

# The effect of FDI liberalization on manufacturing firms' technology upgrading

Maria Bas\*and Nevine El-Mallakh †

March 20, 2019

## Abstract

FDI liberalization promotes the entrance of multinational firms relying on advanced technologies. This paper studies the effects of FDI liberalization on domestic downstream firms technology upgrading through two main mechanisms. Domestic final good producers might benefit from horizontal FDI technological spillovers and from vertical FDI spillovers. These effects can be unequal across domestic firms depending on their initial productivity level. We investigate the effects of FDI reform in India in the beginning of the 1990s on downstream manufacturing firms' decision to upgrade technology (capital investments, R&D and foreign technology embodied in imported inputs). Our estimation strategy relies on a difference-in-differences estimation comparing firms producing in industries where FDI has been liberalized against those firms producing in non-FDI liberalized industries. Our findings suggest that Indian firms benefited from FDI liberalization to improve their technical-know how. These results are concentrated on the most productive firms. The main channel driving these results is horizontal FDI spillovers, while we find only evidence of vertical FDI spillovers for capital investments.

**Keywords:** FDI liberalization, manufacturing firms' technology choice, Horizontal and Vertical FDI spillovers, firm heterogeneity and firm level data.

**JEL Classification:** O10, L8, F2.

---

\*University of Paris 1 Panthéon-Sorbonne. Centre d'Économie de la Sorbonne (CES), 106-112 Bd de l'Hôpital, 75647 Paris Cedex 13. E-mail: maria.bas@univ-paris1.fr.

†University of Paris 1 Panthéon-Sorbonne. Centre d'Économie de la Sorbonne (CES), 106-112 Bd de l'Hôpital, 75647 Paris Cedex 13. E-mail: nevine.el-mallakh@univ-paris1.fr.

# 1 Introduction

FDI liberalization plays an important role in enhancing economic growth through FDI technological spillovers. The micro-econometric literature has shown that the presence of foreign affiliates has positive effects on domestic firms' productivity. According to Görg and Greenaway (2004), there is very weak evidence found for horizontal productivity spillovers from foreign firms to domestic firms. The effect is slightly stronger for vertical productivity spillovers between foreign and domestic firms that are vertically integrated and are located in nearby locations (Kneller and Pisu, 2007). Most of the previous literature has found weak evidence of productivity spillovers until Keller and Yeaple (2009). They show large significant spillover effects within-industry for US firms. They have attributed the stronger results they got to the better identification strategy they deployed. They used a first difference model with an instrumental variable approach to alleviate possible endogeneity of foreign investment in specific sectors.

Little is known about the effects of the presence of foreign affiliates on manufacturing firms' technology choice. The aim of this paper is to fill this gap by investigating the relationship between the Indian reform in FDI in the early 1990s and domestic manufacturing firms' technology upgrading. India represents an interesting setting to study this relationship since it experienced a substantial FDI liberalization reform in the early 1990s. Interactions between foreign affiliates relying on modern technologies and domestic firms create incentives for manufacturing Indian firms to improve their efficiency by upgrading their technology investments. In a context of fixed costs of technology adoption, FDI liberalization allows some manufacturing firms to improve their technological investments through vertical and horizontal links with foreign affiliates. We first present a simple theoretical framework that rationalizes these two main channels through which FDI liberalization affects local firms' technology choice. Our model features two sectors: (1) a downstream sector with heterogeneous firms and fixed technology costs and (2) an upstream sector producing differentiated varieties of intermediate goods under constant returns to scale. FDI liberalization affects a variable regulation cost in both sectors as well as the fixed costs of technology. The presence of multinational firms in the downstream sector is assumed to reduce the fixed technology cost of downstream firms through horizontal FDI technology spillovers and in the upstream sector it reduces the cost of inputs through input-output linkages and vertical FDI spillovers. Since local firms in the downstream sector have different productivity levels, only the initially most productive firms are going to benefit from FDI liberalization to upgrade its technology.

These predictions are tested using Indian firm-level data, Prowess, over the 1989-1997 period, provided by the Centre for Monitoring the Indian Economy. The empirical analysis

identifies the causal relationship of FDI technological spillovers on domestic firms' technology upgrading by relying on exogenous changes in the legislation of FDI in India in 1992 to capture the presence of foreign affiliates. The identification strategy consists in a difference-in-difference methodology exploiting the variation in the magnitude of FDI reform across industries over time. The measure of FDI liberalization used is the share of HS6 products that were liberalized to FDI within an industry in a year. We present evidence that this measure is free of reverse causality concerns. We first show that firms producing in FDI liberalized industries and non-liberalized industries are similar in terms of technology investments in the pre-reform period 1989-1991. We also show that FDI reform is non-correlated to initial firm and industry characteristics.

Relying on this difference-in-difference methodology, we first test if the effect of the presence of foreign affiliates on firms' technological investments is more pronounced for firms producing in industries that experienced a greater proportion of HS6 products that were liberalized to FDI. We also test if the effect of the presence of foreign affiliates is heterogeneous across firms depending on their initial performance as predicted by the theoretical framework. This allows us to identify the firms that have benefited from FDI liberalization. Finally, we disentangle two possible mechanisms through which FDI liberalization affects local firms' technology choice: (1) horizontal FDI spillovers and (2) vertical FDI spillovers. The first one is captured by the direct effects of FDI liberalization on local firms producing final goods in the same industry. The second one is identified through input-output linkages by the effects of FDI liberalization in upstream input sectors on local downstream manufacturing firms relying on Input-Output tables.

Our findings show that FDI liberalization has a positive effect on manufacturing firms' technology choice. Indian firms in downstream sectors have increased their technological domestic and foreign investments in capital goods, R&D, imports of intermediate and capital goods after FDI liberalization. This effect is concentrated on the most productive firms. Moreover, our findings suggest that the main mechanism through which FDI reform affects domestic firms' technology upgrading is through the horizontal FDI spillovers. The vertical FDI spillovers has only a positive effect on downstream firms' decision to increase investment and capital goods but no effect on R&D investments or foreign technology investments.

The rest of the paper is organized as follows. The next section presents a review of literature highlighting the main contributions of our work to this literature. Section 3 presents descriptive evidence of local firms and the FDI liberalization episode in India. Section 4 develops a simple theoretical framework that rationalizes the main mechanisms through which FDI liberalization affects local firms' technology choice. Section 5 describes the firm-level dataset

and FDI liberalization in India. Section 6 presents the empirical identification strategy and the baseline results. Section 7 presents the heterogeneous effects of FDI liberalization and Section 8 disentangles the main channels through which FDI reform affects local firms' technology choice. The last section concludes.

## 2 Literature review

Foreign affiliates of multinational firms (MNF) are known to be bigger, more productive, adopt more advanced technologies, and invest more in R&D than their domestic peers. The impact of exposure of local domestic firms to MNF's activity has long been of interest in international trade literature as positive spillovers are expected to arise if technological know-how spreads over domestic firms. This literature identifies multiple potential channels of technology transfer from foreign affiliates to domestic firms. The first one is related to a learning process: domestic firms can learn the technical know-how and strategies used by more productive foreign firms selling in the same market (Wang and Blomström, 1992). Second, the technology transfer can also be facilitated by labor mobility if employees that used to work in MNF get hired in domestic firms (Fosfuri et al., 2001). Finally, upward and downward linkages between foreign affiliates and local firms can explain the transfer of technology (Javorcik, 2004).

The technological transfer from foreign affiliates to domestic firms has been associated with productivity gains (Keller and Yeaple, 2009), especially when MNF are present in the downstream sectors (Javorcik, 2004), upgrade the quality of their exports (Harding and Javorcik, 2012) and increase the complexity of products (Javorcik et al., 2017). It is well established in the empirical literature that identifying FDI spillovers is challenging as it is subject to endogeneity concerns. The two main challenges are the potential existence of omitted variables and the selection of industries towards which foreign investment is attracted.

The first concern arises due to the difficulty in controlling for unobserved industry and firm characteristics. Overcoming this issue was straightforward by switching the analysis to panel firm-level data which allows the introduction of industry and firm fixed effects to control for time invariant firm and industry characteristics in order to alleviate the omitted variable bias (Haskel et al., 2007; Keller and Yeaple, 2009; Lu et al., 2017). The second challenge is related to a potential endogeneity concern in the choice of industries by foreign investors. A reverse causality may be faced if foreign investors choose to enter industries depending on their initial characteristics. They may be attracted to join industries that were initially more productive if they believe they can learn from domestic firms or alternatively choose to invest in less productive industries to gain a competitive edge. To address this issue Keller and Yeaple (2009), cite Haskel et al. (2007) and Lu et al. (2017) proposed an instrumental variable

approach for the US, the UK and China, respectively. The instruments used by Keller and Yeaple (2009) include changes in shipping costs and tariffs motivated by Brainard (1997) and lagged levels of the real exchange rate interacted with industry dummies (Froot and Stein, 1991), while Haskel et al. (2007) used lagged values of FDI flows and Lu et al. (2017) used the relaxation of FDI regulations in China.

Although the literature on FDI productivity spillovers is rich, it falls short on explaining the impact of exposure to foreign activity on technological choices of local firms. The main contribution of this work to the existent literature is to investigate the causal effects of FDI presence on domestic firms' technology upgrading decisions, identifying horizontal and vertical spillover channels. In this work, our identification strategy to deal with the omitted variable and endogeneity issues previously described is based on an exogenous reform on FDI regulations that took place in India in the early 1990s. This allows us to exploit a difference-in-difference estimation identifying as the treated group those firms producing in industries where FDI was liberalized and the control group firms in the non-liberalized industries. One concern that might arise is that those groups of firms have different performances prior to the reform. Section 5.1. presents descriptive evidence showing that the characteristics of firms in the two groups are statistically indistinguishable in the period before FDI liberalization. The next section provides descriptive evidence on the effects of FDI reform on domestic firms' technology upgrading.

### **3 A first glance at the data**

In the early 1990s, India underwent a major trade and FDI liberalization episode that came as a part of a structural reform policy to combat its balance of payment crisis. The FDI reform was announced and implemented in 1991, opening the market to foreign investors. In each industry, a fraction of products were opened to automatic approval for FDI. In this section, we explore some stylized facts on technology upgrading of Indian local firms during the period 1989-1997. We also provide some descriptive evidence on the existence of a positive correlation between the intensity of FDI liberalization and domestic firms' technology decisions. Since the aim of the study is to investigate FDI spillovers and not the direct effects of acquiring foreign capital investment, we include only domestic firms that do not receive any foreign investment. Hence, the correlation between FDI liberalization and firms' outcomes cannot be attributed to the acquisition of foreign equity. We also consider in this section, domestic firms that are consistently observed in our dataset over the period 1989-1997. The share of HS6 products within a 3-digit industry that were opened will be the index used to measure the intensity of FDI liberalization by industry. We present in this section some facts extracted from the data.

*Empirical Fact 1: The FDI reform coincides with a significant increase in the number of firms investing in RD, in total RD expenditure, total investment in capital employed and total expenditure in imported inputs and imported capital goods.*

From a first glance at the data, we see that FDI reform coincides with an upgrade in domestic firms technological choices. To visualize this event, we follow the evolution of some measures for firms' adoption of new technologies (R&D status, R&D expenditures, total investments -assets-, capital stock, imported inputs and imported capital goods) and compare between FDI liberalized and non-FDI liberalized industries over the period 1989-1997 in figure 1.<sup>1</sup> The trend of the share of firms doing R&D in the industry sharply increased especially for FDI-liberalized industries starting from 1991. Similarly, FDI liberalized industries show a higher increase in total expenditure on R&D, capital employed, assets, imported inputs and imported capital goods compared to non-FDI liberalized industries. These schemes suggest the presence of a correlation between FDI liberalization and technology upgrading.

*Empirical Fact 2: The share of firms investing in technology and the intensity of these investments increased more among larger firms than among smaller firms.*

Innovation and technology adoption may depend on firms' initial characteristics. To investigate the heterogeneity in the adoption of new technologies, we divide firms into 4 quartiles depending on their initial size in 1989. In figure 2, the evolution of the share of firms doing R&D, the intensity of R&D expenditure, the investment in capital, assets, imported inputs and imported capital goods are plotted by initial size quartiles. It appears that there is a correlation between initial firm-size and technology improvements. The share of firms that engage in R&D activity appear to have increase more for firms in the fourth quartile followed by the third, the second and the first in a descending order. Furthermore, the evolution of R&D expenditure, assets, capital employed, imported inputs and capital goods show the same pattern.

*Empirical Fact 3: The correlation between the intensity of FDI liberalization and the increase in the share of firms doing R&D and the change in its intensity is more important for larger firms.*

Previous figures have suggested that technological improvements were correlated to both

---

<sup>1</sup>All variables are aggregated by category of FDI liberalization. FDI liberalized industries are industries where intensity of FDI liberalization is above the median level. Non-FDI liberalized industries are industries where intensity of FDI liberalization is below the median level. The median of FDI liberalization intensity is 0.49.

intensity of FDI liberalization and initial size of domestic firms. We show that the relation between FDI openness and technology upgrading is also heterogeneous depending on initial firm-size. If FDI spillovers help domestic firms upgrade their technology then a positive correlation is expected between the intensity of FDI liberalization and R&D investments. In figure 3 and 4, the change in the measure of technology between 1989 and 1997 at the industry-level are plotted against the FDI liberalization index. Each marker represents a 3-digit industry. To add the dimension of heterogeneity by initial firm-size, the size of the markers is weighted by the average firm-size within the 3-digit industry in 1989.

A clear positive correlation is found between the intensity of FDI liberalization and firm's decision to invest R&D represented in an increase of the share of firms doing R&D in the industry. Likewise, there is evidence on the existence of a positive correlation between FDI liberalization and growth of R&D expenditure over the period. This relation seems to be correlated with firms' initial size. Firms that were initially larger are more concentrated towards the top of the graph which signifies that they were more likely to invest in R&D and increase its expenditure subsequent to the FDI liberalization episode. In other words, industries with relatively bigger firms are the ones that show the biggest improvements in terms of technology upgrading.

Domestic firms can upgrade their technology by importing foreign inputs and capital goods that are embedded with higher technology. In figure 3, the change in total imported intermediates and raw materials on the left and the change in expenditure on imported capital goods on the right are plotted against the intensity of FDI openness at the 3-digit industry-level. A positive correlation between exposure to FDI openness and growth of industries' imports of inputs and capital goods seems to be present. Similar observations are found regarding heterogeneity depending on average firm-size in the first year of sampling. Industries with initially larger firms on average appear to have higher growth of imported intermediates and capital goods.

This descriptive evidence strongly support the existence of a positive relation between exposure to FDI liberalization and technology upgrading of domestic Indian firms. It also suggests the presence of heterogeneity in this relation depending on initial firm characteristics such as size. To rationalize these observations, we develop a simple theoretical reasoning which is presented in the following section.

## 4 Theoretical Motivation

The aim of this section is to present a simple model of the determinants of manufacturing firms' technology choice in a setting with FDI spillovers and input-output linkages. The theory ratio-

nalizes the mechanisms through which FDI liberalization affects downstream firms' decision to invest in a new technology embodied in capital goods. The presence of multinational firms can affect downstream local producers through two different mechanisms: horizontal and vertical FDI spillovers. Horizontal FDI spillovers are modeled by a change in the fixed cost of technology adoption that local downstream firms have to pay to upgrade their technology. This fixed cost involves the costs of investing in a new technology and technical know-how that can be reduced by the presence of MNF producing in the same sector due to positive horizontal technological spillovers. The second mechanism through which FDI liberalization affects downstream local firms technology choice is related to vertical linkages between downstream local firms and the presence of multinational firms in the upstream sector. The presence of multinational firms producing in the same industry as domestic suppliers also affects the supply of inputs used by domestic final good producers in the downstream sector. This channel is represented in the model by access to more varieties of inputs at lower cost that change the price index of intermediate goods.

The model features two sectors: (1) an upstream sector where homogeneous firms produce a continuum of horizontally differentiated intermediate goods in monopolistic competition and (2) a downstream sector where a continuum of firms with different productivity levels produces differentiated varieties of final goods using the varieties of intermediate inputs and capital goods. On the downstream sector, firms consider a binary technology choice with a consequent trade-off between fixed and marginal costs. Firms that decide to upgrade their technology have to pay a fixed cost that increases their efficiency by reducing their marginal cost. This model incorporates an upstream sector producing a continuum of differentiated inputs in a Dixit-Stiglitz monopolistic competition structure in the binary technology choice models with heterogeneous firms à la Melitz (2003).<sup>2</sup>

## 4.1 Preferences

The representative household allocates consumption from among the range of differentiated varieties of final goods  $\omega$ . Consumer preferences are assumed to take the Constant Elasticity of Substitution (CES) utility function:  $U = \left[ \int_{\omega \in \Omega} q(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}}$ , where  $\sigma > 1$  is the elasticity of substitution between two varieties and  $\Omega$  the set of available varieties. The optimal demand function for each differentiated variety is given by:  $q(\omega) = Q \left[ \frac{p(\omega)}{P} \right]^{-\sigma}$ , where  $Q \equiv U$  is the aggregate consumption of available varieties,  $P$  the price index and  $p(\omega)$  the price set by a firm.  $R = PQ$ , aggregate revenue. The price index dual to the CES utility function is  $P = \left[ \int_{\omega \in \Omega} p(\omega)^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}}$ .

---

<sup>2</sup>The binary technology choice models of heterogeneous firms that extend the Melitz (2003) framework are Bas (2012); Bas and Berthou (2017).

## 4.2 Upstream sector producing inputs

The upstream sector produces a continuum of horizontally differentiated inputs,  $s(i)$  with  $i \in [0, \dots, 1]$ , in a Dixit and Stiglitz (1977) monopolistic competition structure. These intermediate goods are used by the downstream final good producers. The CES composite of intermediate goods is given by  $X(i) = \left( \sum_{i=1}^N x \frac{\sigma-1}{\sigma} \right)^{\frac{\sigma}{\sigma-1}}$ . For simplicity, we assume the same elasticity of substitution across varieties ( $\sigma$ ) for both the downstream final good sector and upstream sector as in Puga and Venables (1997).

Firms in this sector use only labor ( $l$ ) to produce the intermediate goods inputs. Labor is fully mobile between the upstream and downstream sector and it is inelastically supplied. Thereby, the same wage prevails, which is normalised to one ( $w = 1$ ). All varieties of intermediate goods are produced with the same cost function:  $l(x) = f_x + \beta x$ , where the parameter  $f_x$  is the fixed production cost in the intermediate goods sector and  $\beta$  is the constant marginal cost (unit-input requirement). Profits of intermediate goods firms are equal to  $\pi_x = p_x x - l = p_x x - (f_x + \beta x)$ , where  $p_x$  is the price of the  $x$  intermediate goods input. After profit maximization, the mill-pricing rule for each producer is given by:  $p_x = \frac{\sigma}{\sigma-1} \beta r$ . We assume that there is a regulation costs affecting variable costs of production in both sectors. This variable regulation cost,  $r$ , consists in all regulation variable taxes for multinational firms to produce in the Indian economy. Thereby, this variable regulation cost affects the presence of multinational firms. The standard CES price index of the composite intermediate good  $X(i)$  is given by:

$$P_x = \left( \sum_{i=1}^N p_x^{1-\sigma} \right)^{\frac{1}{1-\sigma}} = [N_x p_x^{1-\sigma}]^{\frac{1}{1-\sigma}}, \quad (1)$$

where  $N_x$  corresponds to the endogenous number of varieties of intermediate goods inputs. Under free-entry in the upstream intermediate goods sector, profits are driven to zero:  $\pi_x = p_x x - (f_x + \beta x) = 0$ . Using the mill-pricing condition in the free entry condition, one finds the equilibrium output per firm given by:  $x = \frac{f_x}{\beta}(\sigma - 1)$  which depends only on the fixed cost of intermediate goods production, the constant marginal cost parameter and the demand parameter.

Finally, the number of intermediate goods varieties produced in equilibrium can be determined using the full employment condition:  $L = L_x + L_k + L_f$ , where the aggregate labor demand used in the intermediate goods sector is given by  $L_x = N_x (f_x + \beta x)$ , and the equilibrium output per upstream firm  $x = \frac{f_x}{\beta}(\sigma - 1)$ .  $L_k$  is the aggregate labor demand of the capital goods sector and  $L_f$  is the labor used to pay all fixed costs in the economy. In equilibrium, the number of endogenous intermediate goods varieties is then equal to:  $N_x = \frac{L_x}{\sigma f_x}$ . It is de-

terminated by the aggregated labor used in the upstream sector,  $L_x$ , and the fixed production cost in this sector,  $f_x$ . Using  $N_x$  and  $p_x$ , the price index of intermediate goods inputs can be written as a function of the parameters of the model:

$$P_x = \left[ \frac{L_x}{\sigma f_x} \left( \frac{\sigma}{\sigma - 1} \beta r \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \quad (2)$$

Since  $\sigma > 1$ , equation (2) shows that the price index of intermediate goods inputs ( $P_x$ ) is an increasing function of the fixed production costs in the upstream intermediate goods sector ( $f_x$ ), the regulation costs  $r$  and the unit input requirement ( $\beta$ ). Thereby, these parameters affecting the upstream intermediate goods sector determine the intermediate goods input costs for manufacturing downstream firms.

FDI liberalization in the upstream sector is represented by an elimination of entry barriers to produce in this sector for multinational firms. There are two channels through which the presence of multinational firms affect the upstream sector: (1) reductions in fixed production costs of intermediate goods ( $f_x$ ) increasing the varieties of inputs (variety channel) and (2) reductions of the regulation costs that results in an increase in the efficiency of input providers, variation in marginal costs ( $r$ ), that reduces the price of inputs (marginal cost channel). The rationale for this assumption comes from the empirical fact that multinational firms produce with better technologies (lower fixed production cost) and are more efficient (lower marginal costs). FDI liberalization increases the presence of multinational firms in the upstream sector improving the efficiency of the overall sector.

### 4.3 Downstream final good sector

The downstream manufacturing sector produces a continuum of differentiated final goods under monopolistic competition à la Melitz (2003). There is a continuum of final good producers, which are all different in terms of their initial productivity level,  $\varphi$ . The production of each variety of final good requires a CES composite of intermediate goods inputs,  $X(i)$ , and capital goods,  $k$ . These two factors are combined in a CES technology production function with  $\eta$  and  $(1 - \eta)$  the factor shares of intermediate goods inputs and capital goods. The elasticity of substitution between the two types of inputs is  $\theta = \frac{1}{1-\alpha}$ .<sup>3</sup>

$$q(\varphi) = \varphi \left( \eta \left( \frac{X(i)}{\lambda_i} \right)^\alpha + (1 - \eta) k^\alpha \right)^{\frac{1}{\alpha}} \quad \text{for } i = \{LT, HT\} \quad (3)$$

Technology adoption implies incurring a technological investment represented by a fixed

---

<sup>3</sup>Intermediate inputs and capital goods are imperfect substitutes, hence  $0 < \alpha < 1$  and  $1 \leq \theta \leq \infty$ .

cost ( $f_{HT}$ ) measured in terms of labor, which reduces marginal costs of production by  $\lambda_{i=HT}$ .<sup>4</sup> The firm subscripts  $i = \{LT, HT\}$  correspond to firms producing with low technology (LT) and with high technology (HT). The low value of this factor is only available to firms that pay the fixed technology cost ( $f_{HT}$ ). Therefore,  $\lambda_{HT} < 1$  if the firm upgrades its technology and  $\lambda_{LT} = 1$  if the firm does not. Firms producing with high-technology embodied in more advanced capital goods combine both types of capital goods by a Cobb-Douglas function  $k = k_{HT}^\gamma k_{LT}^{1-\gamma}$ . This technological investment increases the efficiency of the intermediate goods inputs in the production process reducing marginal costs of production. Firms producing only with low-technology have  $k = k_{LT}$  and  $\lambda_i = 1$ .

Each firm chooses its price to maximize its profits subject to a demand curve with constant elasticity  $\sigma$ . The equilibrium price reflect a constant markup over marginal cost:  $p_i(\varphi) = \frac{\sigma}{\sigma-1} mc_i$ . The marginal cost includes the variable regulation cost ( $r$ ) and it is equal to  $mc_i = \frac{c_i r}{\varphi}$ , an intrinsic productivity term ( $\varphi$ ) and the CES cost index ( $c_i$ ), which combines the price index of intermediate goods ( $P_x$ ) and the price of capital goods ( $p_k$ ).

Final good producers are price-takers in capital equipment goods markets that are produced under constant returns to scale with labor. The price of low-technology capital goods is then equal to the wage which is used as a numeraire:  $p_{kLT} = 1$ . The price of high-technology capital goods is greater since these goods are assume to be of high-quality and cost:  $p_{kHT} = t_k$ , with  $t_k > 1$  measuring the greater cost of high-technology capital goods. The CES cost index of intermediate inputs and capital goods can be expressed as a function of the price index of intermediate goods ( $P_x$ ), the high-technology enhancing efficiency parameter ( $\lambda_i$ ) and the price of capital goods ( $p_{ki}$ ):  $c_{LT}^{1-\theta} = (1-\eta)^\theta + \eta^\theta (P_x)^{1-\theta}$  and  $c_{HT}^{1-\theta} = (1-\eta)t_k^\theta + \eta^\theta (\lambda_i P_x)^{1-\theta}$ . Firms that pay the fixed technology cost will then reduce their marginal cost by enhancing the efficiency of their inputs in the production process ( $\lambda_{HT} < 1$ ). We assume that the efficiency parameter of more advanced capital goods  $\lambda_{HT}$  is greater in absolute terms than its additional variable cost  $t_k$ . The cost index of high-technology firms  $c_{HT}$  is then lower than the one of low-technology firms  $c_{LT}$ .

Combining the demand and the price function, firms' revenues are given by  $r_i(\varphi) = \left(\frac{P}{p_i(\varphi)}\right)^{\sigma-1} R = A c_i^{1-\sigma} \varphi^{\sigma-1}$ , where  $R$  is the aggregate revenue and  $A = P^{\sigma-1} R \left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1}$  is an index for market demand. Profits are given by  $\pi_{LT}(\varphi) = \frac{r_{LT}(\varphi)}{\sigma} - f$  for low-technology firms and  $\pi_{HT}(\varphi) = \frac{r_{HT}(\varphi)}{\sigma} - f - f_{HT}$  for high-technology firms, where  $f$  corresponds to the fixed production cost that all firms have to pay in order to produce and  $f_{HT}$  to the fixed technology cost. Since there is a fixed production cost ( $f$ ), only those firms with enough operating profits to afford this cost can produce. The profits of the marginal firm that decides to stay and produce

<sup>4</sup>The assumption that the fixed technology cost is measured in terms of labor allows us to study the decision of firms that face homogeneous fixed costs.

are equal to zero:  $\pi_{LT}(\varphi^*) = 0$ . The value  $\varphi^*$  is the survival cutoff productivity to produce. This cutoff is determined by the following condition:  $\pi(\varphi^*) = \frac{r(\varphi^*)}{\sigma} - f = 0$ . This condition implies that the survival cutoff productivity to produce is determined by  $\varphi^{*\sigma-1} = f c_{LT}^{\sigma-1} \frac{\sigma}{A}$ . All firms that have a productivity draw lower than the survival cutoff are not able to pay the fixed production cost, they make losses and exit the market ( $\varphi < \varphi^*$ ). Firms with a productivity draw greater than the survival cutoff stay in the market and produce ( $\varphi > \varphi^*$ ).

### Technology choice

Firms can decide to upgrade their technology to reduce its marginal costs on the basis of its profitability.<sup>5</sup> The decision to upgrade the technology is endogenously determined by the initial productivity draw. Firms with a higher productivity draw have a greater potential payoff from technology upgrading. Therefore, they are more likely to find incurring the fixed technology cost worthwhile. We can identify the downstream manufacturing firms that adopt a high-technology: these are the most productive firms whose increase in revenues thanks to technology upgrading enables them to pay the fixed technology cost. Technology upgrading allows firms to increase their profitability by raising the efficiency of inputs in the production process. The indifference condition for the marginal firm to adopt the high technology is determined by  $\pi_{HT}(\varphi_{HT}^*) = \pi(\varphi_{HT}^*)$ :  $\frac{r_{HT}(\varphi_{HT}^*) - r(\varphi_{HT}^*)}{\sigma} = f_{HT}$ . The productivity cutoff to upgrade technology  $\varphi_{HT}^*$  is the minimum productivity level for the marginal firm that is able to adopt the high technology. The indifference condition implies that  $\varphi_{HT}^{*\sigma-1} = \frac{f_{HT}}{c_{HT}^{1-\sigma} - c_{LT}^{1-\sigma}} \frac{\sigma}{A}$ . By combining the survival productivity cutoff with this indifference condition, one can express  $\varphi_{HT}^*$  as an implicit function of  $\varphi^*$ :

$$\varphi_{HT}^* = \varphi^* \left( \frac{f_{HT}}{f} \right)^{\frac{1}{\sigma-1}} (\chi^{1-\sigma} - 1)^{\frac{1}{1-\sigma}} \quad (4)$$

Where the  $\chi = c_{HT}/c_{LT}$  represents the relative unit costs of firms that upgrade their technology vis-à-vis those that do not determined by:

$$\chi = \left[ \frac{\nu^\theta P_x^{\theta-1} + 1}{\nu^\theta P_x^{\theta-1} t_k^{\gamma\theta} + \lambda_{HT}^{1-\theta}} \right]^{\frac{1}{\theta-1}} \quad \text{with} \quad \nu = \frac{1-\eta}{\eta}. \quad (5)$$

This relative cost is an increasing function of the price index of intermediate goods inputs. Partially differentiating  $\chi$  with respect to  $P_x$ , we find that  $\partial\chi/\partial P_x > 0$  since  $\theta > 1$  and

<sup>5</sup>Firms' technology choice takes place after they discover their productivity draw. There is no other uncertainty or additional time discounting apart from the probability of exit ( $\delta$ ). Thus firms are indifferent between paying the one time investment cost  $F_{HT}$  or paying the amortized per period portion of this cost in every period  $f_{HT} = \delta F_{HT}$ .

$\lambda_{HT} < 1$ . The lower the price index of intermediate goods the lower the relative unit costs of firms that invest in the high technology. <sup>6</sup>

### Industry equilibrium in the downstream sector

The zero cutoff profits condition (ZCP) and the free entry condition (FE) determine the equilibrium value of the productivity cutoff  $\varphi^*$ . These conditions establish two different relationships between average profits and the productivity level of the marginal firm. The value of  $\varphi^*$  at equilibrium will then determine the technology cutoff and the rest of the model's variables. The equilibrium cutoff determined in the Theoretical Appendix is given by:

$$\varphi^{*k} = \frac{\sigma - 1}{k - (\sigma - 1)} \left[ \frac{f + \left[ \left( \frac{\nu^\theta P_x^{\theta-1} + 1}{\nu^\theta P_x^{\theta-1} t_k^\theta + \lambda_{HT}^{1-\theta}} \right)^{\frac{1-\sigma}{\theta-1}} - 1 \right]^{\frac{k}{\sigma-1}} \left( \frac{f_{HT}}{f} \right)^{\frac{-k}{\sigma-1}} f_{HT}}{\delta f_e} \right] \varphi_{\min}^k \quad (6)$$

Where  $k > \sigma - 1$ , the price index of intermediate goods ( $P_x$ ) is determined in equation (2) as a function of the fixed costs of intermediate goods ( $f_x$ ) regulating entry in the upstream sector and the variable regulation cost ( $r$ ). The equilibrium productivity cutoff  $\varphi^*$  is then a function of the parameters determining the upstream intermediate goods sector, the fixed production cost for downstream manufacturing firms and the fixed costs of technology. Changes in the fixed production costs and in the constant marginal cost of intermediate goods inputs will change the price index of intermediate goods ( $P_x$ ) affecting the cost of intermediate goods used by manufacturing firms and thereby, the profitability and the decision of these manufacturing firms to engage in technology upgrading. The survival productivity cutoff then determines the technology cutoff level ( $\varphi_{HT}^*$ ) by plugging equation (6) into equation (4).

#### 4.4 The effects of FDI technological spillovers on manufacturing firms technology upgrading

The simple model presented in the previous section rationalizes the main channels through which FDI liberalization affects local final good producers technology choice (extensive margin of technology) and total investments in high-technology capital goods (intensive margin of technology). The model shows that FDI liberalization shapes the incentives for technology

---

<sup>6</sup>If fixed technology costs are lower than fixed production costs all firms will upgrade their technology. We assume that the fixed technology cost is greater than the fixed production costs. In this case, only a subset of most productive firms have enough operating profits to engage in technology upgrading. The parameter condition that ensures that  $\varphi_{HT}^* > \varphi^*$  is given by  $f_{HT} > f(\chi^{1-\sigma} - 1)$ .

upgrading in the manufacturing sector. This section presents three testable implications of the model on the impact of different FDI liberalization on downstream manufacturing firms' technology choice.

## Heterogeneous effects of FDI liberalization

The model predicts that the effects of FDI liberalization are heterogeneous across local manufacturing firms depending on their initial productivity level  $\varphi$ . Under the assumptions of heterogeneous firms in the final good sector and fixed costs of technology, final good producers that decide to invest in a new technology after FDI liberalization are the most productive ones.

The productivity cutoff for technology upgrading  $\varphi_{HT}^*$  determined in equation (4) decreases with reductions on fixed technology cost (horizontal FDI spillovers) and with reductions of the price index of inputs (vertical FDI spillovers):  $\partial\varphi_{HT}^*/\partial f_{HT} > 0$  and  $\partial\varphi_{HT}^*/\partial P_x > 0$ . FDI liberalization reduces the productivity cutoff to invest in technology allowing firms with high-productivity producing near the technology cutoff to upgrade its technology.

Firms that upgrade their technology paying the fixed cost are able to increase their overall investment in modern and high-technology capital goods ( $k_{HT}$ ) enhancing the intensive margin of technology.

***Testable implication 1:** Downstream manufacturing firms that will benefit from FDI liberalization to upgrade its technology (extensive margin of technology) and increase their total investments in high-technology capital goods (intensive margin of technology) are the ones with a high initial productivity level.*

## Disentangling the channels: FDI spillovers

### Horizontal FDI spillovers

The first channel through which FDI liberalization affects local manufacturing firms' decision to upgrade its technology is through horizontal FDI spillovers. The presence of multinational firms producing in the same industry that local final good producers benefit the local firms through technical knowledge spillovers. Horizontal FDI spillovers are modeled by a reduction in the fixed cost of technology adoption ( $f_{HT}$ ) that local final good producers have to pay to upgrade their technology.

The probability that a manufacturing firm upgrades its technology,  $\rho_{HT} = (\varphi_{HT}^*/\varphi^*)^{-k}$ , increases with reductions in the technology fixed costs:  $\partial\rho_{HT}/\partial f_{HT} < 0$ . This probability can be expressed as a function of the price index of inputs using equations (4) and (5):

$$\rho_{HT} = (f_{HT}/f)^{\frac{-k}{\sigma-1}} \left( \left( \frac{\nu^\theta P_x^{\theta-1} + 1}{\nu^\theta P_x^{\theta-1} t_k^\theta + \lambda_{HT}^{1-\theta}} \right)^{\frac{1-\sigma}{\theta-1}} - 1 \right)^{\frac{-k}{1-\sigma}} \quad (7)$$

In this model, firms that pay the fixed technology cost are able to produce with more advanced capital goods and so they increase their overall investment in modern and high-technology capital goods ( $k_{HT}$ ).

**Testable implication 2:** *FDI liberalization, through horizontal FDI spillovers that reduce the technology fixed costs, increases the probability to upgrade the technology (extensive margin of technology) and total investments in capital goods and technology of local manufacturing firms (intensive margin of technology).*

### Vertical FDI spillovers

The second channel through which FDI liberalization affects technology choice of downstream manufacturing firms is through vertical FDI spillovers and input-output linkages. The increasing presence of multinational firms producing in the same industry as domestic suppliers affects the supply of inputs used by domestic final good producers in the downstream sector. The presence of multinational firms in the upstream sector affect final goods producers through two different mechanisms. The first one is related to the assumption that multinational firms are more efficient and rely on high technology reducing the fixed production costs of intermediate goods ( $f_x$ ) increasing the varieties of inputs (variety channel). The second mechanism is based on changes in the regulation costs of inputs that results in an increase in the efficiency of input providers ( $r$ ) that reduces the price of inputs (marginal cost channel). Both mechanisms reduce the price index of inputs  $P_x$  and thereby the cost of production of final good producers.

The probability that a manufacturing firm upgrades its technology,  $\rho_{HT} = (\varphi_{HT}^*/\varphi^*)^{-k}$ , also increases with reductions in the price index of services inputs:  $\partial\rho_{HT}/\partial P_x < 0$ . Taking the partial derivative of the probability of upgrade technology relative to the price index of inputs gives:  $\partial\rho_{HT}/\partial P_x < 0$  since  $\theta > 1$  and  $\lambda_{HT} < 1$ . Equation (3) shows that  $\partial P_x/\partial r > 0$  and  $\partial P_x/\partial f_x > 0$  since  $\sigma > 1$ . Since the price index of inputs ( $P_x$ ) is an increasing function of both the fixed production costs in the upstream sector ( $f_x$ ) and the variable regulation cost ( $r$ ), the partial derivative of the probability of upgrading technology relative to the fixed costs and the variable regulation costs of input providers is:  $\partial\rho_{HT}/\partial f_x < 0$  and  $\partial\rho_{HT}/\partial r < 0$ .

Firms that upgrade their technology paying the fixed technology cost increase their total investment in high-technology capital goods ( $k_{HT}$ ) increasing also the intensive margin of technology.

**Testable implication 3:** *FDI liberalization, through vertical FDI spillovers that reduce marginal costs or increase in the number of varieties, reduces the cost of inputs increasing the probability to upgrade technology (extensive margin of technology) as well as total investment in high-technology capital goods (intensive margin of technology) of downstream manufacturing firms.*

In the next section, the empirical analysis is carried out to test these empirical implications using the episode of India's FDI liberalization at the beginning of the 1990s.

## 5 Data

### 5.1 Firm level data

The Indian firm-level dataset is compiled from the Prowess database by the Centre for Monitoring the Indian Economy (CMIE)<sup>7</sup>. This dataset contains information from the income statements and balance sheets of listed companies comprising more than 70 percent of the economic activity in the organized industrial sector of India. Collectively, the companies covered in Prowess account for 75 percent of all corporate taxes collected by the Government of India. The database is thus representative of large and medium-sized Indian firms.<sup>8</sup> As previously mentioned this dataset was already used in several studies on the performance of Indian firms.<sup>9</sup>

The dataset covers the period 1989-1997 and the information varies by year. It provides quantitative information on R&D expenditures, sales, capital stock, investments, imports of capital goods and intermediate inputs income from financial and non financial sources, consumption of raw material and energy, wage-bill, ownership group and year of incorporation of the firm. This dataset allows us to compute total factor productivity (TFP) using Levinsohn and Petrin (2003) methodology. The production function is estimated separately for each 2 digit industry.<sup>10</sup>

### 5.2 FDI liberalization data

We use the measure of FDI policy obtained from Aghion et al. (2008) at 3-digit NIC 1987 industry level. Correspondence tables were used to match it with 3-digit NIC 1998. To capture FDI liberalization, the variable is defined as the fraction of HS6 products within each

---

<sup>7</sup>The CMIE is an independent economic center of India. For more information see: <http://www.cmie.com/database>.

<sup>8</sup>Since firms are under no legal obligation to report to the data collecting agency, the Prowess data do not allow properly identifying entry and exit of firms.

<sup>9</sup>See Topalova and Khandelwal (2011), Topalova (2004), Goldberg et al. (2010), Goldberg et al. (2009), Alfaro and Chari (2009), DeLoecker et al. (2016).

<sup>10</sup>Firms' sales, capital stock, materials and wage-bill are deflated using specific NIC industry deflators at the 3 digit level.

3-digit industry that were opened to automatic approval of FDI (up to 51 percent equity). This measure takes a value of zero before 1991 when FDI was strictly controlled which is convenient for the difference-in-differences strategy.

Our methodology relies on this exogenous measure of FDI reform to capture the presence of foreign affiliates in an industry in India. The difference-in-difference identification strategy consists in comparing Indian domestic firms producing in 3-digit industries that were liberalized (the treated group) relative to domestic firms in non-liberalized industries (the controlled group). We first show that firms in both groups were similar in terms of technological investments and performance before the reform in 1989. We divide the intensity of FDI liberalization into two groups using its median value that is equal to 0.49.

A potential issue is that there were several economic reforms (industrial, trade and financial liberalization) that lead to economic growth in the same period of FDI liberalization. This issue arises if FDI liberalized industries were different from those industries not liberalized and these differences were correlated with the growth potential of these industries even absent the FDI reform studied in this paper. We test this possibility comparing firms producing in both types of industries in the prereform year 1989 across a number of characteristics. Table 1 shows the mean values of R&D investment, status, R&D intensity, size (sales), wages, capital stock, assets, share of imported inputs and capital goods. Our findings show that the characteristics of firms in the FDI liberalized industries (above the median) and those in the non liberalized industries (below the median) are statistically indistinguishable, providing evidence against the results being driven by differences in industry characteristics. Table 1 presents in column (4) the t-test for differences in averages for both groups of firms that are not statistically significant. This piece of evidence is a validation of our difference-in-differences specification since it reassures us that prior to the introduction of reforms, FDI liberalized industries did not differ from those that were not liberalized. It is worth noting that all our econometric specifications accounts for differences across these groups of firms by the use of firm fixed effects as well as initial firm size trends and industry-year as well as the region-year fixed effects.

## 6 Identification strategy and baseline results

Using the FDI liberalization index, we study the effects of the presence of foreign affiliates on domestic manufacturing firms' decisions to upgrade their technology. Our identification strategy relies on a difference-in-difference model that compares downstream local firms producing in industries where FDI was liberalized (removal of entry barriers for foreign firms) at the beginning of the 1990s with firms in industries that were non-liberalized.

In order to test the first empirical implication, we estimate a linear model of firms' technology choice with firm fixed effects to take into account unobservable firm characteristics that do not vary over time. We regress different technology measures of domestic firms (total investments, capital stock and R&D status) on the state of liberalization in FDI at the industry-year level using the following difference-in-difference model:

$$Tech_{ist} = \gamma_1 \text{FDI liberalization}_{s,t-1} + \gamma_2 Size_{i,t-1} + \gamma_3 Z_{s,t-1} + \mu_i + v_{jt} + v_{rt} + \epsilon_{ist} \quad (\text{I})$$

Here  $Tech_{ist}$  is one of the three measures of firm technology: logarithm of total investments (total assets), capital goods (machinery) or a dummy variable for firm  $i$  producing in 3-digit industry  $s$  having positive R&D expenditures in year  $t$ .  $\text{FDI liberalization}_{s,t-1}$  represents the proportion of HS6 products within a sector of the 3-digit NIC manufacturing industry  $s$  in year  $t-1$  that was liberalized.  $Size_{i,t-1}$  is an initial firm size trend and  $Z_{s,t-1}$  is a set of industry level control variables including other reforms in India and the industry concentration index. We control for other reforms that took place in India in the early 90s such as trade liberalization (including both output and input tariffs) and industrial liberalization including a dummy variable equal to one when the industry has been liberalized.

Equation (I) includes firm fixed effects,  $\mu_i$  that take into account unobservable firm characteristics that do not change over time. We also control for unobservable shocks varying over time and across sectors including industry 2-digit-year fixed effects and shocks varying across Indian states over time including region-year fixed effects. Those fixed effects allow us to take into account all other reforms that took place in India during that period. Since the FDI index varies at the 3-digit industry level over time, the errors are corrected for clustering across 3-digit industries-year pairs.

Table 2 shows the estimation results for equation (I) using a within firm estimator. Estimates show that the coefficient of FDI index obtained the expected positive sign in all columns. As higher values of the FDI index are associated with higher degree of liberalization,  $\gamma_1 > 0$  indicates that domestic firms producing in industries where more products were liberalized to FDI increase their technological investments in total assets, capital goods and R&D.

Next we look at the effects of FDI liberalization on foreign technology choice. We estimate a poisson model with firm fixed effects using as dependent variable imports of intermediate inputs, capital goods and total imports. Results on Table 3 show that FDI liberalization has also a positive effect on firms' foreign technology investments.

## 6.1 Heterogeneous effects of FDI spillovers

The previous section shows that FDI liberalization generates an incentive for the average domestic manufacturing firm to engage in R&D activities. However, the effect of the presence

of foreign affiliates on firms' technology decision might be heterogeneous across firms depending on firms' initial performance as highlighted in the simple theoretical framework presented in Section 3.

As previous literature has shown that FDI spillovers affects firm TFP, we use the TFP of the firm in the initial year that the firm appears in the sample to deal with endogeneity concerns. Firms are divided up into three initial TFP quartiles, with the first quartile representing the least productive firms.<sup>11</sup> We then interact the FDI index with the firm's initial TFP quartiles. We estimate the following model:

$$Tech_{ist} = \sum_{\rho=1}^3 \chi^{\rho} (\text{FDI lib}_{s,t-1} \times Q_{is}^{\rho}) + \beta_1 Size_{i,t-1} + \beta_2 Z_{s,t-1} + \mu_i + v_{jt} + v_{rt} + \epsilon_{ist} \quad (\text{II})$$

Here firms are classified into four quartiles (Q) of initial TFP by  $\rho$ :  $Q_{is}^1$  is a dummy variable equal to one for firm  $i$  belonging to the first quartile of the initial TFP distribution and so on. Initial TFP quartiles are calculated by 3-digit industry.  $\text{FDI lib}_{s,t-1} \times Q_{is}^{\rho}$  are the interaction terms between the quartiles and the FDI index. Equation (II) includes firm, industry-year and state-year fixed effects. These dummies will capture all the time-varying industry and state level shocks that took place in India during the period. Note that the indicator variables for the quartiles of initial TFP distribution are not included since they are collinear the firm fixed effects.

The estimation results for equation (II) are presented in Table 4. The estimates show that most productive firms benefit the most from FDI liberalization to invest in R&D activities.

## 7 Disentangling the channels: Horizontal vs. Vertical FDI technological spillovers

This section disentangles the two main channels through which FDI liberalization affects local firms' technology decisions. The main FDI liberalization index used in the previous estimations captured the direct effect of increased presence of multinational firms on local firms producing in the same industry through horizontal FDI spillovers. In order to measure vertical FDI spillovers, we rely on input-output tables from India in 1993 to create the vertical linkages between the downstream final good producers and the upstream input providers. We compute a weighted average of the FDI liberalization index using as weights the share of intermediate inputs used in the production of final goods in each 3-digit NIC industry.

Table 5 presents the results including both the FDI liberalization index (horizontal FDI spillovers) and the vertical FDI indicator. Results show that FDI reform affects all firms'

---

<sup>11</sup>Firm TFP is estimated using the Levinsohn and Petrin (2003) methodology.

technology investments through horizontal FDI spillovers. The effects of vertical FDI spillovers are only significant for firms investments in total assets and in capital goods.

## 8 Alternative explanations and robustness tests

There are other potential explanations for the incentives of firms to invest in technology over the early nineties in India, with the FDI technological spillovers being one of them. In this section, we discuss and examine three alternative explanations: other reforms that took place in India during this period, the export-channel (foreign demand shocks) and firms financial health. First, we describe the econometric strategy to deal with these alternative explanations in the estimations. We then present evidence showing that our previous findings remain stable when including these factors suggesting that the FDI liberalization is a key channel determining domestic firms technological investments.

### 8.1 Other structural reforms in India

As discussed in the previous section, a package of structural reforms was implemented in India in the early 1990s after the debt crisis and FDI liberalization being one of them. Among the other key reforms applied in this period we have trade liberalization through reductions of both final goods and intermediate goods tariffs and industrial reform by the removal of the license raj. Those structural reforms might also have a positive effect on Indian firms technological investments. Trade liberalization through foreign competition or access to better inputs might have created incentives to domestic Indian firms to upgrade its technology (Bas and Berthou (2017)). Similarly, industrial liberalization through increasing production capacity might allow domestic firms to increase their investments (Bas and Paunov (2018)).

The previous estimations already take into account the role of these other structural reforms that took place in India during the 1990s in several ways. This section discusses the way in which those reforms are taken into account in our previous estimations. First, all estimations include 2-digit industry-year fixed effects to take into account all unobservable characteristics varying over time that could affect industries. Second, all estimations also include region-year fixed effects to control for unobservable characteristics affecting different Indian states over time. Third, we control directly for trade liberalization including the output and input tariffs at 3-digit industry level set by India. For industrial liberalization, we also include a dummy equal to one if the industry has been delicensing in a year. All our previous results are robust to those alternative reforms that can also affect firms technology choice.

## 8.2 The export-channel

Foreign demand shocks might also increase the incentives for Indian firms to invest in technology or upgrade the quality of goods (Verhoogen, 2008). Expansion of export opportunities due to lower export variable costs leads to higher export profits allowing firms to afford the fixed cost of technology upgrading. If FDI liberalization is positively correlated with export performance or with variations in output tariffs set by India's main trading partners, our previous empirical findings might be just picking up the effects of foreign demand shocks.

Note that the previous estimations already take into account unobservable shocks varying over time and across sectors including industry 2-digit-year fixed effects and address this issue. Here, we provide additional evidence that foreign demand shocks at the industry level captured by export tariffs set by the main trading partners of India are not picking up our results. We extend the baseline estimation by including the average effectively applied tariff at the 3-digit NIC industry level set by the rest of the world to India (export tariff) during the 1989-1997 period from WITS dataset (World Bank).

Columns (1) to (6) of Table 6 report the results. The effect of export tariff is negative and significant in columns (1) and (5). Expansion of export opportunities due to lower export tariffs allowed Indian firms to increase their total investment and imports of capital goods. The coefficient of interest on FDI liberalization remains robust and stable in all specifications when we take into account the role of export-channel. This finding suggests that the demand side mechanism is not picking up our results on the role of FDI spillovers on firms' technology upgrading.

## 8.3 Relaxation of financial constraints

Another possible explanation for Indian firms' investments in technology during the early nineties is associated to expansion of private credit. In this section, we study if our results are not suffering from omitted variable bias related to firms' increase in financial health.

We extend the baseline estimations to include lagged values of the leverage ratio (borrowings over total assets) of the firm. Columns (1) to (6) of Table 7 present the findings. Firms' financial health seems to be a factor determining firms' technological investments. Indian firms with greater leverage face greater credit constraints and have lower investments, imports of intermediate and capital goods. However, our coefficient of interest on FDI liberalization is not affected by the inclusion of firms' financial status.

## 8.4 Other sensitivity tests

Previous works have shown that state-owned firms played an important role in the Indian economy during the reforms relative to private companies (Topalova, 2004; Alfaro and Chari, 2009). Public companies might have benefited more from FDI liberalization through specific connections with foreign-owned companies. To address this issue, we restrict the sample to private firms in Table 8. The point estimates of FDI liberalization remain robust and stable for the sample of private firms, suggesting that FDI technological spillovers matters for Indian domestic private firms.

## 9 Conclusion

This paper shows that FDI liberalization has positive effects on manufacturing firms' technology investments in India. Relying on a difference-in-difference methodology exploiting the effects of FDI reform for firms producing in liberalized industries vs. firms in non-liberalized industries, our findings show that Indian firms in downstream sectors have increased their technological domestic and foreign investments in capital goods, R&D, imports of intermediate and capital goods after FDI liberalization. Our results also suggest that it is the most productive firms that benefited the most from FDI liberalization to upgrade their technological investments. Next we go one step further and disentangle the channels at play. Our results suggest that the main mechanism through which FDI reform affects domestic firms' technology upgrading is through the horizontal FDI spillovers, while vertical FDI spillovers has only a positive effect on downstream firms' decision to increase total investment and capital goods but no effect on R&D investments or foreign technology investments.

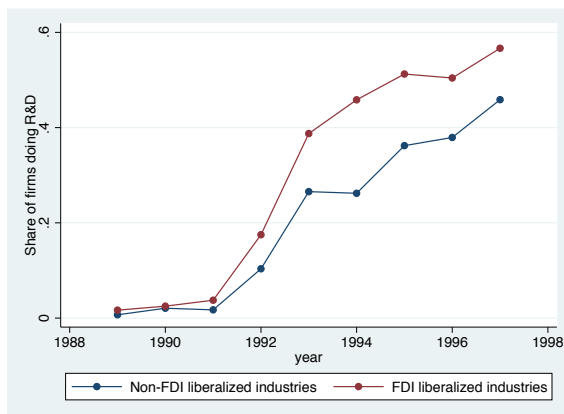
## References

- Alfaro, L. and Chari, A. (2009). India transformed? insights from the firm level 1988-2005. NBER Working Papers 15448.
- Bas, M. (2012). Technology adoption, export status and skill upgrading: Theory and evidence. *Review of International Economics*, 20(2):315–331.
- Bas, M. and Berthou, A. (2017). Does input-liberalisation affect firms' foreign technology choice? *World Bank Economic Review*.
- Bas, M. and Paunov, C. (2018). The effect of india's industrial liberalization on firms decision to innovate: Do business conditions matter? *Journal of Industrial Economics*, LXVI-1.

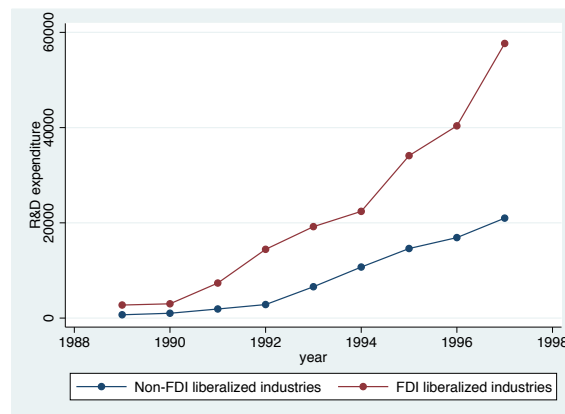
- Brainard, S. L. (1997). An empirical assessment of the proximity- concentration trade-off between multinational sales and trade. *American Economic Review*, 87:520–544.
- DeLoecker, J., Goldberg, P. K., Khandelwal, A. K., and Pavcnik, N. (2016). Prices, markups and trade reform. *Econometrica*, 84(2):445–510.
- Dixit, A. and Stiglitz, J. (1977). Monopolistic competition and optimum product diversity. *American Economic Review*, 67:297–308.
- Fosfuri, A., Motta, M., and Rønde, T. (2001). Foreign direct investment and spillovers through workers mobility. *Journal of international economics*, 53(1):205–222.
- Froot, K. A. and Stein, J. C. (1991). Exchange rates and foreign direct investment: an imperfect capital markets approach. *The quarterly journal of economics*, 106(4):1191–1217.
- Goldberg, P., Khandelwal, A., Pavcnik, N., and Topalova, P. (2009). Trade liberalization and new imported inputs. *American Economic Review Papers and Proceedings*, 99(2):494–500.
- Goldberg, P., Khandelwal, A. K., Pavcnik, N., and Topalova, P. (2010). Imported intermediate inputs and domestic product growth: Evidence from india. *The Quarterly Journal of Economics*, 125(4):1727–1767.
- Görg, H. and Greenaway, D. (2004). Much ado about nothing? do domestic firms really benefit from foreign direct investment? *The World Bank Research Observer*, 19(2):171–197.
- Harding, T. and Javorcik, B. S. (2012). Foreign direct investment and export upgrading. *Review of Economics and Statistics*, 94(4):964–980.
- Haskel, J. E., Pereira, S. C., and Slaughter, M. J. (2007). Does inward foreign direct investment boost the productivity of domestic firms? *The review of economics and statistics*, 89(3):482–496.
- Javorcik, B. S. (2004). Does foreign direct investment increase the productivity of domestic firms? in search of spillovers through backward linkages. *American Economic Review*, 94(3):605–627.
- Javorcik, B. S., Lo Turco, A., and Maggioni, D. (2017). New and improved: Does fdi boost production complexity in host countries? *The Economic Journal*, 128(614):2507–2537.
- Keller, W. and Yeaple, S. R. (2009). Multinational enterprises, international trade, and productivity growth: firm-level evidence from the united states. *The Review of Economics and Statistics*, 91(4):821–831.

- Kneller, R. and Pisu, M. (2007). Industrial linkages and export spillovers from fdi. *The World Economy*, 30(1):105–134.
- Levinsohn, J. and Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *The Review of Economic Studies*, 70(2):317–341.
- Lu, Y., Tao, Z., and Zhu, L. (2017). Identifying fdi spillovers. *Journal of International Economics*, 107:75–90.
- Melitz, M. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica*, 71:1695–1725.
- Puga, D. and Venables, A. (1997). Preferential trading arrangements and industrial location. *Journal of International Economics*, 43(3-4):347–368.
- Topalova, P. (2004). Overview of the indian corporate sector: 1989-2002. IMF Working Papers 04/64.
- Topalova, P. and Khandelwal, A. (2011). Trade liberalization and firm productivity: The case of india. *The Review of Economics and Statistics*, 93(3):995–1009.
- Verhoogen, E. (2008). Trade, quality upgrading and wage inequality in the mexican manufacturing sector. *Quarterly Journal of Economics*, 123:489–530.
- Wang, J.-Y. and Blomström, M. (1992). Foreign investment and technology transfer: A simple model. *European economic review*, 36(1):137–155.

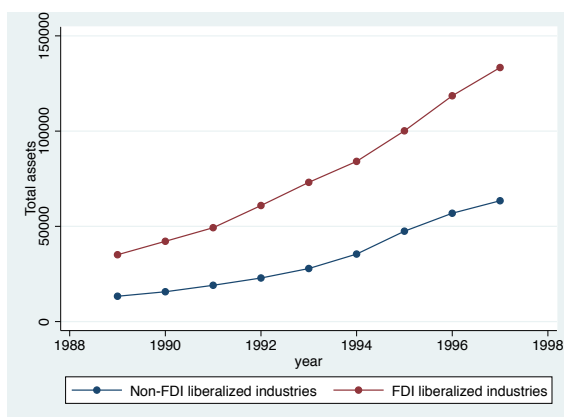
Figure 1: Evolution of technological investments over the period 1989-1997



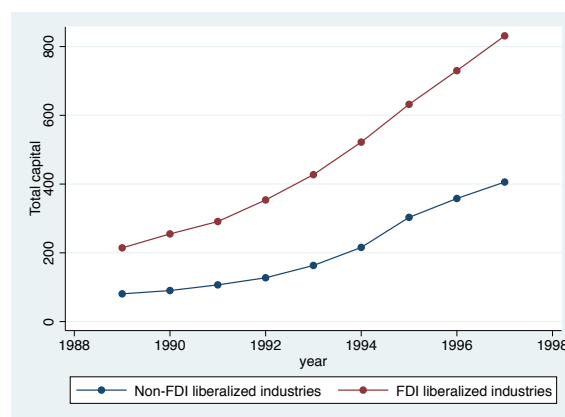
(a) Share of firms doing R&D



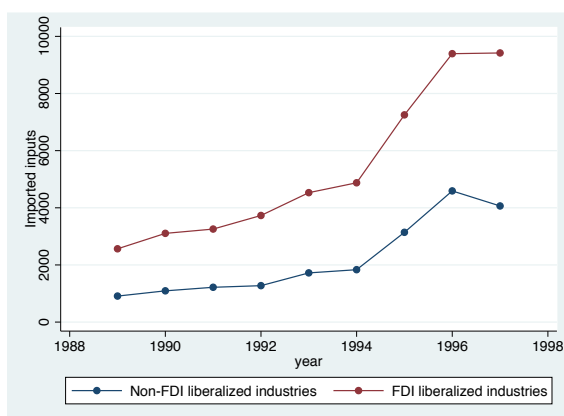
(b) R&D expenditure



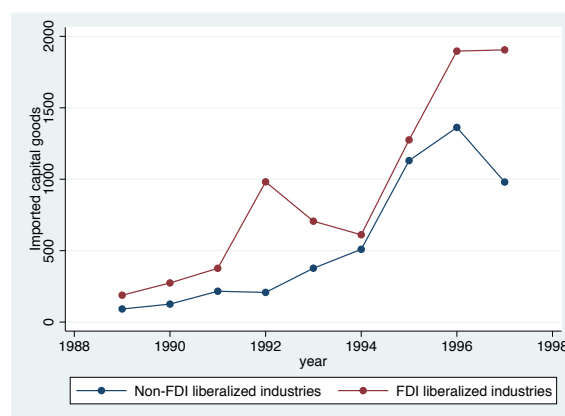
(c) Total Assets



(d) Total capital

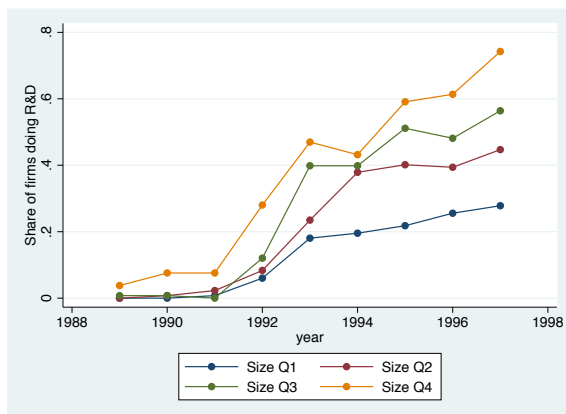


(e) Imported inputs

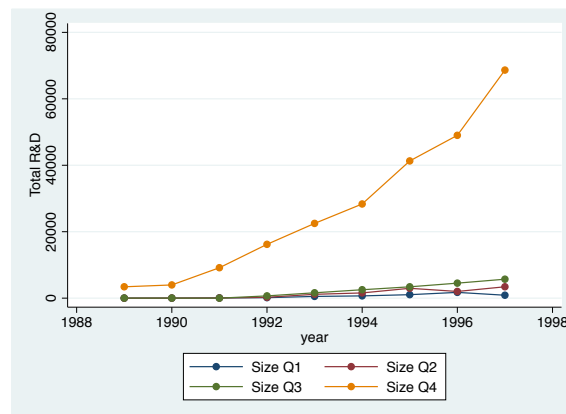


(f) Imported capital goods

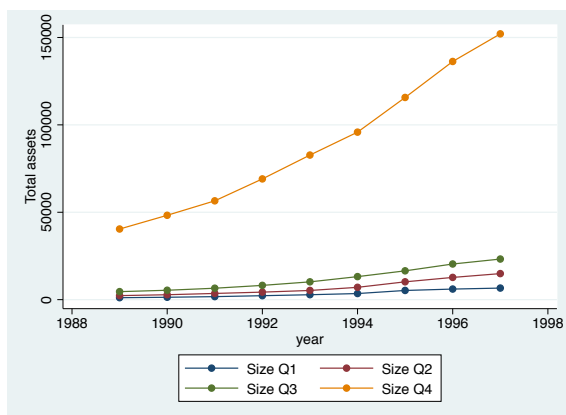
Figure 2: Evolution of technological investments over the period 1989-1997



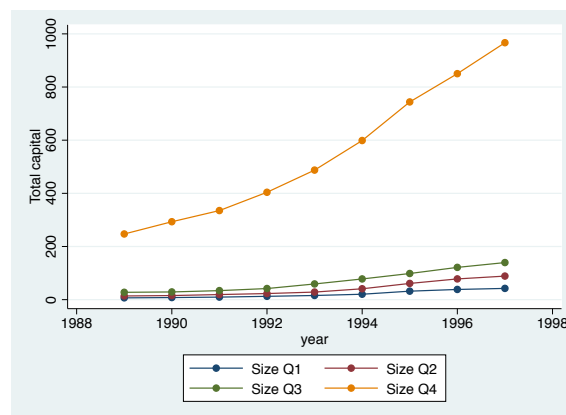
(a) Share of firms doing R&D



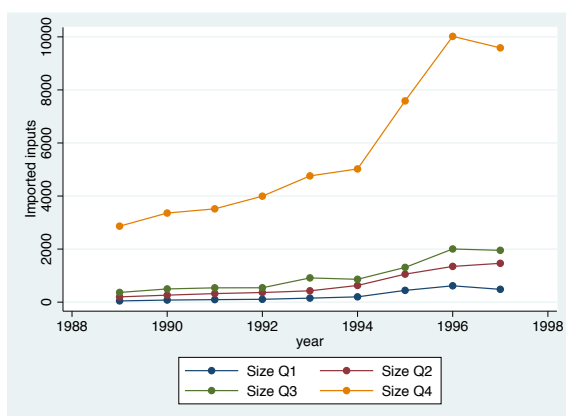
(b) R&D expenditure



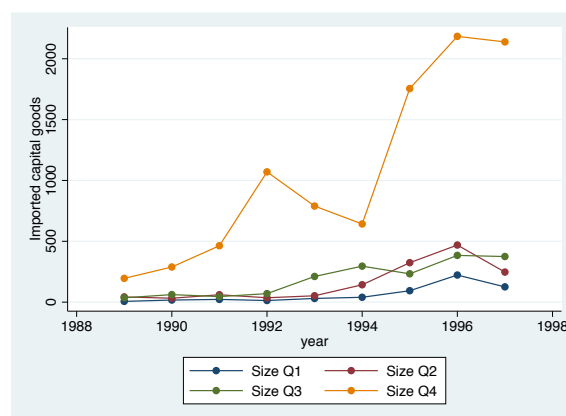
(c) Total Assets



(d) Total capital

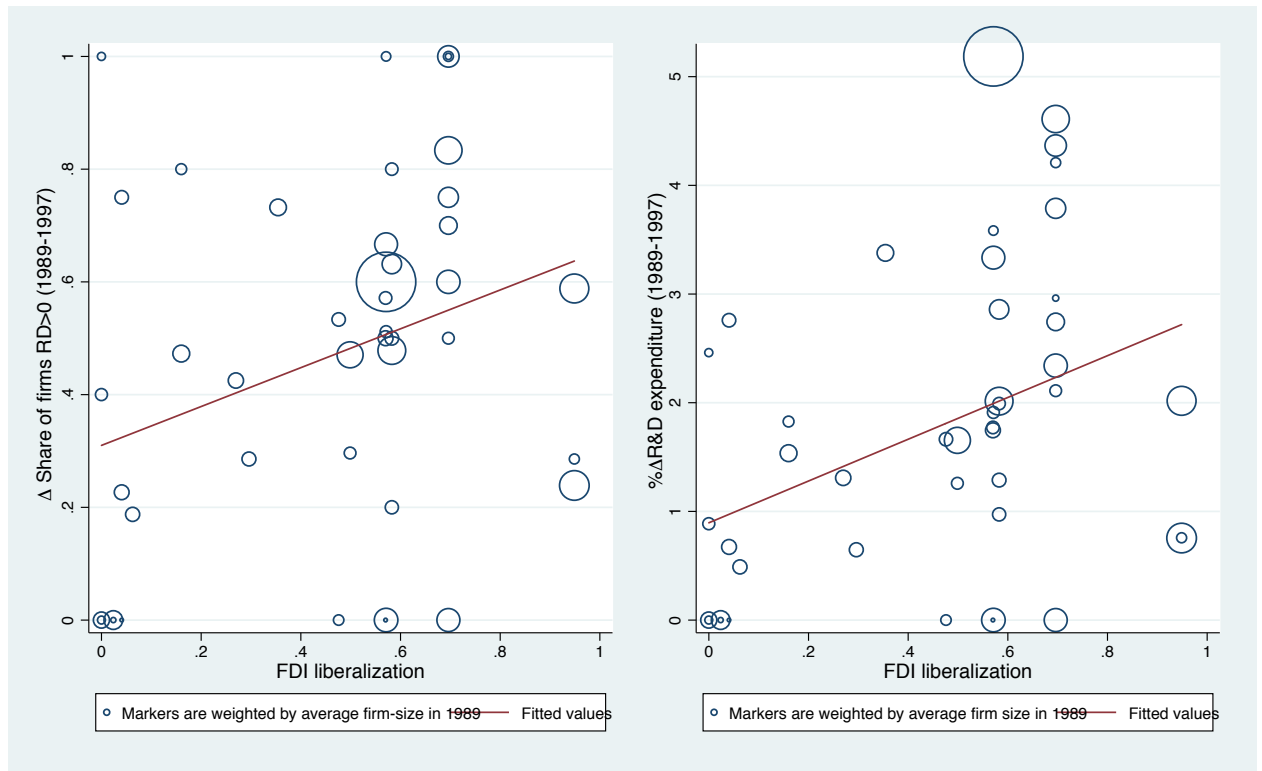


(e) Imported inputs



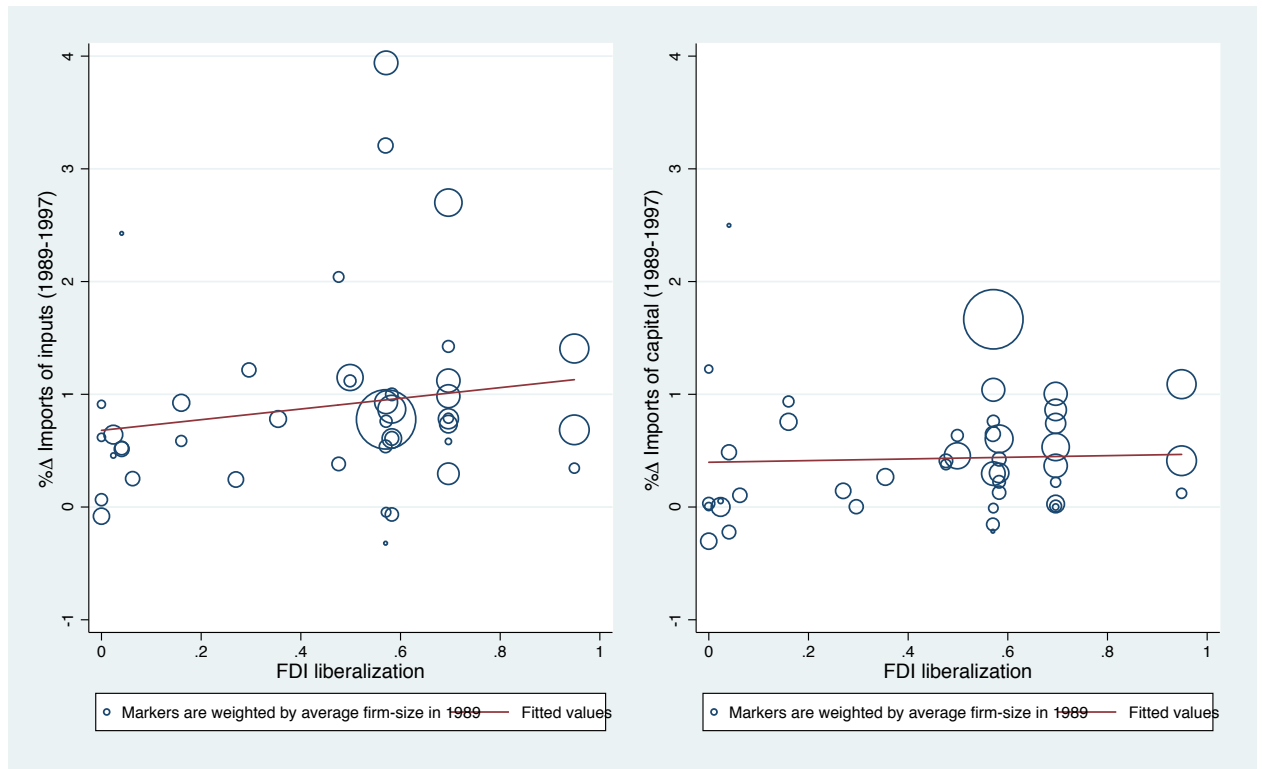
(f) Imported capital goods

Figure 3: Domestic technology upgrading through R&D and FDI liberalization



Source: Author's calculation based on Prowess dataset.

Figure 4: Foreign technology upgrading through imports and FDI liberalization



Source: Author's calculation based on Prowess dataset.

Table 1: Firm performance in FDI liberalized and non-FDI liberalized industries in 1989

	FDI lib>median	FDI lib<median	Difference	T-test	P-value
RD investment	.044	.025	.019	.65	.521
RD status	.010	.004	.005	1	.327
RD intensity	.006	.004	.003	.65	.523
Size	2.95	2.894	.055	.65	.502
Wages	.217	.247	-.029	-.3	.766
Capital	.210	.188	.022	.95	.344
Assets	3.036	2.956	.080	.95	.343
Share of imported raw materials	.707	.697	.009	.35	.745
Share of imported intermediates	.230	.203	.026	1	.310
Share of imported capital goods	.098	.126	-.028	-1.6	.116

*Notes:* The median level of FDI liberalization is 0.49. Size is expressed in terms of sales. Imported raw materials, intermediates and capital goods are expressed in terms of shares in total imports.

Table 2: The effects of FDI liberalization on domestic firms RD decision

	Investment		Capital		RD status	
	(1)	(2)	(3)	(4)	(5)	(6)
FDI liberalization(s,t-1)	0.690*** (0.184)	0.712*** (0.202)	0.863* (0.491)	1.097* (0.567)	0.436*** (0.168)	0.566*** (0.190)
Delicensing(s,t-1)		-0.004 (0.050)		-0.210** (0.104)		0.070** (0.034)
Input tariffs(s,t-1)		-0.108 (0.177)		-0.101 (0.723)		-0.131 (0.182)
Output tariffs(s,t-1)		0.062 (0.051)		0.326 (0.246)		0.046 (0.056)
Herfindhal index(s,t-1)		0.050 (0.068)		0.596** (0.267)		0.094* (0.052)
Age(t-1)		0.388*** (0.039)		0.377*** (0.089)		-0.163*** (0.025)
Observations	12314	12314	12314	12314	12314	12314
Adj. R-squared	0.949	0.950	0.867	0.943	0.525	0.528
Initial firm size trend	No	Yes	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

*Notes:* Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 3: The effects of FDI reform on foreign technology adoption

	Imports of inputs		Imports of capital goods		Total Imports	
	(1)	(2)	(3)	(4)	(5)	(6)
FDI liberalization(s,t-1)	2.195*** (0.847)	1.977** (0.861)	5.358*** (1.627)	6.691*** (1.675)	2.277*** (0.811)	2.194*** (0.834)
Delicensing(s,t-1)		0.077 (0.242)		0.561 (0.604)		0.155 (0.261)
Input tariffs(s,t-1)		0.282 (0.520)		-1.935* (1.091)		-0.001 (0.598)
Output tariffs(s,t-1)		0.100 (0.095)		0.049 (0.304)		0.079 (0.096)
Herfindhal index(s,t-1)		0.113 (0.075)		-0.401* (0.241)		0.072 (0.074)
Age(t-1)		0.350*** (0.063)		0.279** (0.142)		0.319*** (0.059)
Observations	10434	10434	7565	7565	10434	10434
Initial firm size trend	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

*Notes:* Poisson regressions in columns 1 to 6 (observations are dropped when imports are equal to zero). For this reason the number of observations in the specifications are less than in table 2. Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4: The heterogeneous effects of FDI spillovers depending on initial TFP

	Investment (1)	Capital (2)	RD status (3)	Imports of Inputs (4)	Imports of Capital goods (5)
FDI liberalization(s,t-1) × Q1	0.452* (0.241)	-0.133 (0.687)	0.334 (0.229)	1.934** (0.792)	5.397*** (1.593)
FDI liberalization(s,t-1) × Q2	0.554** (0.236)	0.861 (0.675)	0.415* (0.229)	1.941** (0.796)	4.936*** (1.593)
FDI liberalization(s,t-1) × Q3	0.574** (0.244)	2.205*** (0.672)	0.458** (0.221)	2.019** (0.800)	5.240*** (1.594)
Delicensing(s,t-1)	-0.043 (0.049)	-0.167* (0.098)	0.073** (0.034)	0.037 (0.225)	0.490 (0.600)
Input tariffs(s,t-1)	0.206 (0.253)	-1.056 (0.779)	-0.019 (0.288)	0.387 (0.575)	-2.353* (1.382)
Output tariffs(s,t-1)	0.083 (0.062)	0.358 (0.334)	-0.005 (0.064)	0.055 (0.096)	-0.076 (0.307)
Herfindhal index(s,t-1)	0.029 (0.095)	1.058** (0.423)	0.105 (0.066)	0.125 (0.106)	-0.691** (0.274)
Age(t-1)	0.617*** (0.064)	0.898*** (0.214)	-0.300*** (0.048)	0.599*** (0.091)	0.381 (0.249)
Observations	5539	5539	5539	5194	4197
Adj. R-squared	0.955	0.947	0.505		
Initial firm size trend	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

*Notes:* Poisson regressions in columns 4 and 5 (observations are dropped when imports are equal to zero). For this reason the number of observations in the specifications are less than in table 2. Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 5: Disentangling the channels of transmissions: horizontal and vertical FDI spillovers

	Investment (1)	Capital (2)	RD status (3)	Imports of Inputs (4)	Imports of Capital goods (5)
Vertical FDI(s,t-1)	1.756*** (0.524)	2.480* (1.502)	-0.324 (0.398)	0.803 (1.276)	4.019 (3.794)
FDI liberalization(s,t-1)	1.120*** (0.272)	1.755*** (0.531)	0.510** (0.218)	2.150** (0.934)	7.856*** (1.939)
Delicensing(s,t-1)	0.045 (0.053)	-0.133* (0.079)	0.062* (0.034)	0.113 (0.236)	0.732 (0.564)
Input tariffs(s,t-1)	0.237 (0.233)	0.264 (0.858)	-0.222 (0.188)	0.385 (0.559)	-1.325 (1.096)
Output tariffs(s,t-1)	0.044 (0.051)	0.314 (0.251)	0.057 (0.056)	0.097 (0.094)	0.053 (0.311)
Herfindhal index(s,t-1)	0.057 (0.068)	0.617** (0.276)	0.091* (0.053)	0.120 (0.076)	-0.374 (0.251)
Age(t-1)	0.386*** (0.039)	0.365*** (0.090)	-0.165*** (0.025)	0.347*** (0.063)	0.241* (0.141)
Observations	12080	12080	12080	10226	7416
Adj. R-squared	0.950	0.943	0.528		
Initial firm size trend	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

*Notes:* Poisson regressions in columns 4 and 5 (observations are dropped when imports are equal to zero). For this reason the number of observations in the specifications are less than in table 2. Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 6: Alternative explanation: Controlling for foreign demand shocks

	Investment (1)	Capital (2)	RD status (3)	Imports of Inputs (4)	Imports of Capital goods (5)	Total imports (6)
FDI liberalization(s,t-1)	0.721*** (0.215)	1.107* (0.602)	0.568*** (0.194)	1.976** (0.858)	6.820*** (1.680)	2.196*** (0.831)
Export tariff(s,t-1)	-0.182** (0.081)	-0.059 (0.259)	-0.012 (0.080)	-0.039 (0.087)	-0.909*** (0.286)	-0.083 (0.099)
Delicensing(s,t-1)	-0.007 (0.053)	-0.213** (0.107)	0.070** (0.034)	0.088 (0.241)	0.567 (0.613)	0.168 (0.261)
Input tariffs(s,t-1)	-0.187 (0.196)	-0.129 (0.762)	-0.141 (0.189)	0.277 (0.515)	-2.315** (1.101)	-0.019 (0.594)
Output tariffs(s,t-1)	0.048 (0.055)	0.330 (0.254)	0.045 (0.057)	0.097 (0.095)	0.095 (0.300)	0.069 (0.097)
Herfindhal(s,t-1)	0.029 (0.070)	0.651** (0.280)	0.103* (0.054)	0.087 (0.075)	-0.387 (0.249)	0.055 (0.074)
Age(t-1)	0.393*** (0.039)	0.375*** (0.089)	-0.160*** (0.025)	0.353*** (0.063)	0.267* (0.142)	0.321*** (0.059)
Observations	12105	12105	12105	10234	7401	10234
Adj. R-squared	0.950	0.943	0.527			
Initial firm size trend	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

Notes: Poisson regressions in columns 4, 5 and 6 (observations are dropped when imports are equal to zero). For this reason the number of observations in the specifications are less than in table 2. Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 7: Alternative explanation: Relaxing financial constraints

	Investment (1)	Capital (2)	RD status (3)	Imports of Inputs (4)	Imports of Capital goods (5)	Total imports (6)
FDI liberalization(s,t-1)	0.717*** (0.201)	1.099* (0.567)	0.563*** (0.190)	2.019** (0.867)	7.697*** (1.607)	2.264*** (0.836)
Leverage(i,t-1)	-0.073** (0.033)	-0.024 (0.091)	0.037* (0.022)	-0.274*** (0.049)	-1.305*** (0.146)	-0.382*** (0.049)
Delicensing(s,t-1)	-0.006 (0.050)	-0.211** (0.104)	0.071** (0.034)	0.073 (0.244)	0.579 (0.544)	0.149 (0.262)
Input tariffs(s,t-1)	-0.105 (0.176)	-0.100 (0.723)	-0.133 (0.183)	0.237 (0.495)	-2.390** (1.033)	-0.070 (0.563)
Output tariffs(s,t-1)	0.062 (0.051)	0.326 (0.247)	0.046 (0.056)	0.120 (0.095)	0.183 (0.312)	0.108 (0.096)
Herfindhal(s,t-1)	0.050 (0.067)	0.596** (0.267)	0.094* (0.052)	0.107 (0.075)	-0.427* (0.243)	0.063 (0.074)
Age(t-1)	0.385*** (0.039)	0.376*** (0.089)	-0.161*** (0.024)	0.333*** (0.063)	0.262* (0.141)	0.300*** (0.059)
Observations	12312	12312	12312	10432	7565	10432
Adj. R-squared	0.950	0.943	0.528			
Initial firm size trend	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

Notes: Poisson regressions in columns 4, 5 and 6 (observations are dropped when imports are equal to zero). For this reason the number of observations in the specifications are less than in table 2. Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 8: Excluding state-owned firms

	Investment (1)	Capital (2)	RD status (3)	Imports of Inputs (4)	Imports of Capital goods (5)	Total imports (6)
FDI liberalization(s,t-1)	0.671*** (0.207)	1.224* (0.642)	0.555*** (0.192)	2.029** (0.857)	7.189*** (1.719)	2.250*** (0.824)
Delicensing(s,t-1)	-0.010 (0.050)	0.009 (0.111)	0.062* (0.036)	0.078 (0.231)	0.589 (0.599)	0.151 (0.249)
Input tariffs(s,t-1)	-0.075 (0.183)	-0.708 (0.794)	-0.107 (0.189)	0.092 (0.470)	-2.281** (1.049)	-0.159 (0.557)
Output tariffs(s,t-1)	0.051 (0.053)	0.704*** (0.265)	0.051 (0.060)	0.068 (0.096)	-0.084 (0.274)	0.048 (0.094)
Herfindhal(s,t-1)	0.048 (0.071)	0.194 (0.227)	0.082 (0.053)	0.104 (0.083)	-0.380 (0.269)	0.064 (0.083)
Age(t-1)	0.403*** (0.040)	0.292*** (0.074)	-0.158*** (0.026)	0.336*** (0.066)	0.165 (0.142)	0.299*** (0.062)
Observations	11917	11917	11917	10107	7309	10107
Adj. R-squared	0.946	0.836	0.529			
Initial firm size trend	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Nic2d-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year	Nic3d-Year

*Notes:* Poisson regressions in columns 4, 5 and 6 (observations are dropped when imports are equal to zero). For this reason the number of observations in the specifications are less than in table 2. Robust standard errors in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

## 10 Theoretical Appendix

### Industry equilibrium in the downstream sector

As in Melitz (2003), before entering the market and knowing their productivity level, firms calculate the present value of average profit flows  $\tilde{v}$  to decide whether to enter the domestic market:  $\tilde{v} = \left[ \sum_{t=0}^{\infty} (1-\delta)^t \tilde{\pi} \right]$ . The net value of entry given by:  $v^e = \frac{1-G(\varphi^*)}{\delta} \tilde{\pi} - \delta f_e$ , where  $1-G(\varphi^*)$  is the ex-ante probability of survival and  $\delta f_e$  is the amortized per-period portion of the sunk entry cost. In equilibrium, where entry is unrestricted, the net value of entry is equal to zero:  $\tilde{\pi} = \frac{\delta f_e}{1-G(\varphi^*)}$ . Once firms pay the fixed entry costs, entrants then draw their productivity from a known Pareto distribution function  $g(\varphi) = k \frac{\varphi_{\min}^k}{(\varphi)^{k+1}}$  with  $\varphi_{\min} > 0$  the lower bound of the support of the productivity distribution and a shape parameter  $k$ . The Pareto cumulative distribution function is  $G(\varphi) = 1 - \left( \frac{\varphi_{\min}}{\varphi} \right)^k$ .<sup>12</sup>

$$\tilde{\pi} = \left( \frac{\varphi^*}{\varphi_{\min}} \right)^k \delta f_e \quad (\text{FE})$$

The second condition that also determines a relationship between average profits of each type of firm and the productivity level of the marginal firm is the zero cutoff profits condition (ZCP). This condition depends on the average productivity levels of firms that rely on low technology ( $\tilde{\varphi}$ ) and of firms that produce with high technology ( $\widetilde{\varphi}_{HT}$ ).  $\rho_{HT} = \frac{1-G(\varphi_{HT}^*)}{1-G(\varphi^*)} = \left( \frac{\varphi_{HT}^*}{\varphi^*} \right)^{-k}$  represents the ex-ante probability of upgrading technology with  $\rho = 1 - \rho_{HT}$ .

$$\tilde{\pi} = \rho \pi(\tilde{\varphi}) + \rho_{HT} \pi_h(\widetilde{\varphi}_{HT}) \quad (\text{ZCP})$$

Combining the free entry and zero cutoff profit conditions, the equilibrium survival cutoff productivity can be solved:

$$\varphi^{*k} = \frac{\sigma - 1}{k - (\sigma - 1)} \left[ \frac{f + \left[ \left( \frac{\nu^\theta P_x^{\theta-1} + 1}{\nu^\theta P_x^{\theta-1} t_k^\theta + \lambda_{HT}^{1-\theta}} \right)^{\frac{1-\sigma}{\theta-1}} - 1 \right]^{\frac{k}{\sigma-1}} \left( \frac{f_{HT}}{f} \right)^{\frac{-k}{\sigma-1}} f_{HT}}{\delta f_e} \right] \varphi_{\min}^k \quad (6)$$

<sup>12</sup> Assuming that productivity draws are Pareto distributed implies that firm size and variable profits are also Pareto distributed with a shape parameter  $k/(\sigma - 1)$ . The condition for average variable profits to be finite is that  $k > \sigma - 1$ . Axtell (2001) provides empirical evidence that the Pareto distribution is a good approximation of firm size distribution.