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Import Competition and Vertical Integration: Evidence from India

Joel Stiebale Dev Vencappa [1]

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Abstract

Recent theoretical contributions provide conflicting predictions about the effects of product market competition on firms' organizational choices. This paper uses a rich firm-product-level panel data set of Indian manufacturing firms to analyze the relationship between import competition and vertical integration. Exploiting exogenous variation from changes in India's trade policy, we find that foreign competition, induced by falling output tariffs, increases backward vertical integration by domestic firms. The effects are concentrated among firms with high productivity and in industries with relatively low initial levels of competition. In contrast, falling input tariffs seem to have countervailing effects on vertical integration incentives. We also provide evidence that vertical integration is associated with lower marginal costs and increasing markups at the firm-product level.

JEL codes: *F14, F61, L25, L22, L23*
Keywords: *Trade Liberalization, Competition, Vertical Integration, Markups, Marginal Costs*

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1 Introduction

There has been a long-standing interest in the adjustment of firms to trade liberalization and foreign competition. Seminal theoretical and empirical contributions stress the reallocation of resources across heterogeneous firms within industries as a mechanism by which international trade raises industry-level productivity (e.g., Melitz, 2003; Pavcnik, 2002). Over time, the focus has shifted towards analyzing adjustments *within* firms via productivity-enhancing investment (see, for instance, Bustos, 2011; Lileeva and Trefler, 2010) or changes in firms' product mix (Bernard et al., 2012; Eckel and Neary, 2010) as an important component of potential gains from trade.[1] These adjustments play a crucial role in developing countries which are typically characterized by less advanced technologies and low productivity.[2]

Recently, it has been pointed out that international competition can also affect productivity via firms' organizational choices such as their vertical integration intensity (Acemoglu et al., 2010; Alfaro et al., 2016; Aghion et al., 2006; Conconi et al., 2012; Legros and Newman, 2013, 2014).[3] However, the theoretical literature often yields mixed and non-monotonic predictions regarding the effects of product market competition on the organizational structure of domestic firms (Grossman and Helpman, 2002; Aghion et al., 2006; Legros and Newman, 2014).[4] Therefore, the question of how import competition affects vertical integration in domestic firms ultimately boils down to an empirical matter. An empirical test of this relationship is not only of theoretical interest but also highly relevant for economic policy. There is evidence that vertical integration is often associated with higher productivity, lower prices, and enhanced innovation incentives.[5] Vertical integration is arguably of particularly importance for firms in developing countries as a means of dealing with poor contract enforcement (e.g., Boehm and Oberfield, 2020; Du et al., 2012; Khanna and Palepu, 2000). Hence, if competition reduces incentives for vertical integration as argued by recent research (e.g., Conconi et al., 2012; Legros and Newman, 2014), policy measures such as deregulation and trade liberalization might have unintended consequences for the developing world.

This paper provides evidence on the effects of import competition, induced by falling output tariffs, on vertical integration decisions in the context of India's manufacturing sector. The case

[1] See also the surveys of related empirical literature in Bernard et al. (2012) and Shu and Steinwender (2019). For recent applications in the context of developing countries, see Linarello (2018) or Liu et al. (2021).

[2] Verhoogen (2020) provides an overview of the determinants of technology upgrading in developing countries.

[3] Recent empirical studies that analyze the role of competition and trade for other aspects of firm organization include Cuñat and Guadalupe (2009); Bloom et al. (2010); Guadalupe and Wulf (2010); Marin and Verdier (2014); Görg and Hanley (2017); Chakraborty and Raveh (2018); Chakraborty and Sundaram (2019).

[4] Another strand of literature analyzes vertical integration and outsourcing of multinational firms in international markets (e.g. McLaren, 2000; Grossman and Helpman, 2003; Antràs and Helpman, 2004; Antràs, 2013). In this paper, we are primarily concerned with the effects of import competition on *domestic* firms' vertical integration.

[5] Although vertical integration can have anti-competitive effects via foreclosure, it is often found that the positive effects (from a welfare perspective) dominate (e.g., Hortaçsu and Syverson, 2007; Lafontaine and Slade, 2007; Slade, 2020; Hansman et al., 2020).

of India is particularly interesting for several reasons. First, Indian firms have been exposed to a substantial decline in output tariffs. The average most-favored nation tariff across industries—our inverse measure of import competition—fell from more than 100% in 1989 to about 15% towards the end of our sample period and varies substantially across products. The decline in tariffs was arguably associated with a large increase in foreign competition. As documented by Goldberg et al. (2009), real imports in the early trade liberalization episode, 1989 to 1997, increased by 130%. In line with the previous literature, we document that falling output tariffs are associated with higher import penetration at the industry level, lower markups and reduced output in domestic firms. Previous empirical evidence shows that variations in this decline of output tariffs across industries has been mostly unaffected by lobbying of domestic firms and displays little correlation with industry performance in years before tariff changes (e.g., Goldberg et al., 2010a; Topalova and Khandelwal, 2011). Therefore, tariffs provide plausibly exogenous variation to the vertical integration decisions of domestic firms in India. In contrast to previous studies that exploit variations in tariffs across industries or industry-country pairs to analyze the relationship between competition and vertical integration, we provide within-country evidence and are able to control for unobserved heterogeneity across firms, products and industries. Finally, the legal requirement for Indian firms to report product-level production and sales data facilitates a more refined analysis of markups, which is important for our empirical approach.

Vertical integration is arguably of particular importance for Indian firms. Indian courts are infamously reputed to be very slow and congested and score very poorly in the area of contract enforcement (India ranked 163 out of 190 countries in the 2020 World Bank's Doing Business report).[6] Boehm and Oberfield (2020) find that in Indian states with weak contract enforcement, the organisation of production leans heavily towards a more vertically integrated model, and Alfaro et al. (2016) document that Indian firms are characterized by the highest degree of vertical integration across more than 200 countries. Furthermore, previous research has found that the Indian economy has been characterized by substantial misallocation of inputs across firms (Hsieh and Klenow, 2009) and high within-industry dispersion of productivity compared to other countries (see, for instance, Syverson, 2011). Vertical integration is a factor that potentially explains a significant part of this variation in efficiency across firms and time.

To measure vertical integration, we follow previous empirical studies (e.g., Acemoglu et al., 2009; Alfaro et al., 2016) and construct an index based on the products firms produce and input-output tables. Specifically, we measure the fraction of inputs used in the production of a product that can be produced within the firm.[7] Our results show that this measure is significantly negatively

[6] See `https://www.doingbusiness.org/en/doingbusiness` accessed online on 30 June 2021.

[7] We focus on backward (rather than forward) vertical integration, i.e. inputs being integrated into downstream

correlated with output tariffs, indicating that foreign competition induces vertical integration by domestic firms. This result is robust to limiting the analysis to a firm's core product or assessing all products a firm produces; it is also robust to controlling for firm-product fixed effects, sectoral trends, input tariffs, various other industry- and firm-level control variables and—for a subsample of multi-product firms— firm-year fixed effects. This allows us to rule out several alternative explanations for our results that are based on unobservable time-varying factors at the firm or industry-level.

A possible explanation for our results is that Indian firms vertically integrate to escape foreign competition. Consistent with the view that vertical integration is a productivity-enhancement investment or improves product quality, we provide evidence that vertical integration events in our sample are associated with lower marginal costs and higher profitability.

A large literature has analyzed how the incentives for productivity-enhancing investments respond to changes in (foreign) competition (see Shu and Steinwender, 2019, for an overview). On the one hand, competition reduces profit margins and market shares per firm and thus the returns to investment—the well-known Schumpeterian effect. On the other hand, competition also decreases rents in the absence of investment, inducing firms to invest to escape competition.[8] Aghion et al. (2005) were the first to formalize these countervailing mechanisms in a duopoly model, but recent papers extend their framework to account for more general market structure and explicitly model *import* competition. For instance, Bombardini et al. (2018) incorporate productivity-enhancing investment into the heterogeneous firm framework developed by Melitz and Ottaviano (2008) and derive a negative price effect and a positive "escape-competition effect". Gutiérrez and Philippon (2017) analyze similar trade-offs in a model with industry leaders and a competitive fringe.[9] Due to the countervailing mechanisms, this literature generally provides ambiguous predictions on the relationship between competition and investment. However, they also predict that positive effects due to the escape-competition mechanism are more likely for technological leaders than for laggard firms. For instance, in Bombardini et al. (2018), a reduction in import tariffs increases the probability that a domestic firm is replaced by a foreign rival. By investing in cost reductions, domestic firms reduce the probability of being replaced by foreign competitors. The most productive firms have a better chance to cope with foreign competitors and hence have higher incentives to engage in cost-reducing activities to escape competition. Another prediction of these class of models is that the positive effects of increased competition are more likely when initial competition is low.

production since, in line with previous evidence (e.g., Acemoglu et al., 2010), we find that this is the empirically more important phenomenon.

[8] This mechanism goes back to Arrow (1962). Similarly, in in an oligopolistic market, an increase in competition can lead to more investment as it increases the sensitivity of demand to enhanced efficiency (Schmutzler, 2013; Vives, 2008).

[9] Fieler and Harrison (2020), Lim et al. (2018) and Medina (2017) also derive escape competition effects which are based on differentiating products from those of foreign rivals.

We provide evidence for heterogeneous effects that are consistent with the escape-competition mechanism. First, the negative effects of output tariffs are concentrated in markets with low initial competition, measured by lagged average markups at the industry-level. Further, we find that positive effects of foreign competition are concentrated among firms with higher initial levels of total factor productivity (TFP) or previous engagement in research and development (R&D) which are more likely to compete neck-to-neck with foreign producers that are exporting to India. Consistent with the escape-competition mechanism, we also find that output and markup reductions are mostly driven by firms with relatively low levels of initial productivity.[10]

Our paper is related to a growing literature that analyzes the impact of market structure on vertical integration and other organizational choices (see Legros and Newman, 2014, for an overview). In a model inspired by property rights theory, Aghion et al. (2006) predict a U-shaped relationship between competition and vertical integration. According to their theory, starting from a high level of market concentration, a small increase in competition reduces producers' incentives to integrate by improving suppliers' outside option which increases their investment incentives. For high degrees of competition, the model predicts that producers will have a high incentive to vertically integrate because independent suppliers can capture most of the surplus generated by the producer in the absence of integration. Grossman and Helpman (2002) predict that a non-linear *inverted* U-shaped relationship between competition—operationalized as the degree of product differentiation—and vertical integration can arise, depending on cost differences between vertically integrated and specialized producers and the relative bargaining power between upstream and downstream firms. In line with these theories, our results indicate that there is indeed a non-monotonic relationship between tariffs and vertical integration. However, according to our results, the negative effects of tariffs on vertical integration (implying a positive relationship between competition and vertical integration) hold across almost all subsamples. Consistent with the importance of suppliers relative bargaining position, we find that input tariffs have opposite effects on vertical integration to those of output tariffs and are positively related to vertical integration for most subsamples.

Aghion et al. (2006) find support for a U-shaped relationship using entry rates as measure of competition for a sample of industries in the UK. However, as discussed by the authors, their results are rather suggestive. Specifically, they do not account for possible endogeneity of entry rates. In our empirical analysis, we address potential endogeneity problems by exploiting plausibly exogenous variations in tariff rates.

[10]Note that the fact that effects of tariffs are concentrated in initially more productive firms is inconsistent with some alternative theories of competition and productivity-enhancing investments based on managerial firms (see, for instance, Shu and Steinwender, 2019). Another mechanism implying that competition can spur investment occurs when production factors are trapped inside firms and competition lowers the opportunity costs of redeploying these factors towards other uses (Bloom et al., 2016; Medina, 2017). However, such theories predict that firms reallocate production from old to new goods and are thus less suitable for explaining vertical integration for existing products.

Closely related to our empirical analysis is Alfaro et al. (2016), who exploit variations in tariffs across sectors and countries in a cross-section of plants around the world to show that output tariffs—which they use as a proxy for variations in price levels—and vertical integration are positively correlated. Alfaro et al. (2016) anchor their findings on a theoretical model from the organizational industrial organization (OIO) literature (Legros and Newman, 2014, 2017) in which vertical integration is regarded as productivity-enhancing investment. This literature argues that high prices spur the incentives for vertical integration since the benefits from increased productivity increase with the level of prices while costs of vertical integration are independent of price and output levels.[11] Dam and Serfes (2020) show that the relationship between price levels and vertical integration is ambiguous and non-monotonic (possibly inverted-U shaped) when there is heterogeneity in productivity among upstream or downstream firms. These predictions are broadly consistent with the empirical results of our paper. However, studies within the OIO literature analyze the impact of prices in a perfectly competitive setting. While the assumption of price-taking firms might be reasonable for some markets, it is unlikely to hold for Indian manufacturing industries which seem to be characterized by considerable market power, pricing heterogeneity and incomplete cost pass-through (De Loecker et al., 2016; Stiebale and Vencappa, 2018).

Evidence for a negative effect of competition on vertical integration via prices is also provided by McGowan (2017) who exploits a natural experiment in the U.S. coal mining industry. Acemoglu et al. (2010) find a negative association between a higher number of firms producing on the domestic market and the incidence of backward vertical integration in a cross-section of UK industry-pairs.[12] Buehler and Burghardt (2015) find that a reduction of non-tariff barriers and the introduction of mutual recognition of product standards between Switzerland and the EU reduced the vertical integration propensity of Swiss plants. In contrast to this paper, we focus on the reduction of tariffs in a univariate trade liberalization event which allows us to isolate the effects of import competition.[13]

[11] A negative relationship between competition and vertical integration is also predicted by the transaction cost approach whereby competition reduces asset specificity and therefore the need for vertical integration (Aghion et al., 2006) and by a version of the property rights theory approach developed in Acemoglu et al. (2010) which mainly focuses on the relationship between technology and vertical integration. See the seminal contributions by Williamson (1975), Williamson (1985) for the transaction cost approach and by Grossman and Hart (1986), Hart and Moore (1990) for the property rights theory approach. Lafontaine and Slade (2007) provide a survey on the general determinants and effects of vertical integration.

[12] As discussed by Shu and Steinwender (2019), the majority of empirical studies finds a negative association between international competition and productivity-enhancing investments such as R&D in the US. The results for European countries are mixed and most studies based on developing countries estimate a positive relationship, possibly due to differing levels of initial competition intensity and institutional environment. Interestingly, these differences are consistent with the contrasting results between our analysis and those obtained by other studies like Alfaro et al. (2016), Acemoglu et al. (2010) and McGowan (2017).

[13] A few recent papers use outcomes that are broadly related to vertical integration. Liu et al. (2019) find that reductions of output tariffs in Chinese *upstream* industries—induced by China's WTO entry—are associated with a decline in the number of firms in these industries that are acquired by downstream firms. Unlike this paper, we focus on tariffs in *downstream* industries and investigate a broader measure of vertical integration which is not limited to integration via acquisitions. Chakraborty and Sundaram (2019) analyze the relationship between import competition from China and a firm-level measure of outsourcing activity.

We contribute to the existing literature in various ways. First, we provide evidence that firms engage in vertical integration to escape foreign competition. We also estimate heterogeneous effects across firms with different productivity and industries with different levels of initial competition. Second, we compare the effects of changes in tariffs on vertical integration with those of other productivity-enhancing activities such as R&D and business investment. We therefore also contribute to the literature on the consequences of trade liberalization for developing countries in general and India in particular. Finally, we contribute to the literature on the determinants of productivity in developing countries by providing evidence of how vertical integration events affect markups and marginal costs in Indian firms.

The rest of this paper is organized as follows. In section 2, we describe India's trade liberalization which we explore in the empirical analysis. Section 3 discusses our data set and construction of variables. Our empirical strategy is detailed in section 4, with results discussed in section 5. Section 6 concludes.

2 India's trade policy

India's post-independence external sector policies broadly fall into three phases: 1950–75, marking a trend toward tighter controls, culminating in near self-sufficiency by the end of the period; 1976–91, when some liberalization took place, and 1991 onward, when deeper and more systematic liberalization was started which continues to this day.[14] A first attempt at trade liberalization started in the late 1970s with the reintroduction of the old Open General Licencing (OGL) list. The OGL list initially contained a small list of 79 capital goods that could be imported without a licence from the Ministry of Commerce. By April 1988, this list had expanded to cover 1170 capital goods and 949 intermediate inputs. By April 1990, the list had expanded to account for about 30% of total imports. During that period, tariff rates were substantially increased, mainly to allow governments to capture quota rents. However, these tariff rates did not significantly add to the restrictive effects of licensing as items on the OGL list benefited from tariff exemptions.

By 1990, thirty-one sectors had been freed from industrial licensing, freeing machinery imports in these sectors from industrial licensing clearance. This modest liberalization, complemented by expansionary fiscal policy, raised India's growth rate from approximately 3.5 percent during 1950–80 to 5.6 percent during 1981–91. Nevertheless, the expansionary fiscal policy that complemented the modest liberalization policies led to internal and external borrowing that could not be sustained and culminated in a massive balance of payments crisis that forced the government to approach the IMF.

[14]For a detailed review and periodic evaluation of these reforms, see the various issues of the World Trade Organisation Trade Policy Review India at `https://www.wto.org/english/tratop_e/tpr_e/tp_rep_e.html`

The IMF loans came attached with the strong conditionality that, by popular account, eventually led the government to undertake major economic reforms. Thus, in 1991 a New Industrial Policy was introduced, with a clear switch in favour of a move toward an outward-oriented, market-based economy.

The trade liberalization program initiated in the 1991 budget was comprehensive, although the pace remained gradual and there were occasional hiccups. These reforms paved the way for a major reduction of average tariffs, tariff peaks, simplification of the tariffs and quota regimes, and removal of several import restrictions. The July 1991 reforms eliminated import licensing on all but a handful of intermediate inputs and capital goods. Consumer goods, accounting for approximately 30% of tariff lines, initially remained under licensing but a decade later could be imported freely.

A number of studies have argued that the 1991 trade reforms in India that arose from the external crisis were drastic and unexpected (e.g., Hasan et al., 2007; Topalova and Khandelwal, 2011). Since the trade liberalization was externally exposed, there was relatively little scope for lobbying of domestic firms and adjustment of tariffs to reflect the competitiveness of Indian producers which suggest that tariff changes were exogenous to the performance of domestic firms (Topalova and Khandelwal, 2011; Goldberg et al., 2009). After the main trade liberalization period, tariffs were further reduced as part of India's five-year plans during the time periods 1992-1997, 1997-2002, 2002-2007 and 2007-2012. India is also an active user of anti-dumping measures and is currently the main user of anti-dumping measures in the WTO, with the majority of its measures applied to imports originating from China. It is also an active user of safeguard measures. This has led to some increase in applied tariffs over time. As these temporary adjustments are potentially affected by lobbying of domestic firms, we focus on most favored nation (MFN) rates in our analysis. In section 3.6, we discuss potential endogeneity concerns in more detail. For this purpose, we follow previous studies and analyze to what extent industry characteristics at the beginning of each 5-year plan period predict future changes in tariffs.

Table A1 in the Appendix reports the yearly evolution of output and input tariffs data over the period of our analysis (see section 3.3 for construction of output and input tariffs). There has been a substantial downward trend in both input and output tariffs over time. While the average and median output tariff rates were above 110% in 1989, the average rate fell below 35% towards the end of the first liberalization period in 1997 and further decreased to around 15% towards the end of our sample period. The standard deviation of tariffs across industries has also fallen substantially over time indicating more uniform tariffs in later years of our sample. As discussed in Topalova and Khandelwal (2011), this reflects the fact that industries with higher initial tariff rates experienced more substantial declines. Similar declines can be observed for input tariffs.

3 Data and Variables

Our empirical analysis draws from several data sources. Our primary data set is the Centre for Monitoring of the Indian Economy (CMIE) Prowess database. We augment this primary data source with a number of additional data sets. We carry out the analysis at the level of National Industrial Classification (NIC) version 2008 and, where external data sources use international industrial classifications such as the Harmonised System (HS) codes, we mapped these onto NIC following the concordance tables published by Debroy and Santhanam (1993).

3.1 Firm and Product Level Data

Prowess provides information on company balance sheets and income statements for both publicly listed and unlisted firms across industries in the manufacturing, services, utilities and financial sectors.[15] These firms account for more than 70% of industrial output from the organised sector, 75% of corporate taxes and 95% of excise taxes collected by the government.

The construction of the vertical integration index at the firm level requires us to identify the products produced by the firm. By law, Indian firms are required to report product-level data on quantities and values of sales and production.[16] The data thus allows separating production used as an input for other products from intermediate goods sold to other firms. Each product is allocated a twenty-digits code from CMIE's own internal classification of 5908 sub-industries and products. Of these, 4833 products fall under the manufacturing sector. CMIE's own classification is largely based on the Indian National Industrial Classification (NIC) and the HS schedule. Examples of products across different industries include shrimps, corned meat, sponge iron, pipe fittings and rail coaches. Goldberg et al. (2010b) provide a detailed description of the product-level data in Prowess.

We extracted data spanning the period 1989 (the first year firms appear in the database) until 2011 and focus on the manufacturing sector. Hence, we create an unbalanced panel tracking products of each firm every year, mapping the product codes onto India's NIC 2008.[17] In our main estimation sample, we exclude multinational firms since we do not have detailed information on the products they produce abroad. Further, these firms may not be affected by import competition in the same way as domestic firms. However, as we discuss in the robustness section, this restriction is not crucial

[15] This database has been used in a number of recent papers, e.g. Goldberg et al. (2009, 2010a,b); De Loecker et al. (2016); Stiebale and Vencappa (2018).

[16] This is a requirement of the 1956 Companies Act.

[17] In setting up this firm-product-year panel, we checked and adjusted the CMIE product codes to address a number of instances where the same product code was attributed to different products, or where different product codes were allocated to the same product. In addition, we noticed a number of cases where product names varied in spelling and also noted frequent differences in levels of aggregation for what constitutes a product. After cleaning the data, accounting for missing values, and aggregating some products, we were left with 2782 clean and unique CMIE product codes in Prowess.

for our results.

3.2 Vertical Integration Indices

We follow Fan and Lang (2000) and Alfaro et al. (2016) in constructing measures of vertical integration for each firm and product. For this purpose, we use several issues of published Indian input-output (IO) tables. IO tables report transaction coefficients which measure the rupee value of output from industry i required to produce a rupee's worth of output for industry j. Hence, a transaction coefficient of 0.05 means that 5 Indian rupee cents (paise) worth of output in industry i are required to produce one rupee's worth of products in industry j. We combine information on firms' production activities in the Prowess database with IO tables, and construct IO indices for each product produced in industry j by firm f at year t. We define a firm based on unconsolidated accounts and therefore implicitly treat firms that are part of corporate groups as independent entities. This is consistent with recent evidence that physical input flows between firms of corporate groups are limited (Atalay et al., 2014). However, as we discuss in a robustness section, excluding firms that are part of a corporate group from the estimation sample does not notably affect our results.

For our main specification, we use constant IO transaction coefficients which stem from an IO table referring to the fiscal year 1993/94. Constant IO weights across time within industries ensure that our empirical analysis captures variation in firms' production activities rather than time series variation in IO transaction coefficients for firms with a constant product portfolio. For completeness and robustness purposes, we also experiment with time varying weights. IO tables are published on an interval of roughly about 5 years, and to create a product-year panel of IO weights, we use the 1993/94 IO transaction coefficients for years 1988-1997, the 1998/99 IO coefficients for adjacent years 1998-2002, the 2003/2004 IO coefficients for adjacent years 2003-06 and the 2007/08 IO coefficients for the remaining years 2007-11 of our sample.[18]

We construct vertical integration indices at the level of the firm as well as at the firm-product level by combining IO transaction coefficients with information on firms' production activities from Prowess. At the firm-product level, the IO index, IO_{fijt}, follows the identity:

$$IO_{fijt} \equiv IO_{ij} \times I_{fijt} \tag{1}$$

IO_{ij} is the IO coefficient for product-industry pair (i, j) and measures how much of i is typically needed to produce one unit of j. The second element, I_{fijt}, is an indicator variable that equals one

[18]IO 1989-90 tables, which we could have used for years 1988-1992, are unfortunately not available to us.

if the firm produces both i and j at time t. If a firm produces both i and j, it is assumed to supply itself with all the i that is necessary to produce j. Hence, a firm that produces i will be measured to be more integrated in the production of j, the higher is IO_{ij}.

The firm's vertical integration index for a product produced in industry j is the sum of IO coefficients across all industries in which it is active:

$$v_{fjt} = \sum_i IO_{fijt} \tag{2}$$

As an example in our sample, consider the product "printing of newspaper". The product-specific input-output coefficients for inputs newspaper ink and paper for newspaper printing are 0.0004 and 0.0021, respectively. A firm that prints newspapers and produces both inputs has a vertical integration index of 0.0025 for that product. A firm that produces paper but no ink is defined to be more vertically integrated than a firm that produces ink but not paper.[19]

At the firm level, the vertical integration index is as per equation (2), but calculated for its main industry of activity only.[20]

3.3 Tariffs

Tariffs data were sourced from World Integrated Trade Services (WITS). Following Alfaro et al. (2016), we use most favored nation (MFN) tariff rates applied by GATT/WTO members. We select the tariffs data reported at 6 digits HS codes, and map these to NIC codes following the concordance tables published by Debroy and Santhanam (1993).[21] We construct simple averages of tariff rates aggregating from six digits HS codes to 3 digits NIC 2008 codes.

We also construct a measure of tariffs applied to imported inputs, which simply weighs the applied MFN tariffs using normalised IO coefficients as weights.

$$inptariff_{jt} = \sum_{i \neq j} tariff_{it} * IO_{ij} \tag{3}$$

where $tariff_{jt}$ are MFN tariff rates and IO_{ij} represents the IO transaction coefficients.

[19] We also experimented with a dummy variable for vertical integration events and found that our results were not sensitive to the weighting of inputs.

[20] We define a firm's main product as the product with the highest revenue share throughout the sample period.

[21] The tariffs data were brought to the common HS 1992 codes and from there on mapped onto NIC codes.

3.4 Further Variables

We construct a further set of variables (see Table 1) which we use as additional controls in our regressions or to measure heterogenous effects where relevant. These include two measures of technological intensity (averaged at the industry level): *investment intensity*, measured as firm investment over sales and *R&Dintensity*, measured as firm R&D relative to sales. Another industry-level measure is average *size* of firms within an industry measured by the log of sales. At the firm-level we construct *exports* and *imports* measured relative to sales. A firm's size is captured by *log(sales)*. Further variables include *log(R&D)*, which denotes the log(research and development expenditure + 1) and *homogenous good*, which is a dummy variable taking value 1 if the product belongs to a category defined as homogenous and 0 if differentiated, following the classification proposed in Rauch (1999).[22] The variable *markup* is defined as the ratio of price to marginal costs as is calculated following the methodology of De Loecker et al. (2016) Under the assumption that firms minimize costs it can be shown that the markup equals the material-output elasticity divided by the material to sales ratio. The material-output elasticity is estimated from a translog production function with physical quantity as output and materials, capital and labour as production factors. We explain the estimation of productivity and markups in detail in Appendix B.[23] Observed prices (unit values) divided by these estimated markups give us our measure of *marginal cost*.

3.5 Summary Statistics

Table 1 reports summary statistics for our main variables of interest. In our sample, the median vertical integration index at the firm (firm-product level) is 0.116 and the mean is 0.135 (0.134).[24] The distribution of the vertical integration index is depicted in Figure A1 in the Appendix. Around 45% of the products considered in our data set are classified as being homogenous goods. The average markup of 2.82 seems quite high, but the median markup is 1.33 for the whole sample.[25] On average, exports make up about 10% of production. Table A1 in the Appendix reports the yearly evolution of output and input tariffs data over the period of our analysis. Average output tariffs fell at a rapid pace in the earlier years around the 1991 reforms and slowed down in later years. A similar observation can be made for input tariffs.

[22] For details on the Rauch classification, see `http://econweb.ucsd.edu/~jrauch/rauch_classification.html`, accessed on August 6, 2019.

[23] See also Stiebale and Vencappa (2018) for details on the construction of product level markups and marginal costs using the same data set as this paper.

[24] The correlation coefficient between firm and firm-product-level vertical integration is 0.74 across all products and 0.56 when excluding firms' main product.

[25] These figures are similar to those obtained by De Loecker et al. (2016) who estimate a markup distribution for Indian manufacturing over an earlier time period, reporting an average of 2.70 and a median of 1.34.

3.6 Exogeneity of Trade Policy

A particular concern around the use of a trade policy measure such as tariffs is the possible endogeneity of this variable. For instance, governments might perceive that specific domestic industries are not sufficiently mature to face import competition, and would seek to protect them. Similarly, labour or trade union groups or domestic firms might lobby for higher protection from foreign competition. As we discussed in section 2, a number of studies have argued that tariff reductions during India's main trade liberalization period are likely to be exogenous as they were externally imposed. Yet, as Topalova and Khandelwal (2011) point out, variations in trade policy across industries could be affected by previous industry performance for more recent trade liberalization episodes in India.

In contrast to Topalova and Khandelwal (2011), our paper uses MFN tariffs and we argue that these can be assumed to be exogenous to vertical integration. As Alfaro et al. (2016) point out, MFN tariffs are agreed following long rounds of multilateral trade negotiations at the end of which every member commits to not exceed agreed tariff bounds. Failure to respect this commitment entitles the affected parties to take matters to the dispute settlement body of the WTO. Once agreed, the tariff rates must be applied in a non-discriminatory way to imports from all WTO members.[26] Pressure for protection from lobby groups is unlikely to be directed to MFN tariffs; governments can instead focus on alternative measures such as antidumping measures and countervailing duties.

Although the above are strong arguments for MFN tariff rates being exogenous, we follow Topalova and Khandelwal (2011) and run a variety of checks prior to estimating a causal link of tariffs on our outcome variables. Firstly, we use industry level data from various issues of the Annual Survey of Industries to run regressions of changes in trade policy measures (output and input tariffs) on lagged industrial characteristics for each distinct time period corresponding to India's five-year plans as well as the whole sample period from 1989-2012.[27] Industry performance indicators include employment, output, average wage, concentration, share of skilled workers, the growth of industry output and employment, and mean values of our vertical integration index at the industry-level. Specifically, we run the following regressions:

$$tariff_{jt} - tariff_{j0} = \delta_0 + \delta_1 x_{j0} + u_j \tag{4}$$

where $tariff_{jt}$ is either input or output tariff in industry j at time t, and x_{j0} is each of a set of industrial characteristics measured at the beginning of each 5-year time period.

[26] Exceptions to this rule are when WTO members form part of a preferential trade agreement, in which case members are allowed to discriminate between members inside and outside the preferential trade agreement.

[27] Over the period 1989-2012 India delivered its 7th to 11th five-year plans for the periods 1985-1990, 1992-1997, 1997-2002, 2002-2007 and 2007-2012.

Table 2 reports results of these simple regressions. While for some variables and some time periods, tariff changes appear to be correlated with industry characteristics, most of these correlations are small and—with a few exception—statistically insignificant or weakly significant. All in all, there is no strong evidence that policy makers systematically adjusted tariffs to previous industry performance. Nonetheless, as we discuss in section 5.2, we verify that our results are robust towards controlling for time-varying industry characteristics as well as lagged industry characteristics interacted with time dummies.

We also follow Topalova and Khandelwal (2011) in a second set of regressions to check whether policy makers adjusted tariffs in response to industry productivity shocks and regress each of the trade policy measures on a one-year lagged industry productivity measure:

$$tariff_{jt} = \zeta \ TFP_{j,t-1} + \mu_t + a_j + u_{jt} \tag{5}$$

where TFP_{jt} denotes average log total factor productivity, estimated using the methodology proposed by Levinsohn and Petrin (2003).[28] The industry-level measure is constructed as a sales-weighted average of (absolute) firm-level TFP.

Table A2 in the Appendix reports the results of these regressions for different time periods with output tariffs in Panel A and input tariffs depicted in Panel B. Coefficients are small and statistically insignificant for the sample period as a whole and insignificant or weakly significant for the different sub-samples. Even the highest coefficient, the correlation between TFP_{t-1} and output tariffs within the time period 1997-2002 suggest that a 10% increase in total factor productivity is associated with only 0.64 percentage points higher output tariffs and has the opposite sign that we would expect when policy makers try to protect low-productivity industries with high tariffs. Taken together, the results from tables 2 and A2 suggest that potential endogeneity concerns around our tariffs variables are mitigated.

4 Empirical Method

The aim of the empirical analysis is to estimate the effects of tariffs on vertical integration. We exploit variations in MFN tariffs across products and years within and between firms. For this purpose, we start with the following regression at the firm-level:

$$v_{f(j)t} = \beta \ tariff_{jt} + X'_{f(j)t}\Pi + \alpha_f + \eta_{kt} + \epsilon_{f(j)t} \tag{6}$$

[28] We use sales as a measure of output and material costs, wage bill and fixed assets to measure inputs.

where $v_{f(j)t}$ denotes the vertical integration index of firm f with main activity in industry j in year t. $tariff_{jt}$ denotes the tariff rate applied to industry j at time t and $X_{f(j)t}$ is a vector of firm-and product specific control variables. The firm fixed effect α_f captures permanent differences among firms including location (which might affect the supply of intermediate inputs). η_{kt} are time dummies which control for changes in market conditions and technology common to all firms which we allow to vary across 2-digit industries (k) in most specifications. Finally, $\epsilon_{f(j)t}$ is an error term.

In a second step, we move the analysis to the firm-product-level and consider all products produced by a firm, not only their core product. Therefore, equation (6) becomes:

$$v_{fjt} = \theta \ tariff_{jt} + X'_{jt}\Theta + \alpha_{fj} + \eta_{kt} + \epsilon_{fjt} \tag{7}$$

where v_{fjt} denotes the vertical integration index of a product in industry j produced by firm f in year t and α_{fj} is a firm-product specific fixed effect which captures permanent differences in technology and product characteristics. Since tariffs vary across industries within multi-product firm-years, we additionally control for firm-year fixed effects, φ_{ft}, in a further amplification of the model:

$$v_{fjt} = \gamma \ tariff_{jt} + X'_{jt}\Gamma + \alpha_{fj} + \varphi_{ft} + \eta_{kt} + \epsilon_{fjt} \tag{8}$$

An advantage of controlling for firm-year fixed effects is that we can control for time-varying adjustments within firms such as changes in management, financial factors or productivity (as long as these changes are not firm-product-year specific). Firm-year fixed effects also control for the effects of product-specific tariffs that affect a firm as a whole, for instance via liquidity and credit constraints. A disadvantage of this approach is that we can only run this regression on a selected sample of multi-product (multi-industry) firms which are arguably not a random sample from the population.

Our main identifying assumption is that $E[\epsilon_{fjt}|tariff_{jt}, X_{jt}, \alpha_{fj}, \varphi_{ft}, \eta_{kt}] = 0$. Hence, we assume that unobservables affecting vertical integration decisions which are not captured by firm-year, firm-product or sector-year fixed effects are uncorrelated with variations in tariffs across time within industries. To assess the validity of this approach, we include a set of control variables, X_{ijt}, which are potentially correlated with both vertical integration and tariff rates in some specifications. A potentially important control variable is input tariffs which can affect producers' vertical integration decisions via prices and competition in upstream markets (Acemoglu et al., 2010; Alfaro et al., 2016). Further, technological characteristics might determine the degree of relation-specificity and investment incentives (Acemoglu et al., 2010). To capture changes in technological characteristics across industries and time, we control for the average of the R&D to sales ratio and the level of investment relative to sales across firms within industries. We also control for variation in average firm size (measured by log sales) to capture general changes in technology. At the firm-level, we control for the ratio of export to sales and imports to sales to account for the fact that firms with access to foreign markets might react differently to changes in import competition. We refrain from controlling for further firm-level variables such as productivity, size, capital or R&D since these variables might be affected by firms' vertical integration choices. However, these variables are implicitly controlled for using firm-year fixed effects in our product-level specifications.

Next, we analyze heterogeneous effects to uncover the mechanism that generates the association between tariffs and vertical integration. Since firms are arguably more affected by output tariffs if they mainly operate on the domestic market, we follow Alfaro et al. (2016) and also test for heterogeneous effects using the following specification:

$$v_{fjt} = \nu_1 \, tariff_{jt} + \nu_2 \, tariff_{jt} \times H_f(j) + X'_{jt}\Psi + \alpha_{fj} + \varphi_{ft} + \eta_{kt} + \epsilon_{fjt} \qquad (9)$$

where H_f denotes a firm or industry characteristic. Specifically, we differentiate according to firms with different productivity levels, R&D or firms that are active in industries with different characteristics such as initial competition and capital intensity.

In all specifications, we use two-way clustered standard errors. First, we cluster at the product-level since our main variable of interest, tariffs, varies at the product-level while the dependent variable is firm-product specific. Second, we cluster at the firm-level since vertical integration decisions might be correlated within firms across products and years.

5 Results

5.1 Tariffs and competition

Before discussing our main results, we assess the suitability of tariff changes as a measure of foreign competition. For this purpose, we relate output tariffs to various industry characteristics including the number of domestic firms and products, the import penetration ratio, sales and markups of domestic firms[29], controlling for industry and year fixed effects. Results are documented in Table 3. The effects are economically and statistically significant. For instance, a reductions in tariffs by 10 percentage points is associated with a 6% reduction in the number of domestic firms, a 12% reduction in the number of firm-products, a 8% decline in sales and a 2.6% decline in average industry-level

[29] We describe our measures of markups which we estimate from production functions according to the method proposed De Loecker et al. (2016) in detail in the Appendix.

markups of domestic firms. As expected, tariffs are also negatively correlated with the ratio of imports to domestic production. These results are consistent with trade theoretical models with heterogeneous firms such as in Melitz and Ottaviano (2008), where a reduction in output tariffs leads to entry of foreign exporters, drives domestic firms out of the market and leads to a reduction in sales and markups of domestic firms.

Next, we move the analysis to the firm-product level to assess whether heterogeneity in firm-level responses exist. For this purpose, we relate quantities and markups at the firm-product level to industry-level tariffs, controlling for firm-product and year fixed effects and document the results in Table 4. As expected, tariff reductions are associated with declining quantities and markups in domestic firms.[30] In columns (3) to (6), we split the sample into firms with initial total productivity below and above the median.[31] Results suggest that reductions in quantities and markups are mostly driven by relatively unproductive firms. Consistent with predictions of trade theoretical models (e.g., Bombardini et al., 2018; Gutiérrez and Philippon, 2017), these findings suggest that more productive firms do a better job in coping with foreign competition, an observation we return to in the next subsection.

5.2 Tariffs and vertical integration

Table 5 reports the results of our firm-level regressions based on estimation of equation (6). Column (1) shows regression results that control for firm fixed effects and year dummies. The coefficient indicates that a 100 percentage point increase in output tariffs is associated with a decline of the vertical integration index by 0.022 which corresponds to about 19% of the median value of the index. While the estimated effect becomes somewhat smaller when we control for sector (2-digit industry)-year fixed effects in columns (2), it increases again once we add further control variables. In column (3), we control for input tariffs, while column (4) adds additional control variables at the (3-digit)industry level to the regression which include investment and R&D intensities (as a proxy for technology) and average firm size. In column (5), we control for two additional variables at the firm level, import and export shares. Column (6) includes interactions between time dummies and initial industry characteristics which we related to tariffs in section 3. The results for output tariffs remain highly statistically significant and indicate economically important effects as well. According to the coefficient estimates in columns (4)-(6) and descriptive statistics in Table 1, an increase in output tariffs by one standard deviation decreases the expected vertical integration index by 0.0064 which is about 5.5% of the median vertical integration index. As we discuss below, the effects

[30] De Loecker et al. (2016) discuss in detail the effects of India's trade liberalization on markups of domestic firms.

[31] We provide a detailed discussion of our measure of productivity in the Appendix.

are even more pronounced for some subsamples. Among the control variables, mainly investment intensity turns out to be significant. This is in line with Acemoglu et al. (2010) who argue that technological intensity in the producer's industry increases the incentives for vertical integration. Both input tariffs and R&D intensity are positively associated with changes in vertical integration, but the results are mostly statistically insignificant.

Results of firm-product level regressions based on estimation of equation (7) are depicted in Table 6. Column (1) shows results of regressions that control for firm-product fixed effects and year dummies. In column (2), we add sector fixed effects and column (3) controls for input tariffs. The estimated effects are again statistically significant and, in absolute terms, even somewhat higher than in the firm-level regressions. A more restrictive test of the effects of tariffs on vertical integration is whether particular firms are more likely to vertically integrate in products/industries with lower tariff rates. For instance, variations in tariff rates across time and industries might be correlated with unobserved changes in corporate culture or company-wide trends in investment, management or productivity. To assess this possibility, we add firm-year fixed effects to the model. Identification of the effects of tariffs in this specification is limited to firms that produce in at least two different industries. The estimates become even stronger. For instance, column (4) indicates that a one-standard deviation increase in tariffs is associated with declines in vertical integration of 0.012 which is more than 10% of the median vertical integration index. The results remain significant if we control for sector-year fixed effects and input tariffs in columns (5) and (6).

In column (6), the coefficient for input tariffs becomes statistically significant. As we will see below, the lack of significance of the input tariff coefficient in some specifications is mainly due to heterogeneous responses to input tariffs across firms and industries. While the coefficient for input tariffs is in absolute terms much larger than the coefficient for output tariffs, the magnitude of the relative impact is rather similar. A one standard deviation increase in input tariffs increases vertical integration by 0.011. The positive association between import tariffs and vertical integration is plausible given the positive association between markups and tariffs documented in the previous section. When input tariffs are high, downstream firms have to pay more for their inputs in the case of separation which increases the profitability of integration.

While India's main liberalization period was characterized by a univariate trade liberalization, one might be concerned that tariff changes in some industries and time periods are correlated with foreign market access by Indian firms. For this purpose, we computed average industry-level tariffs faced by Indian firms in foreign markets.[32] Table A3 in the Appendix shows that controlling for foreign tariffs hardly changes our results for output tariffs. The results indicate that foreign

[32]The tariffs data are again sourced from WITS

tariffs are negatively associated with vertical integration decisions. These results are consistent with theoretical predictions from Legros and Newman (2013) who predict that positive demand shocks increase incentives for vertical integration. They are also consistent with the international trade literature which stresses the role of market access for the incentives to invest in productivity-enhancing activities in general (e.g., Bustos, 2011; Lileeva and Trefler, 2010; Guadalupe et al., 2012).

5.3 Heterogeneous effect

In this subsection, we estimate heterogeneous effects across firm- and industry-level characteristics. In most theoretical models with competition and productivity-enhancing investment, the overall effect of competition is ambiguous. On the one hand, competition reduces margins which reduces gains from investment (often called the Schumpeterian effect). On the other hand, competition makes investment more profitable by increasing the sensitivity of demand to lower prices or higher quality, the escape-competition or business-stealing effect. A general result of this literature is that the escape-competition effect is more pronounced for industry leaders (low cost or high quality) than for laggard firms (Aghion et al., 2005; Bombardini et al., 2018; Gutiérrez and Philippon, 2017). The reason for this heterogeneity is that the more advanced firms are better able to compete with foreign rivals (Shu and Steinwender, 2019).

To test whether our results are consistent with escape-competition effects, we split the sample between firms with an initial level of productivity above and below the median.[33] Results documented in columns (1) and (2) of Table 7 show that although the results are positive in both subsamples, the impact of tariffs is somewhat more pronounced for highly productive firms. As an alternative dimension of heterogeneity, we also analyze separate effects for firms that engage in R&D. As shown in columns (3) and (4), the impact of tariffs on firms with positive R&D investment, which are arguably more likely to be technological leaders, is almost twice as large as for the remaining firms. The results are thus consistent with theoretical models in which firms invest to increase productivity to escape foreign competition. In contrast, it is unlikely that the positive effect of competition on vertical integration in our sample is driven by managerial slack in non-profit maximizing firms as such theories would predict that the effects are concentrated among the least productive firms (Shu and Steinwender, 2019).

If the coefficients for output tariffs reflect a causal effect of import competition on Indian firms, the estimated effects should be less pronounced for firms that mainly operate outside of India. To test this hypothesis, we ran a separate regression for firms that export on average more than half

[33] We measure productivity in the year when firms enter the sample to reduce endogeneity concerns and demean productivity by industry. See the Appendix for our procedure to estimate production functions.

of their output within our sample period. Results documented in columns (5) and (6) of Table 7 indicate that the overall negative effect of tariffs is indeed driven by firms that mainly operate on the domestic market while the estimated coefficient is statistically indistinguishable from zero for the subsample with high export shares.[34]

We document additional results on firm-level heterogeneity regarding ownership in Table A4 in the Appendix. Although the estimated coefficients are slightly larger for private relative to state-owned firms, and for stand-alone firms relative to firms that are part of a corporate group, the effects of tariffs are not statistically significantly different across these different groups of firms.

Next, we analyze heterogeneity with respect to industry characteristics. First, we analyze the extent to which the effect of tariff varies with initial levels of competition. For instance, models with escape-competition effects predict that increased competition is more likely to increases incentives to invest in productivity-enhancing activities when the initial level of competition is low. To test this hypothesis, we construct a measure of the (inverse of the) level of competition as the average markup at the industry-level, a standard measure of competition in the literature (see, e.g. Aghion et al., 2005). Again, markups are estimated by the method proposed by De Loecker et al. (2016) which we discuss in the Appendix. Results documented in Table 8 indicate that the effects of tariffs on vertical integration are indeed concentrated in industries with low initial levels of competition. In Table A5 the Appendix, we extend the analysis to four different quartiles of the markup distribution. The results indicate positive effects of competition on vertical integration for all but the highest quartile of competition which is consistent with the escape-competition effect predicted by the theoretical literature.[35]

Theories of vertical integration such as the property rights theory predict that the benefits for backward vertical integration increase with the downstream industries' capital intensity (e.g., Acemoglu et al., 2010). We therefore investigated heterogeneity with respect to an industry's capital intensity, measured as the mean value of fixed assets to output at the industry-level at the beginning of the sample. Columns (3) and (4) of Table 8 show results of this sample split. The results indicate that the effects of competition on vertical integration are indeed mainly driven by capital intensive industries.

[34] Firms with high export shares seem to respond much more to changes in import tariffs than domestic firms. A possible explanation is that firms with high export shares have better access to foreign input suppliers and use these to substitute domestic in-house production of intermediates. The share of importers among firms which export more than half of their output is almost 90% while it is below 40% for other firms. Unfortunately, our data set does not provide detailed information about the goods that firms import, preventing us from analyzing this channel in more detail.

[35] The results of a positive but not-monotonic effect of product market competition on vertical integration is also broadly consistent with the theory proposed by Dam and Serfes (2020) in which vertical integration improves coordination but increases managerial effort. Their theoretical model, however, assumes that firms and consumers are price takers.

Finally, we also analyzed heterogeneous effects across industries that were subject to delicensing and thus experienced substantial entry (Aghion et al., 2008) and those that remained highly regulated during the main trade liberalization episode. For this purpose, we split the sample into industry-years before and after delicensing and alternatively for those that were not deregulated until 1991. Results documented in Table A6 show that the effects of tariffs on vertical integration are driven by delicensed industries indicating complementarity between trade and entry liberalization.[36]

5.4 Extensions and additional robustness checks

We checked the robustness of our results towards different empirical methods, functional forms and estimation samples and measures of competition which are documented in Appendix A.[37]

First, we assess to which extent an alternative measure of competition shows a similar correlation with vertical integration decisions of domestic firms. For this purpose, we computed the average markups across firm-products within an industry-year, analogous to the time-invariant measure we used for the sample split in Table 8. Note that since we do not have data on markups of foreign importers, this is essentially a measure of domestic competition, although import competition is likely to affect domestic markups as we discussed in section 4.1. Table A7 in the Appendix shows results where we relate vertical integration decisions of domestic firms to the log of industry-level markups which we lag by one year to reduce endogeneity concerns. We find that lagged industry-level markups are indeed negatively correlated with vertical integration decisions, with or without controlling for tariffs. A one log point decline in markups is associated with an increase in the vertical integration index by about 0.03, confirming the positive relationship between competition and vertical integration in our sample. As this time-vayring measure of market could be affected by vertical integration decissions besides using lagged values and aggregating to the industry level, we prefer tariffs as our main measure of the extent of (foreign) competition.

So far, except for the sample splits, we have not a allowed for a non-monotonic relationship between competition and vertical integration. Column (1) of Table A8 shows results of adding a squared term of tariffs to the regression. For instance, Aghion et al. (2006) predict a U-shaped relationship between competition and vertical integration. The coefficients indeed indicate a non-linear relationship where the negative effects of tariffs on vertical integration is decreasing in the level of tariffs. The predicted turning point, where further increases in tariffs have positive effects on vertical integration, is however at a tariff rate of 115% percent which is above the 98-percentile of the distribution of tariffs. Hence, the effect of foreign competition seems to be positive for the vast

[36] As stated by Topalova and Khandelwal (2011), it was difficult for firms in regulated industries to adjust their production technology or input mix which could explain the lack of changes in vertical integration in these industries.

[37] We would like to than two anonymous referees for suggesting some of the robustness checks in this section.

majority of firms in our sample. As shown by Lind and Mehlum (2010), a significant positive term for a squared variable is not a sufficient test for a U-shaped relationship. Following, their suggested test procedure we cannot reject the null hypothesis of a monotone or non-U shape relationship against the alternative of a U-shaped relationship between tariffs and VI in our sample for conventional levels of significance (p-value= 0.13).

We also experimented with alternative functional forms for the relationship between tariffs and vertical integration. For instance, following Alfaro et al. (2016), we regress $\ln(v+1)$ on $\ln(tariff+1)$ and—within the subsample of firm-product-years with strictly positive values of vertical integration and tariffs—we relate $\ln(v)$ to $\ln(tariff)$. The results depicted in column (2) and (3) confirm the negative relationship between output tariffs and vertical integration. The specification in column (4) adds a squared value of $\ln(tariff+1)$ to the specification. Again, the results indicate a turning point well above the 95^{th} percentile of tariffs.[38]

Next, we check the robustness of our results towards alternative estimation methods which explicitly account for zero values in the dependent variable. In particular, we estimate a Tobit model with a censoring point at zero, fractional response Logit and Probit models and a quasi-maximum likelihood estimator of an exponential mean model based on a Poisson distribution. Due to the incidental parameters problem and computational difficulties, we cannot control for firm-product fixed effects in these estimations. Instead, we control for industry dummies at the 3-digit level to ensure that our estimates identify variation in tariffs and vertical integration within industries across time. The results are documented in Table A9. Columns (1) to (3) show marginal effects from the Tobit, fractional Logit and fractional Probit estimations respectively. In column (4), coefficients from an exponential mean model, which can be interpreted as semi-elasticities, are depicted. All these alternative estimation methods confirm the negative effects of output tariffs on vertical integration.

We performed further robustness checks which relate to the selection of the estimation sample. First, we limited the sample to stand-alone firms since it is not clear whether our vertical integration index describes the production activities of firms within corporate groups accurately. Results, depicted in Table A10, show that excluding firms that are part of corporate groups does not affect our conclusions. In our main estimation sample, we exclude multinational firms since we have no detailed information about their foreign production activities. However, as documented in Table A11, including these firms and their production activities in India in the estimation sample does not affect our main results either. Finally, we checked the robustness of our results to aggregating all production activities to the 3-digit industry level which corresponds to the level of aggregation where most of the variation of the tariff variables occur. Results, depicted in Table A12 show very

[38] Since $\ln(tariff)$ is negative for most observations, a squared term of $\ln(tariff)$ is not appropriate for describing a U-shaped relationship. Hence, we do not report the results of such a specification.

similar coefficients as in the baseline regressions. All in all, the results are robust to different control variables, functional forms, econometric methods and estimation samples and indicate that there is a strongly significantly negative effect of import competition on the vertical integration propensity of domestic firms.

5.5 Vertical integration and efficiency

Consistent with most theoretical models we discussed, we is interpret vertical integration as an efficiency enhancing investment. It is thus natural to ask whether it is indeed associated with improved performance in our sample. For this purpose, we analyzed whether vertical integration events are associated with subsequent changes of firm-product-level measures of marginal costs and markups.

To identify the effects of vertical integration, we employ propensity score matching and reweighting (to construct the counterfactual) and combine it with a difference-in-differences (DiD) estimator.[39]

As in Guadalupe et al. (2012), we implement the DiD estimator in a weighted regression of a fixed effects model:

$$y_{fjt} = \zeta_{fj} + \phi PostVI_{fjt} + d_t + u_{fjt} \tag{10}$$

where y_{ijt} is an outcome at the product-level (log markup or log marginal cost) and $PostVI_{fjt}$ takes on a value of one in all post-vertical integration periods. A vertical integration event takes place in a year where the VI index of a firm-product increases because a firm starts producing a new product that can be used as an input into the production of product j. d_t represents time dummies, ζ_{fj} is a firm-product fixed effects which controls for unobserved time-invariant heterogeneity as well as differences in units across products and firms, and u_{fjt} is an error term.

Different estimators are proposed in the matching literature. First, we follow Guadalupe et al. (2012) and estimate a propensity score reweighting estimator (e.g. Imbens, 2004) where we assign a weight equal to $\frac{\hat{Pr}(VI_t=1|\boldsymbol{x}_{t-1})}{1-\hat{Pr}(VI_t=1|\boldsymbol{x}_{t-1})}$ for all products of firms that do not vertically integrate. VI takes on a value of one in case of a vertical integration event and $\hat{Pr}$ denotes the predicted probability from a Probit model. However, we also conduct nearest neighbor matching based on the propensity score. In this matching exercise, each firm-product with a vertical integration event has one comparison product from a firm that does not vertically integrate, implying each treated firm-product and each

[39]Propensity score matching and reweighting methods are widely applied in the context of binary events such as acquisition. See, for instance, Brucal et al. (2019); Imbruno and Ketterer (2018); Javorcik and Poelhekke (2017); Guadalupe et al. (2012) for recent applications.

matched control is given a weight of one.

To estimate the propensity score, we use pre-vertical integration values of firm-product-level sales, markups and marginal costs and firm-level sales. To ensure that treated and control products are characterized by parallel trends, we also include lagged growth rates of each variable and match within broad (2-digit) industries and years. Results on the balancing test depicted in Table A13 in the Appendix shows that there are no statistically significant differences in any of the variables employed in the matched sample.

Results of the DiD equations are displayed in Table 9. Columns (1) and (2) show results for the unmatched sample. Results from reweighting and one-to-one nearest neighbour matching are depicted in columns (3)-(6). The results indicate that vertical integration events are, on average, associated with a decline in marginal costs between 10% and 13%. Markups seems to increase by about the same magnitude indicating that vertical integration events increase both efficiency and variable profits.[40] As depicted in Table A14 in the Appendix, we obtain qualitatively similar effects if we use a vertical integration index from our main specification instead of binary events in simple OLS regressions.

5.6 Tariffs, R&D and investment

The positive association between vertical integration and firm performance raises the question of whether tariffs have similar effects on other (potentially productivity-enhancing) activities like investments and R&D. Since we have no information about the allocation of investment and R&D across product lines, we investigate the effects of tariffs in a firms' main industry on the log of firm-level investment and R&D. Results are displayed in Panel A and B of Table 10 with output tariffs in column (1) and a specification with both output and input tariffs in column (2). These regressions show rather small and statistically insignificant coefficients.

It is, however, likely that there are varying responses across heterogeneous firms. In particular, due to escape-competition effects and Schumpeterian effects, more productive firms might increase their investments due to increased foreign competition while less productive firms might be discouraged to invest (e.g., Aghion et al., 2005; Bombardini et al., 2018). To allow for these heterogeneous responses, we split the sample, again, into firms with initial levels of TFP above and below the median, based on the year they enter the sample and relative to the industry mean. Columns (3) and (4) show results of this specification. The results indicate substantial heterogeneity in response to import competition. For relatively unproductive firms, high output tariffs are associated with

[40] Note that rising markups do not necessarily imply that vertical integration increases market power as vertical integration might also yield higher product quality. Consistent with this hypothesis, we found in unreported regressions that vertical integration events are associated with higher quantities, conditional and unconditional on price.

high R&D expenditures and investment, while foreign competition seems to induce R&D and investment by high-productivity firms. The effects are quantitatively important. For instance, based on estimates in columns (3) and (4) in Panel A, an increase in output tariffs by 10 percentage points decreases R&D expenditures in the high-productivity subsample by about 4.3% (= $[\exp(0.1 \cdot 0.42) - 1]$ in %) but increases R&D in low-productivity firms by about 2.5%. The results are qualitatively similar for investment as documented in Panel B. The negative relationship between input tariffs and R&D, as well as with investment, is also concentrated in more productive firms. In column (5), we differentiate between the effects of tariffs across quartiles of the initial productivity distribution. The estimated coefficients confirms a positive relationship between productivity and the likelihood of positive effects of competition which is consistent with the escape-competition mechanism.

All in all, the effects of *output* tariffs on R&D and investment are qualitatively similar to those on vertical integration for highly productive firms, while the effects seem to be quite different for firms with low productivity. As discussed by Legros and Newman (2014, 2017), vertical integration might respond differently to competition because this decision is more easily reversible than innovation expenditures. Further, limited capabilities in less productive firms might play a more important role for innovation activities than for vertical integration. The negative effect of input tariffs for R&D and investment in high-productivity firms is consistent with previous research showing that domestic R&D and access to foreign inputs tend to be complements (e.g., Bøler et al., 2015).

6 Conclusion

Recent theoretical contributions provide conflicting predictions about the relationship between competition and firms' organizational choices. In this paper, we use a rich firm-product level panel data set of Indian manufacturing firms to analyze the relationship between import competition and vertical integration. Our identification strategy exploits the fact that foreign competition faced by domestic firms increased substantially due to India's trade liberalisation which reduced average MFN output tariffs from more than 100% in 1989 to about 15% in 2011.

Following previous empirical studies, we construct an index of vertical integration based on firms' products and IO tables, which captures the fraction of inputs used in the production of a product that can be produced in-house. Relating this measure to output tariff rates, our inverse measure of import competition, we find a strong and statistically significant negative relationship, suggesting that foreign competition induces vertical integration by domestic firms. This result holds whether we consider all the products of a firm or focus only on their core product. Our finding are similarly robust to controlling for firm-product fixed effects, sectoral trends, input tariffs, various other industry- and firm-level control variables and even firm-year fixed effects.

Consistent with the predictions of theoretical models of competition and productivity-enhancing investments, we find that the effects are concentrated in industries were initial competition is low and among firms that are initially more productive. Furthermore, we provide evidence that the effects of import tariffs are larger for firms that mainly operate on the domestic market and in industries with high capital intensity. There is also evidence that higher input tariffs induce backward vertical integration for some firms and industries.

We also show that vertical integration is associated with improved performance. Specifically, product-level vertical integration events are associated with declining marginal costs and rising markups at the product level. This association holds in simple fixed effects models and when a control group is constructed from propensity score matching or reweighting.

Finally, we compare the effects of foreign competition on vertical integration to the effects on other productivity-enhancing investments such as R&D and capital expenditures. Our results indicate that R&D and investment increases as a response to foreign competition in the most productive firms, but decreases in firms with relatively low levels of initial productivity. Hence, vertical integration seems to adjust to import competition in a similar way as R&D in some firms but not in others.

From an economic policy point of view, vertical integration may be an important element in understanding the effects of trade agreements on firms' productivity in developing countries. Our results indicate that concerns that increased foreign competition may have a negative effect on firm performance via reducing incentives for vertical integration do not seem to be justified, at least in the context of India. It will be an interesting topic for future research to investigate whether these results hold for other developing countries.

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Table 1: Summary Statistics

Variable	Definition	Mean	Median	Std.dev.
v_{ft}	vertical integration index (firm-level)	0.135	0.116	0.115
v_{fjt}	vertical integration index (product-level)	0.134	0.116	0.115
$tariff_{kt}$	most-favored nations (MFN) tariff	0.332	0.297	0.279
$input\_tariff_{kt}$	MFN tariffs weighted by IO transaction coefficients	0.084	0.064	0.078
$investment\_intensity_{kt}$	investment / sales (average at the industry-level)	0.061	0.057	0.032
$R\&D\_intensity_{kt}$	R&D / sales (average at the industry-level)	0.002	0.001	0.002
$industry\_size_{kt}$	log(sales), (average at the industry-level)	6.283	6.182	0.720
$homogenous\_good_{j}$	=1 if homogenous good (Rauch 1999 classification)	0.450	0.000	0.497
$exports_{ft}$	export / sales	0.094	0.004	0.195
$imports_{ft}$	imports / input expenditures	0.239	0.093	0.319
log_sales_{ft}	log(sales),	6.477	6.429	2.049
$log\_R\&D_{ft}$	log (R&D expenditures + 1)	0.584	0.000	1.273
$markup_{fjt}$	price / marginal cost	2.828	1.339	4.831
$marginal\_cost_{fjt}$	marginal cost, deviation from product-year average	0.000	-0.002	149.1

f, j, k denote variable measured at firm, product and industry level respectively. t represents year.

Table 2: Changes in output tariffs and industrial characteristics

	output tariffs						input tariffs					
Industrial Characteristics	1989-1992	1992-1997	1997-2002	2002-2007	2007-2012	1989-2012	1989-1992	1992-1997	1997-2002	2002-2007	2007-2012	1989-2012
Mean VI	-0.389	0.115	0.056	-0.141	0.105	-0.779	-0.133	0.031	0.059	0.072	-0.017	-0.419
	(0.519)	(0.246)	(0.105)	(0.155)	(0.095)	(0.610)	(0.155)	(0.081)	(0.048)	(0.095)	(0.038)	(0.271)
Log mean wage	-0.035	-0.104	0.041	-0.072***	-0.011	-0.178*	-0.067***	-0.049***	-0.008	-0.006	-0.012***	-0.166***
	(0.113)	(0.097)	(0.045)	(0.017)	(0.009)	(0.100)	(0.023)	(0.010)	(0.008)	(0.010)	(0.003)	(0.037)
Share of non-production workers	0.574	-0.979	0.581*	-0.135	-0.042*	-0.289	-0.237	-0.230***	-0.049	0.004	-0.025*	-0.754**
	(0.768)	(0.638)	(0.297)	(0.112)	(0.179)	(0.085)	(0.081)	(0.074)	(0.014)	(0.311)	(0.025)	(0.744)
Capital labour ratio	-0.008	-0.025	0.002	-0.001	-0.001	-0.046	0.013	-0.000	0.000	0.000*	-0.000	0.011
	(0.040)	(0.020)	(0.003)	(0.001)	(0.000)	(0.049)	(0.010)	(0.004)	(0.001)	(0.000)	(0.000)	(0.020)
Log output	-0.008	-0.018	0.022**	0.006	-0.001	0.007	-0.014	-0.007	-0.003	0.004	-0.000	-0.009
	(0.010)	(0.005)	(0.003)	(0.003)	(0.001)	(0.022)	(0.010)	(0.005)	(0.003)	(0.003)	(0.001)	(0.022)
Factory size	-0.000	0.000	0.000	-0.000	0.000	-0.000	0.000	0.000	0.000	0.000	-0.000	-0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log employment	0.004	0.003	0.011	0.007	-0.002	0.028	-0.010	-0.003	-0.004	0.005	0.001	0.003
	(0.029)	(0.010)	(0.008)	(0.006)	(0.002)	(0.030)	(0.013)	(0.006)	(0.003)	(0.003)	(0.002)	(0.025)
Growth in output	0.105	-0.180	-0.047**	-0.020	0.001	-0.014	0.115	0.020	0.009	-0.029	-0.001	-0.010
	(0.250)	(0.166)	(0.021)	(0.023)	(0.001)	(0.016)	(0.086)	(0.022)	(0.012)	(0.021)	(0.002)	(0.026)
Growth in employment	-0.537	-0.134	-0.056***	-0.018	0.001	-0.023	-0.285	-0.002	0.001	-0.056**	-0.003	-0.027
	(0.564)	(0.113)	(0.020)	(0.021)	(0.001)	(0.015)	(0.244)	(0.048)	(0.009)	(0.025)	(0.002)	(0.021)
Observations	68	68	69	67	66	65	50	50	43	45	45	43

Bivariate regressions of change in output tariffs on each industry characteristic, weighted by the number of factories in each industry.
Apart from growth in output and employment, industrial characteristics are at beginning of period values, i.e. 1989 for period 1989-1992, 1992 for period 1992-1997,etc.
Growth in output and employment is lagged relative to sample period, i.e. 1992-1997 for period 1997-2002.
Robust standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Tariffs and competition

	(1) num products	(2) num firms	(3) import ratio	(4) Dom sales	(5) Markups
tariff	1.196***	0.588***	-0.074**	0.800***	0.258***
	(0.359)	(0.178)	(0.037)	(0.300)	(0.096)
Observations	1088	1088	1088	1088	1088
Sector fixed effects	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes

Standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

tariff is the MFN tariff rate

Table 4: Tariffs and firm-product level responses

	(1)	(2)	(3)	(4)	(5)	(6)
	Markups	Output	Markups	Output	Markups	Output
Subsample	all firms	all firms	TFP<median	TFP<median	TFP≥median	TFP≥median
tariff	0.157**	0.374***	0.245**	0.429***	0.067	0.220
	(0.080)	(0.106)	(0.125)	(0.127)	(0.111)	(0.145)
Observations	106435	106435	53282	53282	53153	53153
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

tariff is the MFN tariff rate.

Table 5: Vertical integration and tariffs, firm-level

	(1)	(2)	(3)	(4)	(5)	(6)
tariff	-0.022**	-0.017**	-0.025***	-0.025***	-0.025***	-0.025***
	(0.010)	(0.007)	(0.009)	(0.009)	(0.009)	(0.008)
input tariff			0.057	0.047	0.047	0.064*
			(0.044)	(0.043)	(0.043)	(0.038)
investment intensity				0.164***	0.164***	0.192***
				(0.047)	(0.047)	(0.044)
R&D intensity				0.497	0.498	0.043
				(0.517)	(0.517)	(0.583)
industry size				-0.001	-0.001	-0.004
				(0.005)	(0.005)	(0.005)
export share					0.001	0.001
					(0.002)	(0.002)
import share					-0.000	-0.001
					(0.001)	(0.001)
Observations	66664	66664	66664	66664	66664	66664
Firm fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	no	yes	yes	yes	yes	yes
Year fixed effects	yes	no	no	no	no	no
Industry-characteristics-year FE	yes	no	no	no	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{it}, the vertical integration index in a firm's main industry.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Size, Investment and R&D intensity are measured at the industry-level.

Export and import share are measured at the firm-level.

Table 6: Vertical integration and tariffs, firm-product-level

	(1)	(2)	(3)	(4)	(5)	(6)
tariff	-0.027**	-0.024***	-0.034***	-0.064***	-0.024***	-0.042***
	(0.012)	(0.007)	(0.009)	(0.014)	(0.006)	(0.010)
input tariff			0.072			0.138***
			(0.046)			(0.049)
Observations	121443	121443	121443	81275	81275	81275
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	no	yes	yes	no	yes	yes
Firm-year fixed effects	no	no	no	yes	yes	yes
Year fixed effects	yes	no	no	yes	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table 7: Vertical integration and tariffs, firm-level heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)
Subsample	TFP≥median	TFP<median	R&D	no R&D	domestic	non-domestic
tariff	-0.047***	-0.027***	-0.054***	-0.028***	-0.034***	-0.016
	(0.012)	(0.009)	(0.017)	(0.009)	(0.009)	(0.030)
input tariff	0.101	0.052	0.091	0.084*	0.067	0.712**
	(0.064)	(0.045)	(0.068)	(0.051)	(0.046)	(0.285)
Observations	54415	54457	27520	92740	116989	4401
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	yes	yes	yes	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table 8: Vertical integration and tariffs: industry characteristics

	(1)	(2)	(3)	(4)
Subsample	low competition	high competition	low cap.intensity	high cap.intensity
tariff	-0.040***	-0.019	-0.002	-0.096**
	(0.010)	(0.019)	(0.008)	(0.045)
input tariff	0.123***	-0.102	-0.224***	1.272***
	(0.046)	(0.107)	(0.041)	(0.215)
Observations	59740	60240	53838	56708
Firm-product fixed effects	yes	yes	yes	yes
Sector-year fixed effects	yes	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Low (high) competition defines industries with initial markups above (below) the median.

Capital intensity is defined as the ratio of the initial capital stock to employment.

Table 9: Vertical events, marginal costs and markups: matching and reweighting

	(1)	(2)	(3)	(4)	(5)	(6)
	unweighted		pscore-reweighted		1-1 matching	
	marg. cost	markup	marg. cost	markup	marg. cost	markup
post VI event	-0.127***	0.137***	-0.106***	0.103***	-0.132***	0.110***
	(0.023)	(0.021)	(0.032)	(0.030)	(0.027)	(0.026)
Observations	114621	114621	83964	83964	52516	52516
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes

All regressions are estimated at the firm-product-year level.

Robust standard errors, clustered by firm, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable in columns (1), (3) and (5) is the log of marginal costs at the firm-product-level.

The dependent variable in columns (2), (4) and (6) is the log of the markup at the firm-product-level.

Table 10: Tariffs, investment and R&D

Subsample	(1) All firms	(2) All firms	(3) TFP≥median	(4) TFP<median	(5) All firms
Panel A: R&D expenditures					
tariff	0.034	0.043	-0.420***	0.250***	0.297***
	(0.043)	(0.043)	(0.090)	(0.061)	(0.047)
input tariff		-0.104	-0.930***	0.323**	0.501***
		(0.157)	(0.347)	(0.152)	(0.117)
2nd TFP quartile × tariff					-0.121***
					(0.027)
3rd TFP quartile × tariff					-0.356***
					(0.056)
4th TFP quartile × tariff					-0.947***
					(0.168)
2nd TFP quartile × input tariff					-0.449***
					(0.107)
3rd TFP quartile × input tariff					-0.930***
					(0.213)
4th TFP quartile × input tariff					-1.774***
					(0.618)
Panel B: Investment					
tariff	0.085	0.060	-0.394**	0.429***	0.345***
	(0.080)	(0.088)	(0.172)	(0.120)	(0.099)
input tariff		0.146	-0.901	0.525	0.959***
		(0.308)	(0.675)	(0.334)	(0.293)
2nd TFP quartile × tariff					-0.230***
					(0.087)
3rd TFP quartile × tariff					-0.499***
					(0.141)
4th TFP quartile × tariff					-0.778***
					(0.280)
2nd TFP quartile × input tariff					-0.729***
					(0.266)
3rd TFP quartile × input tariff					-1.249***
					(0.471)
4th TFP quartile × input tariff					-1.739*
					(1.008)
Observations	62138	62138	28335	26944	55279
Firm fixed effects	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes

All regressions are estimated at the firm-year level.

The dependent variable in Panel A is $\ln(RD+1)$, the log of R&D expenditures +1.

The dependent variable in Panel B is $\ln(invest+1)$, the log of investment +1.

Robust standard errors, clustered two-way by firm and industry-year, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

TFP is measured at the time firms enter the sample and is demeaned by industry-year.

Appendix A: Additional tables and figures

Table A1: Tariffs over time

	output tariff			input tariff		
year	mean	median	sd	mean	median	sd
1989	1.119	1.168	0.485	0.308	0.295	0.186
1990	0.964	0.968	0.387	0.263	0.254	0.154
1991	0.797	0.730	0.289	0.217	0.220	0.121
1992	0.632	0.609	0.220	0.170	0.186	0.089
1993	0.573	0.556	0.213	0.153	0.169	0.081
1994	0.514	0.502	0.202	0.135	0.153	0.072
1995	0.461	0.423	0.212	0.120	0.136	0.063
1996	0.410	0.370	0.227	0.104	0.119	0.055
1997	0.325	0.298	0.188	0.085	0.095	0.044
1998	0.341	0.321	0.180	0.078	0.084	0.044
1999	0.355	0.343	0.166	0.083	0.090	0.047
2000	0.356	0.366	0.133	0.082	0.094	0.047
2001	0.349	0.339	0.149	0.080	0.088	0.044
2002	0.318	0.298	0.140	0.072	0.078	0.042
2003	0.293	0.250	0.140	0.083	0.093	0.047
2004	0.318	0.300	0.139	0.091	0.106	0.051
2005	0.212	0.156	0.170	0.055	0.060	0.034
2006	0.190	0.124	0.178	0.045	0.046	0.029
2007	0.196	0.132	0.173	0.055	0.057	0.034
2008	0.153	0.085	0.173	0.038	0.036	0.030
2009	0.159	0.086	0.185	0.040	0.038	0.030
2010	0.148	0.082	0.172	0.037	0.036	0.029
2011	0.151	0.082	0.180	0.041	0.039	0.030
all	0.329	0.294	0.272	0.085	0.064	0.078

Table A2: Tariffs and lagged productivity

	1989-1992	1992-1997	1997-2002	2002-2007	2007-2012	1989-2012
		Panel A: Output tariffs				
TFP_{t-1}	0.066	-0.002	0.064*	-0.016	0.011*	0.004
	(0.076)	(0.007)	(0.033)	(0.015)	(0.006)	(0.013)
		Panel B: Input tariffs				
TFP_{t-1}	0.033	0.002	0.005	-0.010	0.004*	0.001
	(0.022)	(0.003)	(0.006)	(0.008)	(0.002)	(0.010)
Observations	132	216	225	222	212	860
Industry fixed effects	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes

Standard errors, in parentheses, are clustered by industry.

All regressions are weighted by the number of firms in each industry

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Vertical integration, Indian and foreign tariffs, firm-product-level

	(1)	(2)	(3)	(4)	(5)	(6)
tariff	-0.031**	-0.029***	-0.038***	-0.073***	-0.027***	-0.046***
	(0.013)	(0.008)	(0.010)	(0.015)	(0.007)	(0.010)
foreign tariff	-0.070	-0.133***	-0.136***	-0.076**	-0.087**	-0.103**
	(0.050)	(0.040)	(0.041)	(0.030)	(0.041)	(0.042)
input tariff			0.086*			0.160***
			(0.048)			(0.051)
Observations	112047	112047	112047	75683	75683	75683
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	no	yes	yes	no	yes	yes
Firm-year fixed effects	no	no	no	yes	yes	yes
Year fixed effects	yes	no	no	yes	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

foreign tariff is the average tariff rate faced by firms exporting from India.

Table A4: Tariffs and vertical integration: heterogeneity by ownership

	(1) State-owned	(2) Private	(3) Individual	(4) Group
tariff	-0.032**	-0.038***	-0.043***	-0.028***
	(0.015)	(0.010)	(0.011)	(0.011)
input tariff	0.110	0.068	0.101	0.037
	(0.087)	(0.051)	(0.064)	(0.053)
Observations	7908	96464	60678	35668
Firm-product fixed effects	yes	yes	yes	yes
Sector-year fixed effects	yes	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A5: Vertical integration and tariffs: industry characteristics

Initial markups	(1) 1st quartile	(2) 2nd quartile	(3) 3rd quartile	(4) 4th quartile
tariff	0.065	-0.059***	-0.091***	-0.023***
	(0.045)	(0.020)	(0.025)	(0.007)
input tariff	-0.509***	0.467***	0.327***	0.031
	(0.122)	(0.130)	(0.115)	(0.039)
Observations	30289	29910	29615	30068
Firm-product fixed effects	yes	yes	yes	yes
Sector-year fixed effects	yes	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Initial markups indicate

Table A6: Tariffs and vertical integration: heterogeneity by delicensing status

	(1) Delicensed	(2) Not delicensed	(3) Delicensed 1991	(4) Not Delicensed 1991
tariff	-0.050***	-0.006	-0.053***	-0.010
	(0.017)	(0.016)	(0.015)	(0.008)
input tariff	0.120	0.037	0.145	-0.087**
	(0.094)	(0.085)	(0.090)	(0.041)
Observations	102346	2228	94106	25679
Firm-product fixed effects	yes	yes	yes	yes
Sector-year fixed effects	yes	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A7: Industry-level markups as measure of domestic competition

	(1)	(2)	(3)
Lag industry markup	-0.033**	-0.034**	-0.030**
	(0.014)	(0.014)	(0.013)
input tariff		0.239***	0.342***
		(0.046)	(0.052)
tariff			-0.091***
			(0.016)
Observations	96707	96707	96707
Firm-product fixed effects	yes	yes	yes
Year fixed effects	yes	yes	yes

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

Industry markup is the log of the mean of markups of domestic firms at the industry-level.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A8: Vertical integration and tariffs: non-linearities

	(1)	(2)	(3)	(4)
	v	ln(v)	ln(v+1)	ln(v+1)
tariff	-0.079***			
	(0.025)			
tariff^2	0.034***			
	(0.011)			
input tariff	0.401***			
	(0.088)			
input tariff^2	-0.655***			
	(0.120)			
ln(tariff)		-0.270***		
		(0.102)		
ln(input tariff)		0.885***		
		(0.087)		
ln(tariff+1)			-0.052***	-0.104**
			(0.015)	(0.045)
ln(input tariff+1)			0.076	0.457***
			(0.048)	(0.088)
$(\ln(\text{tariff}+1))^2$				0.081**
				(0.036)
$(\ln(\text{input tariff}+1))^2$				-1.023***
				(0.163)
Observations	121443	103149	121443	121443

Robust standard errors, clustered two-way by firm and industry, in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
The dependent variable in column (1) is v_{ijt}.
The dependent variable is $\ln(v_{ijt})$ ($\ln(v_{ijt} + 1)$) in column 2 ((3) and (4)).
v_{ijt} is the vertical integration index of a firm-product in year t.
tariff is the MFN tariff rate.
input tariff is the weighted tariff rate of supplying industries.

Table A9: Alternative estimation methods

Method	(1) Tobit	(2) Fractional Probit	(3) Fractional Logit	(4) Exponential pseudo ML
tariff	-0.076***	-0.091***	-0.090***	-0.721***
	(0.002)	(0.003)	(0.003)	(0.025)
input tariff	0.367***	0.456***	0.443***	3.594***
	(0.009)	(0.012)	(0.012)	(0.095)
Observations	123340	123340	123340	123340
Industry and year dummies	yes	yes	yes	yes

Numbers are average marginal effects in columns (1)-(3) and coefficients in column (4).
Robust standard errors, clustered two-way by firm and industry, in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
The dependent variable is v_{ijt}, the vertical integration index of a firm-product.
tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A10: Excluding corporate groups

	(1)	(2)	(3)	(4)	(5)	(6)
tariff	-0.025**	-0.026***	-0.038***	-0.039***	-0.020***	-0.034***
	(0.012)	(0.008)	(0.011)	(0.013)	(0.008)	(0.010)
input tariff			0.104*			0.132**
			(0.053)			(0.063)
Observations	81398	81398	81398	51991	51991	51991
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	no	yes	yes	no	yes	yes
Firm-year fixed effects	no	no	no	yes	yes	yes
Year fixed effects	yes	no	no	yes	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
The dependent variable is v_{ijt}, the vertical integration index of a firm-product.
tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A11: Including multinationals

	(1)	(2)	(3)	(4)	(5)	(6)
tariff	-0.027**	-0.024***	-0.033***	-0.063***	-0.027***	-0.043***
	(0.010)	(0.006)	(0.009)	(0.013)	(0.006)	(0.009)
input tariff			0.066			0.103**
			(0.045)			(0.045)
Observations	148994	148983	148983	103642	103618	103310
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	no	yes	yes	no	yes	yes
Firm-year fixed effects	no	no	no	yes	yes	yes
Year fixed effects	yes	no	no	yes	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A12: Products aggregated to the 3-digit industry level

	(1)	(2)	(3)	(4)	(5)	(6)
tariff	-0.023**	-0.021***	-0.027***	-0.056***	-0.024***	-0.040***
	(0.010)	(0.007)	(0.009)	(0.012)	(0.006)	(0.009)
input tariff			0.029			0.135***
			(0.043)			(0.049)
Observations	88523	88508	88508	35360	35276	35163
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Sector-year fixed effects	no	yes	yes	no	yes	yes
Firm-year fixed effects	no	no	no	yes	yes	yes
Year fixed effects	yes	no	no	yes	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable is v_{ijt}, the vertical integration index of a firm-product.

tariff is the MFN tariff rate. input tariff is the weighted tariff rate of supplying industries.

Table A13: Balancing property - vertical integration events

Variable	Mean			t-test	
	Treated	Control	%diff	t	$p > \|t\|$
ln(markup)	0.216	0.217	0.0	-0.020	0.985
Δln(markup)	0.039	0.050	-1.3	-0.660	0.510
marginal cost, demeaned	-0.718	-0.842	0.6	0.320	0.751
Δ(marginal cost)	-0.753	-0.648	-0.3	-0.180	0.858
ln(Sales)	4.769	4.750	0.9	0.460	0.646
Δln(Sales)	0.134	0.130	0.5	0.280	0.779
ln(Sales), firm-level	6.543	6.569	-1.4	-0.730	0.465
Δln(Sales), firm-level	0.103	0.097	1.4	0.740	0.462

Notes: Table shows mean values of variables for the matched sample.

All variables, unless indicated otherwise, measured at the firm-product level.

Table A14: Vertical integration index, marginal costs and markups: simple regressions

	(1) marg. cost	(2) markup	(3) marg. cost	(4) markup	(5) marg. cost	(6) markup
vertical integration index	-0.488***	0.292**	-1.118***	1.121***	-0.790**	0.912***
	(0.149)	(0.136)	(0.301)	(0.275)	(0.336)	(0.337)
Observations	114,621	114,621	114,621	114,621	82,005	82,005
Firm-product fixed effects	yes	yes	yes	yes	yes	yes
Product-year fixed effects	no	no	yes	yes	no	no
Firm-year fixed effects	no	no	no	no	yes	yes
Year fixed effects	yes	yes	no	no	no	no

Robust standard errors, clustered two-way by firm and industry, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The dependent variable in columns (1), (3) and (5) is the log of marginal costs at the firm-product-level.

The dependent variable in columns (2), (4) and (6) is the log of the markup at the firm-product-level.

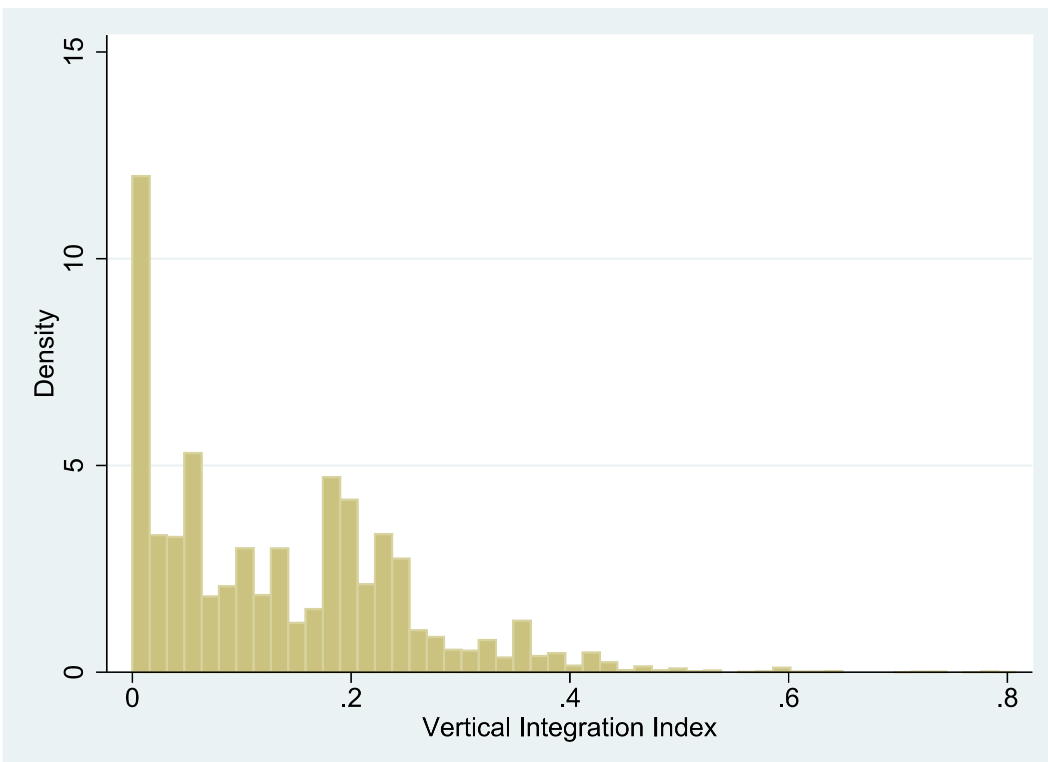

Figure 1: Vertical Integration Index

Appendix B: Estimation of productivity, markups, and marginal costs

To estimate productivity, markups, and marginal costs, we follow the methodology recently introduced by De Loecker et al. (2016), henceforth LGKP. This method accounts for endogeneity of productions inputs similar to standard techniques in the productivity literature (Ackerberg et al., 2015; Levinsohn and Petrin, 2003; Olley and Pakes, 1996). In addition, it relies on the availability of quantities and prices at the product level to separate true efficiency from revenue based productivity. As most (if not all) firm-product-level data sets, Prowess does not include complete information on prices of all inputs and has no information about how inputs are allocated across products for multi-product firms. The main innovations of the LGKP approach are the introduction of a control function for unobserved input prices and a method to recover the allocation of inputs across products. We describe the methodology below.

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

$$Q_{ijt} = F_j(M_{ijt}, K_{ijt}, L_{ijt})\Omega_{it} \tag{11}$$

where Q_{ijt} denotes physical output, M_{ijt} denotes a freely adjustable input (materials in our case), K_{ijt} and L_{ijt} are capital stock and labor input respectively and Ω_{it} denotes total factor productivity (TFP). All production inputs are defined in physical units. A firm minimizes costs product-by-product subject to the production function and input costs.

As shown by De Loecker and Warzynski (2012) and LGKP, this cost minimization yields an expression for the firm-product specific markup as:

$$\mu_{ijt} = \left(\frac{P_{ijt}Q_{ijt}}{W^M_{ijt}M_{ijt}} \right) \frac{\partial Q_{ijt}(.)}{\partial M_{ijt}} \frac{M_{ijt}}{Q_{ijt}} = \frac{\theta^M_{ijt}}{\alpha^M_{ijt}} \tag{12}$$

where P_{ijt} denotes the output price, W^M_{ijt} is the input price of materials, α^M_{ijt} is the ratio of expenditures on input M_{ijt} to a product's revenue and θ^M_{ijt} is the elasticity of output with respect to this input. Intuitively, the output elasticity equals the input's revenue share only in the case of perfect competition. Under imperfect competition, the output elasticity will exceed the revenue share. θ^M_{ijt} can be estimated from a production function and α^M_{ijt} can be calculated, once the allocation of inputs across a firms' product has been estimated. Marginal costs (mc_{ijt}) can then be calculated as the ratio of observed prices to estimated markups:

$$mc_{ijt} = \frac{P_{ijt}}{\mu_{ijt}} \tag{13}$$

The basis for productivity estimation is the logarithmic version of equation (11) with an additive error term, ϵ_{ijt} which captures measurement error:

$$q_{ijt} = f_j(\boldsymbol{v}_{ijt}; \boldsymbol{\beta}) + \omega_{it} + \epsilon_{ijt} \tag{14}$$

where $\boldsymbol{v}_{ijt}$ denotes a vector of logarithmic physical inputs (capital k_{ijt}, labor l_{ijt} and materials m_{ijt}) allocated to product j and ω_{it} is the log of TFP. For our application, we use a translog production function, hence:

$$\begin{aligned} f_j(\boldsymbol{v}_{ijt}; \boldsymbol{\beta}) =& \beta_l l_{ijt} + \beta_m m_{ijt} + \beta_k k_{ijt} + \beta_{lm} l_{ijt} m_{ijt} + \beta_{lk} l_{ijt} k_{ijt} + \beta_{mk} m_{ijt} k_{ijt} \\ &+ \beta_{ll} l_{ijt}^2 + \beta_{mm} m_{ijt}^2 + \beta_{kk} k_{ijt}^2 + \beta_{lmk} l_{ijt} m_{ijt} k_{ijt} \end{aligned} \tag{15}$$

The translog production function yields a physical output-material elasticity:

$$\theta_{ijt}^M = \beta_m + \beta_{lm} l_{ijt} + \beta_{mk} k_{ijt} + 2\beta_{mm} m_{ijt} + \beta_{lmk} l_{ijt} k_{ijt} \tag{16}$$

which varies across firms within industries and nests a Cobb-Douglas production function as a special case.

Physical inputs can be expressed as $v_{ijt} = \rho_{ijt} + \tilde{v}_{it} - w_{ijt}$ where $\tilde{v}_{it}$ denotes observed input expenditures at the firm-level, ρ_{ijt} is the log of the input share allocated to product j and w_{ijt} denotes the log of an input price index (defined as deviations from industry-specific deflators). When the log of input allocations, ρ_{ijt}, is captured by a function $A(\rho_{ijt}, \tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta})$ and the log of the unobserved input price index, w_{ijt}, are captured by a function $B(w_{ijt}, \rho_{ijt}, \tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta})$, output can be rewritten as a function of firm-specific input expenditures instead of unobserved product-specific input quantities (see LGKP for the exact functional form of $A(.)$ and $B(.)$ for the translog case):

$$q_{ijt} = f_j(\tilde{\boldsymbol{v}}_{ijt}; \boldsymbol{\beta}) + A(\rho_{ijt}, \tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta}) + B(w_{ijt}, \rho_{ijt}, \tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta}) + \omega_{it} + \epsilon_{ijt} \tag{17}$$

Estimation of the parameters of the production function is based on a sample of single product firms for which $A(.)$ can be ignored. Unobserved input prices w_{it} in $B(.)$ are approximated by output prices (p_{it}), market shares (s_{it}), product dummies ($\boldsymbol{D_j}$),and export status (ex_{it}) to account for differences in product quality and local input markets. We also include our vertical integration measure ($\boldsymbol{vi}_{it}$), as we want to allow for the possibility that vertical integration is associated with different input prices.

Material demand is assumed to be a function of productivity, other inputs, output prices, market share, product, export and vertical integration, hence: $\tilde{m}_{it} = m(\omega_{it}, \tilde{k}_{it}, \tilde{l}_{it}, p_{it}, \boldsymbol{D}_j, s_{it}, ex_{it}, \boldsymbol{vi}_{it})$. Inverting the material demand function yields and expression for productivity: $\omega_{it} = h(\tilde{\boldsymbol{v}}_{it}, \boldsymbol{c}_{it})$ where $\boldsymbol{c}_{it}$ includes all variables from the input demand function except input expenditures.

The use of single product firms induces a further complication of endogenous sample selection since single-product firms might be less productive compared to multi-product firms. Analogous to the exit correction proposed by Olley and Pakes (1996), the probability of remaining a single product firm (SP_{it}) is a function of previous year's productivity and an unobserved productivity cutoff.[41]

For the evolution of productivity, the following law of motion is assumed:

$$\omega_{it} = g(\omega_{i,t-1}, ex_{it}, \boldsymbol{vi}_{i,t-1}, SP_{it}) + \varsigma_{it} \tag{18}$$

In addition to export status and the probability of remaining a single product firm, we allow the evolution of productivity to depend on the degree of vertical integration.

Since for single product firms, we do not face the problem of unobserved input allocation across products and can drop the product-specific subscript of the production function, equation (17) becomes:

$$q_{ijt} = f(\tilde{\boldsymbol{v}}_{ijt}; \boldsymbol{\beta}) + B(w_{ijt}, \rho_{ijt}, \tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta}) + \omega_{it} + \epsilon_{ijt} \tag{19}$$

One can combine $f(.)$, $B(.)$ and $g(.)$ into a function $\phi(\tilde{\boldsymbol{v}}_{ijt}, \boldsymbol{c}_{it})$ such that output can be expressed as a function of observable variables and measurement errors: $q_{it} = \phi(\tilde{\boldsymbol{v}}_{it}, \boldsymbol{c}_{it}) + \epsilon_{it}$.

$\phi(.)$ is approximated by a linear combination of all its elements and a polynomial in all continuous variables. While this expression does not identify any parameters of the production and input price functions, it identifies output net of measurement error ϵ_{it} which is denoted by $\hat{\phi}_{it}$. Productivity can then be expressed as:

$$\omega_{it} = \hat{\phi}_{it} - f(\tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta}) - B(\boldsymbol{c}_{it}, \boldsymbol{c}_{it} \times \tilde{\boldsymbol{v}}_{it}, \boldsymbol{\beta}, \boldsymbol{\delta}) \tag{20}$$

where $\boldsymbol{\delta}$ are the parameters of the input price function to be estimated. For identification of param-

[41] SP_{it} is estimated by a Probit regression of a dummy variable for remaining a single-product firm on $\tilde{\boldsymbol{v}}_{i,t-1}$ $\boldsymbol{c}_{i,t-1}$, investment, year and industry dummies.

eters, equation (18) can be used to construct moment conditions:

$$E[\varsigma_{it}(\boldsymbol{\beta}, \boldsymbol{\delta})\boldsymbol{Z}_{it}] = 0 \tag{21}$$

$\boldsymbol{Z}_{it}$ is a vector which includes current values of labour and capital, lagged values of materials and their higher order and interaction terms as they appear in the production function. It further includes lagged values of market shares and prices as well as interactions of lagged prices with lags of production factors and market share. We treat labor as a dynamic input that is characterized by adjustment costs due to the rather rigid Indian labor market. Estimation is undertaken using the GMM procedure suggested by Wooldridge (2009) which is based on moment conditions on the combined error term $\varsigma_{it} + \epsilon_{it}$.

This estimation procedure yields estimates of $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$, hence, it identifies all parameters from the production and input price functions. We estimate $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ separately for each industry to allow for industry-specific production technologies and input prices. Under the assumption that $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ are the same for multi- and single-product firms within industries, input allocations across products within multi-product firms can be recovered which allows estimation of markups and marginal costs for each firm-product-year. Note that as discussed by LGKP, this assumption does not rule out differences in productivity levels between single- and multi-product. Since productivity is modeled to be factor-neutral, differences in TFP do not imply differences in $\boldsymbol{\beta}$ or output elasticities. The approach also allows for TFP to depend on the number of products which can imply (dis)economies of scope. Under the assumption of a common production technology within industries, one can express predicted output as: $\hat{q}_{ijt} = f(\tilde{\boldsymbol{v}}_{ijt}, \boldsymbol{\beta}, \hat{w}_{ijt}, \rho_{ijt}) + \omega_{it}$ and divide the production function into two parts, f_1 and f_2, such that only f_2 depends on input allocations across products. This yields a system of equation for each firm-year which allows identifying productivity ω_{it} for each firm-year and the input share allocation ρ_{ijt} for each firm-product-year:

$$\begin{aligned} \hat{q}_{ijt} - f_1(\tilde{\boldsymbol{v}}_{ijt}, \boldsymbol{\beta}, \hat{w}_{ijt}) =& f_2(\tilde{\boldsymbol{v}}_{ijt}, \hat{w}_{ijt}, \rho_{ijt}) + \omega_{it} \\ \sum_j \exp(\rho_{ijt}) =& 1 \end{aligned} \tag{22}$$

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