressions exclude outliers in the top and bottom 3rd percent of the markup distribution, and include firm-product fixed effects and sector-year fixed effects. The final row uses the average 62% and 24% declines in output and input tariffs from 1989-1997, respectively, to compute the mean and standard error of the impact of trade liberalization on each performance measure. That is, for each column the mean impact is equal to the $-0.62 \cdot 100 \cdot \{\text{coefficient on output tariff}\} + -0.24 \cdot 100 \cdot \{\text{coefficient on input tariff}\}$. The regressions use data from 1989-1997. The table reports the bootstrapped standard errors that are clustered at the industry level. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 10: Pro-Competitive Effects of Output Tariffs

	Log Markup _{ijt}			
	(1)	(2)	(3)	(4)
Output Tariff _{it}	0.125 **	0.127 **	0.104 **	0.117 *
	0.049	0.061	0.051	0.061
Output Tariff _{it} x Top _{fp}			0.440 ***	0.213
			0.142	0.156
Within R-squared	0.58	0.57	0.58	0.57
Observations	21,122	15,887	21,122	15,887
2nd-Order Marginal Cost Polynomial	yes	yes	yes	yes
Firm-Product FEs	yes	yes	yes	yes
Sector-Year FEs	yes	yes	yes	yes
Instruments	no	yes	no	yes
First-stage F-test	-	8.1	-	8.1

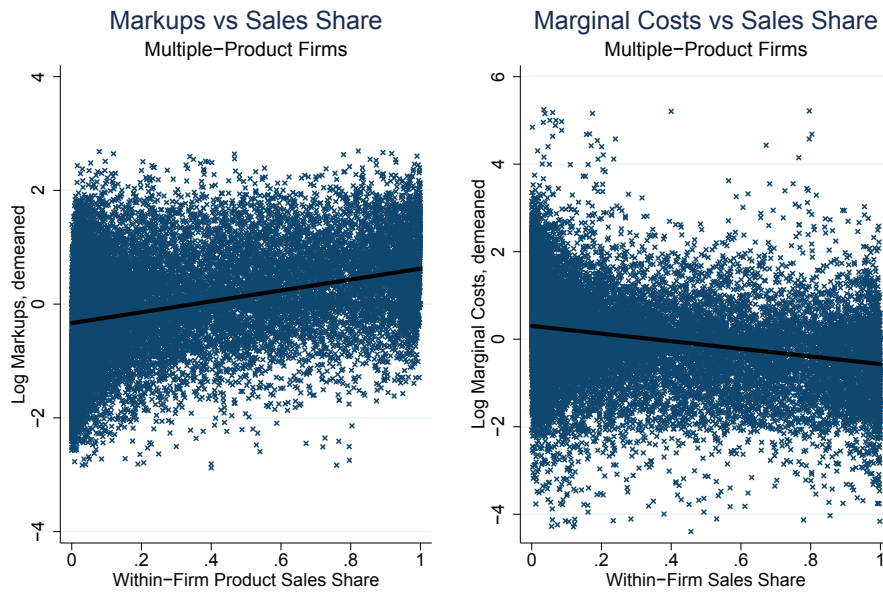
Notes: The dependent variable is (log) markup. All regressions include firm-product fixed effects, sector-year fixed effects and a second-order polynomial of marginal costs (these coefficients are suppressed and available upon request). Columns 2 and 4 instrument the second-order polynomial of marginal costs with second-order polynomial of lag marginal costs and input tariffs. Column 3 interacts output tariffs and the second-order marginal cost polynomial with an indicator if a firm-product observation was in the top 10 percent of its sector's markup distribution when it first appears in the sample. The regressions exclude outliers in the top and bottom 3rd percent of the markup distribution. The table reports the bootstrapped standard errors that are clustered at the industry level. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Figure 1: Marginal Costs and Quantities



Variables demeaned by product-year FEs.
Markups, cost and quantity outliers are trimmed below and above 3rd and 97th percentiles.

Figure 2: Markups, Costs and Product Sales Share



Markups and marginal costs are demeaned by product-year and firm-year FEs.
Markup and marginal cost outliers are trimmed below and above 3rd and 97th percentiles.

Figure 3: Distribution of Prices in 1989 and 1997

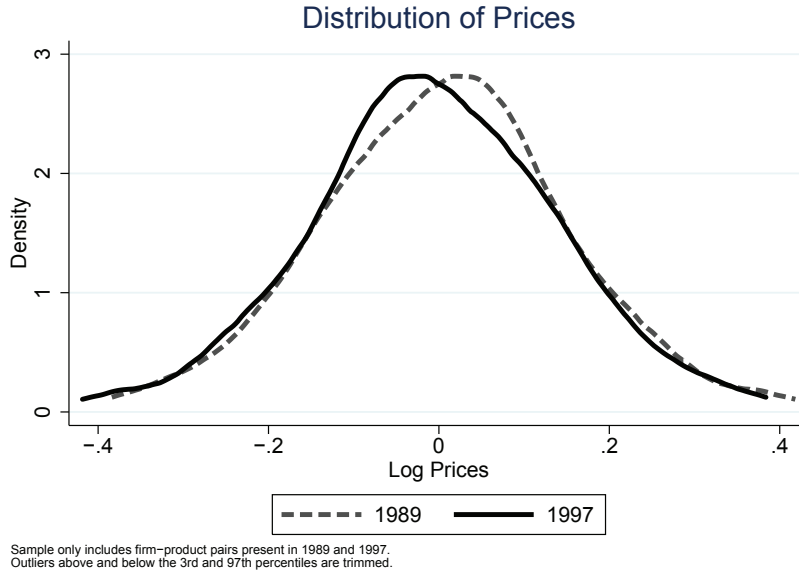
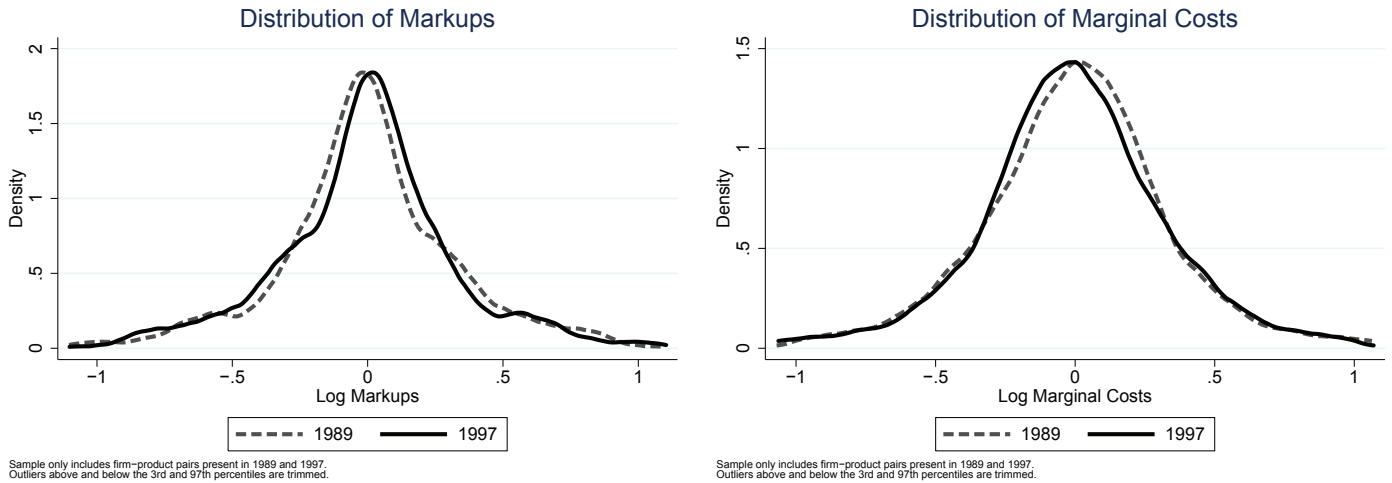


Figure 4: Distribution of Markups and Marginal Costs in 1989 and 1997



Appendix

A A Formal Model of Input Price Variation

This appendix provides a formal economic model that rationalizes the use of a flexible polynomial in output price, market share and product dummies to control for input prices. The model is a more general version of the models considered in Kremer (1993) and Verhoogen (2008).

We proceed in the following steps. We first show that under the assumptions of the model, the

quality of *every* input is an increasing function of output quality. Next, we show that this implies that the price of *every* input will be an increasing function of output quality. In the final step, we show that output quality can be expressed as a flexible function of output price, market share and a set of product dummies. Having established a monotone relationship between input prices and output quality, this implies that the price of every input can also be expressed as a function of the above variables.

A.1 Production Function for Output Quality

In order to proceed, we must specify the production function for quality. Let v_j indicate quality of product j and ψ_i indicate the quality of input i used to produce product j .⁵⁴ The production function for output quality is given by:

$$v_j = \prod_{i=1}^n [\psi_i]^{\kappa_i} \omega_j \quad \text{with} \quad \sum \kappa_i < 1 \quad (\text{A.1})$$

For example, with three inputs, the above production function takes the form:

$$v_j = \psi_K^{\kappa_K} \psi_L^{\kappa_L} \psi_M^{\kappa_M} \omega_j$$

This function belongs to the class of ‘O-Ring’ production functions discussed in Kremer (1993) and Verhoogen (2008). The particular (multiplicative) functional form is not important; the important feature is that $\frac{\partial v_j}{\partial \psi_i \partial \psi_k} > 0, \forall i, k$ and $i \neq k$. This cross-derivative implies complementarity in the quality of inputs. A direct consequence is that higher output quality requires high quality of *all* inputs (e.g., high quality material inputs are used by high-skill workers operating high-end machinery).

In addition to the production function for quality, we assume that higher quality inputs are associated with higher input prices. Let \bar{W}_i denote the sectoral average of the price of input i (e.g., sectoral wage) and $W_i(\psi_i)$ the price of a specific quality ψ of input i . Then,

$$W_i(\psi_i) - \bar{W}_i = z_i \psi_i \quad \text{and} \quad z_i > 0. \quad (\text{A.2})$$

The equation above says that in order to use higher quality inputs, a firm needs to pay higher input prices. There are many ways to justify this relationship. For example, if input markets are competitive but have vertical differentiation, firms must pay higher prices for higher quality inputs. So while high quality inputs are expensive, all firms pay the same input prices *conditional* on input quality.

A.2 Demand

We close the model by specifying the demand and firms’ behavioral assumptions.

⁵⁴Here, the subscript j denotes a particular product produced by a firm.

The indirect utility V_{nj} that consumer n derives from consuming one unit of product j can be written in general form as:

$$V_{nj} = \theta_n v_j - \alpha p_j + \varepsilon_{nj} \quad (\text{A.3})$$

where p_j is output price, θ_n denotes the willingness to pay for quality and ε_{nj} denotes an idiosyncratic preference shock. This specification is general and encompasses all demand models commonly used in the literature. In its most general formulation, the specification above corresponds to the random coefficients model. In models of pure vertical differentiation, the utility will be given by the above expression with $\varepsilon_{nj} = 0$. A simple logit sets $\theta_n = \theta = 1$ (i.e., no observable consumer heterogeneity) and ε_{nj} is assumed to follow the extreme value distribution. In the nested logit, $\theta_n = \theta = 1$ and ε_{nj} follows the generalized extreme value distribution. Following the Industrial Organization literature, it is convenient to define the mean utility δ_j of product j as $\delta_j = v_j - \alpha p_j$. The output quality v_j is typically modeled as a function of product characteristics.

We now show how to control for quality variation across firms using observable characteristics using the specification in (A.3). Berry (1994) shows that the actual market share of a product (ms_j) is a function of product characteristics and output price:

$$ms_j = s_j(\boldsymbol{\delta}, \boldsymbol{\sigma}) = s_j(\mathbf{v}, \mathbf{p}, \boldsymbol{\vartheta}) \quad (\text{A.4})$$

where $\boldsymbol{\sigma}$ denotes a vector of density parameters of consumer characteristics and $\boldsymbol{\vartheta}$ denotes a parameter vector. While the exact functional form is determined by choice of a particular demand structure, the general insight is that market shares are a function of product characteristics (i.e., quality) and prices. Berry (1994) shows that equation (A.4) can be inverted to obtain the mean utilities $\boldsymbol{\delta}$ as a function of the observed market shares and the density parameters to be estimated.⁵⁵ With the δ 's in hand, quality is function of output price and the mean utility. This insight is exploited by Khandelwal (2010) who uses a nested logit model to express quality as a function of output price and conditional and unconditional market shares. In a simple logit model, quality is a function of only output prices and unconditional market shares. Here, we use a general formulation that specifies quality as a function of output price, a vector of (conditional and unconditional) market shares and a set of product dummies:

$$v_j = v(p_j, \mathbf{ms}_j, \mathbf{D}) \quad (\text{A.5})$$

The product dummies are used in lieu of product characteristics (which are not available in our data) and can accommodate more general demand specifications such as the nested logit and random coefficients model.

⁵⁵In the random coefficients model, the δ 's are solved numerically. In simpler models, one can solve for the parameters analytically.

A.3 The Firm's Maximization Problem

Without loss of generality, we assume that firms use prices and quality as strategic variables to maximize profits. Conditional on exogenous (to the firm) input prices that are determined in competitive input markets, firms choose input qualities. These choices determine the output quality according to the quality production function in (A.1). Let mc_j denote the marginal cost of producing a product j of quality v_j . The marginal cost can be written as a function of quantity produced q_j , quality v_j , a parameter vector γ and productivity ω_j , $mc_j(q_j, v_j, \gamma, \omega_j)$.

The profit function for a firm producing product j is:

$$\pi_j = N \cdot s_j [p - mc_j(q_j, v_j(\boldsymbol{\psi}, \omega_j), \gamma, \omega_j)] \quad (\text{A.6})$$

where N denotes the market size (number of potential consumers). Output quality v_j is now explicitly written as a function of a vector of input qualities $\boldsymbol{\psi}$ and productivity ω_j using the production function for quality in (A.1).

The first order condition with respect to price is

$$p_j = mc_j(q_j, v_j, \gamma, \omega_j) + \frac{s_j}{|\partial s_j / \partial p_j|}. \quad (\text{A.7})$$

The term $s_j / |\partial s_j / \partial p_j|$ represents the markup, and as shown in Berry (1994), p. 254) it equals $\frac{1}{\alpha} [s_j / (\partial s_j / \partial \delta_j)]$.

The first order condition with respect to the quality of each input i , ψ_i , is:

$$(p_j - mc_j) \cdot \frac{\partial s_j}{\partial \psi_i} - s_j \frac{\partial mc_j}{\partial \psi_i} = 0 \quad (\text{A.8})$$

From the first order condition with respect to price, we have

$$(p_j - mc_j) = \frac{s_j}{|\partial s_j / \partial p_j|} = \frac{1}{\alpha} \frac{s_j}{\partial s_j / \partial \delta_j}. \quad (\text{A.9})$$

Substituting this latter expression for the markup into the first order condition for input quality, we obtain:

$$s_j \frac{1}{\alpha} [1 / (\partial s_j / \partial \delta_j)] \frac{\partial s_j}{\partial \psi_i} - s_j \frac{\partial mc_j}{\partial \psi_i} = 0 \quad (\text{A.10})$$

or

$$\frac{1}{\alpha} [1 / (\partial s_j / \partial \delta_j)] \left[\frac{\partial s_j}{\partial v_j} \frac{\partial v_j}{\partial \psi_i} \right] = \frac{\partial mc_j}{\partial \psi_i} \quad (\text{A.11})$$

From $\delta_j = v_j - \alpha p_j$ follows that $\frac{\partial s_j}{\partial v_j} = \frac{\partial s_j}{\partial \delta_j}$, and the above first order condition simplifies to:

$$\frac{1}{\alpha} \frac{\partial v_j}{\partial \psi_i} = \frac{\partial mc_j}{\partial \psi_i} \quad (\text{A.12})$$

Using the production function for quality to obtain the derivative $\frac{\partial v_j}{\partial \psi_i}$ and substituting into (A.12), we obtain

$$\psi_i = \frac{1}{\alpha} \kappa_i v_j \left[1 / \frac{\partial mc_j}{\partial \psi_i} \right] \quad \forall i \quad (\text{A.13})$$

This expression is similar to the one derived in Verhoogen (2008), but with two differences. First, as we have shown above, the above expression can be derived from a very general demand system and market structure. Second, we did not assume a Leontief production technology. The last feature of the model complicates the analysis slightly. With a Leontief production technology, the derivative $\frac{\partial mc_j}{\partial \psi_i}$ is constant, and it will be positive given the assumption that higher quality inputs demand higher prices. However, with more general production technologies, this derivative will itself depend on quality. We therefore need to show explicitly that ψ_i is an increasing function of v_j . The latter can be established using the second order conditions associated with profit maximization:

$$\begin{aligned} \frac{1}{\alpha} \kappa_i \frac{\partial v_j}{\partial \psi_i} \frac{1}{\psi_i} - \frac{1}{\alpha} \kappa_i v_j \frac{1}{(\psi_i)^2} - \frac{\partial^2 mc_j}{\partial \psi_i^2} &< 0 \\ \frac{1}{\alpha} \kappa_i^2 \frac{v_j}{(\psi_i)^2} - \frac{1}{\alpha} \kappa_i \frac{v_j}{(\psi_i)^2} - \frac{\partial^2 mc_j}{\partial \psi_i^2} &< 0 \end{aligned} \quad (\text{A.14})$$

Let us define function $F \equiv \psi_i \left(\frac{\partial mc_j}{\partial \psi_i} \right) - \frac{1}{\alpha} \kappa_i v_j$. From the implicit function theorem, $\frac{\partial \psi_i}{\partial v_j} = -\frac{F_j}{F_i}$ where

$$F_j = -\frac{1}{\alpha} \kappa_i < 0 \quad (\text{A.15})$$

and by virtue of the second order condition,

$$F_i = \frac{\partial mc_j}{\partial \psi_i} + \psi_i \frac{\partial^2 mc_j}{\partial \psi_i^2} - \frac{1}{\alpha} \kappa_i^2 \frac{v_j}{\psi_i} = \frac{1}{\alpha} \kappa_i v_j \frac{1}{\psi_i} + \psi_i \frac{\partial^2 mc_j}{\partial \psi_i^2} - \frac{1}{\alpha} \kappa_i^2 \frac{v_j}{\psi_i} > 0 \quad (\text{A.16})$$

It follows that $\frac{\partial \psi_i}{\partial v_j} = -\frac{F_j}{F_i} > 0$. That is, input quality is an increasing function of output quality for every input.

Given the assumption that higher input quality demands a higher input price, it immediately follows that input prices will also be an increasing function of output quality for all inputs. From equation (A.2):

$$W_i(\psi_i) = \bar{W}_i + z_i \psi_i = \bar{W}_i + z_i \frac{1}{\alpha} \kappa_i v_j \left[1 / \frac{\partial mc_j}{\partial \psi_i} \right]$$

In light of the above discussion, each input price facing a particular firm can be expressed as a function of the firm's output quality, $W_i = g(v_j)$. Moreover, given that output quality is a function of output price, market share and product dummies, we have: $W_i = w(p_j, \mathbf{ms}_j, \mathbf{D})$.

B Estimation Procedure under a Special Case: Cobb-Douglas Production Function

We present our estimation procedure under the predominantly used production function specification in applied work: the Cobb-Douglas (CD) production function. While restrictive on the input-substitution patterns and the output elasticities, it greatly simplifies the estimation routine and the recovery of the input allocation terms (ρ). In addition, it helps to highlight the fundamental identification forces as the input price correction term does not include (interactions of) deflated expenditures.

We follow the structure of the main text (Section 3) and impose the CD functional form:

$$f(\mathbf{x}_{fjt}) = \beta_l l_{fjt} + \beta_m m_{fjt} + \beta_k k_{fjt}. \quad (\text{B.1})$$

Following the same steps as in the main text we get the following estimating equation for the single-product firms corresponding to equation (10). We omit the product subscript j given that the firms used in the estimation produce a single product:

$$q_{ft} = \beta_l \tilde{l}_{ft} + \beta_m \tilde{m}_{ft} + \beta_k \tilde{k}_{ft} - \Gamma w_{ft} + \omega_{ft} + \epsilon_{ft}, \quad (\text{B.2})$$

where $\Gamma w(\cdot)$ is a special case of the function $B(\cdot)$ in the main text, $\Gamma = \beta_l + \beta_m + \beta_k$ is the returns to scale parameter, and as before $w_{ft} = \tilde{x}_{ft} - x_{ft} \forall x = \{l, m, k\}$.

After running the first stage

$$q_{ft} = \phi_t(\tilde{\mathbf{x}}_{ft}, \mathbf{z}_{ft}) + \epsilon_{ft}, \quad (\text{B.3})$$

with $\tilde{\mathbf{x}}_{ft} = \{\tilde{l}_{ft}, \tilde{m}_{ft}, \tilde{k}_{ft}\}$, we have an estimate of predicted output ($\hat{\phi}_{ft}$). It is then immediate that the input price correction term $B(\cdot)$ enters in equation (20) in a separate and additive fashion:

$$\omega_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta}) = \hat{\phi}_{ft} - \beta_l \tilde{l}_{ft} - \beta_m \tilde{m}_{ft} - \beta_k \tilde{k}_{ft} - \Gamma w(p_{ft}, \mathbf{ms}_{ft}, \mathbf{D}, \mathbf{G}_{ft}; \boldsymbol{\delta}), \quad (\text{B.4})$$

where $-\Gamma w(\cdot)$ is a special case of the function $B(\cdot)$ in the main text. If one assumes a vertical differentiation model of demand, then the input price control function $w(\cdot)$ will take only output price as its argument, and the last term in (B.4) becomes $\Gamma w(p_{ft}, \boldsymbol{\delta})$. We form moments on $\xi_{ft}(\boldsymbol{\beta}, \boldsymbol{\delta})$ by exploiting the same law of motion of productivity in equation (18), and the same timing assumptions as in the main text.

To estimate markups and marginal costs we need the input allocation terms ρ_{fjt} . In the case of the CD, their derivation is simplified to solving the system of equations given by:

$$\omega_{ft} + \Gamma \rho_{fjt} \hat{w}_{fjt} = \hat{\phi}_{fjt} - \beta_l \tilde{l}_{ft} - \beta_m \tilde{m}_{ft} - \beta_k \tilde{k}_{ft} \quad (\text{B.5})$$

where \hat{w}_{fjt} is the input price term that we compute based on the estimated function $w(\cdot)$ and Γ is defined as above. Taking into account that $\sum_j \exp(\rho_{fjt}) = 1$, this results in a system of $J_{ft} + 1$

equations (one for each product j produced by firm f at time t , plus the summing up constraint for the input allocations) in $J_{ft} + 1$ unknowns (the J_{ft} input allocations for each firm-year pair and firm productivity) and we can solve for ρ_{fjt} and ω_{ft} .

We now have all we need to compute markups and marginal costs. The major difference is that $\theta_{fjt}^M = \beta_m$, so that all the variation in markups (and marginal costs) comes from the expenditure share α_{fjt} .

C Data Appendix

We use the Prowess data, compiled by the Centre for Monitoring the Indian Economy (CMIE), that spans the period from 1989 to 2003. In addition to standard firm-level variables, the data include annual sales and quantity information on firms' product mix. Although Prowess uses an internal product classification that is based on the Harmonized System (HS) and National Industry Classification (NIC) schedules, our version of Prowess did not explicitly link the product names reported by the firms to this classification. We hired two research assistants, working independently, to map the codes to the product names reported by firms. The research assistants assigned product codes with identical NIC codes in 80% of the cases, representing 91% of output. A third research assistant resolved the differences between the mappings done by the first two research assistants by again manually checking the classifications.

To estimate the production function, we need firm-level labor, capital and materials. Prowess does not have reliable employment information, so we use the total wage bill (which includes bonuses and contributions to employees' provident funds) as our measure for labor. Materials are defined as the consumption of commodities by an enterprise in the process of manufacturing or transformation into product. It includes raw material expenses and consumption of stores and spares. Capital is measured by gross fixed assets, which includes movable and immovable assets. These variables are deflated by two-digit NIC wholesale price indexes.

We match the firm variables to tariff data. The tariff data are reported at the six-digit HS level and were compiled by Topalova (2010). We pass the tariff data through India's input-output matrix for 1993-94 to construct input tariffs. We concord the tariffs to India's NIC schedule developed by Debroy and Santhanam (1993). Formally, input tariffs are defined as $\tau_{it}^{\text{input}} = \sum_k a_{ki} \tau_{kt}^{\text{output}}$, where $\tau_{kt}^{\text{output}}$ is the tariff on industry k at time t , and a_{ki} is the share of industry k in the value of industry i .

D Markups and Monopsony Power

If firms have monopsony power, this would alter the first order conditions in Section 3.1 (equations 3-5). We briefly discuss under which conditions our main results, relating markups to tariff changes, are not affected.

Consider a firm that produces just one product, and suppose production requires just one flexible

input V_{ft}^v . The Lagrangian in this case would be:

$$\mathcal{L} = W_{ft}^v V_{ft}^v + \lambda_{ft} (Q_{ft} - Q_{ft}(V_{ft}^v, \omega_{ft})). \quad (\text{D.1})$$

Taking first order conditions and allowing for monopsony power gives:

$$\frac{\partial \mathcal{L}}{\partial V_{ft}^v} = W_{ft}^v + \frac{\partial W_{ft}^v}{\partial V_{ft}^v} V_{ft}^v - \lambda_{ft} \frac{\partial Q(\cdot)}{\partial V_{ft}^v} = 0. \quad (\text{D.2})$$

If a firm has no monopsony power, $\frac{\partial W_{ft}^v}{\partial V_{ft}^v} = 0$. For firms with monopsony power, $\frac{\partial W_{ft}^v}{\partial V_{ft}^v} < 0$: the more the firm buys, the lower the price of the input. We can rearrange the FOC as:

$$W_{ft}^v + \frac{\partial W_{ft}^v}{\partial V_{ft}^v} V_{ft}^v = \lambda_{ft} \frac{\partial Q(\cdot)}{\partial V_{ft}^v} \quad (\text{D.3})$$

The Lagrange multiplier remains: $\lambda_{ft} = P_{ft}/\mu_{ft}$, we get

$$\mu_{ft} \left(W_{ft}^v + \frac{\partial W_{ft}^v}{\partial V_{ft}^v} V_{ft}^v \right) = P_{ft} \frac{\partial Q(\cdot)}{\partial V_{ft}^v}. \quad (\text{D.4})$$

If we now compare a firm with and without monopsony power, *ceteris paribus*, the markup for the firm with monopsony power will be larger. This implies that we may be under-estimating the markup by ignoring potential monopsony power.

However, even if our estimates of the markup levels were biased due to the existence of monopsony power, it is still unlikely that our conclusions regarding the effects of tariffs on markups and costs would be affected. To see this, note that the above expression can be simplified to⁵⁶

$$\mu_{ft} = (\theta_{ft} \alpha_{ft}^{-1}) / (1 + v_{ft}). \quad (\text{D.5})$$

where v is the elasticity of the input price with respect to the quantity of the input purchased $v_{ft} = \frac{\partial W_{ft}^v}{\partial V_{ft}^v} \frac{V_{ft}^v}{W_{ft}^v}$, and the other variables are as defined in the main text. If there is no monopsony power, then $v_{ft} = 0$, and the markup expression corresponds to the one we use in the main text of the paper. Taking logs of the more general markup expression implies that in our trade regressions (see Section 4.3) we run $\ln \mu_{ft} + \ln(1 + v_{ft})$ against output and input tariffs (in multi-product firms, markups and input price elasticities would be indexed by both firm f and product j). The inclusion of firm-product fixed effects implies that we will only bias our results if the input price elasticity changed post-trade reforms. Moreover, we have two empirical pieces of evidence that our results are robust to monopsony power. We might expect that the firms that are most likely to have monopsony power are larger firms or firms that are parts of Indian business groups. However we do not find differential effects of the trade reform across initial firm sizes or if a firm belongs to a

⁵⁶Dividing through by W^v , and dividing and multiplying the right-hand-side by (V^v/Q) , and rearranging terms.

business group.⁵⁷ This leads us to believe that monopsony power is not a first order concern in our setting.

⁵⁷Results are available upon request.