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Product Sophistication and Spillovers from Foreign Direct Investment

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Abstract

Foreign direct investment (FDI) in developing countries is often associated with higher economic growth due to knowledge and technology spillovers to local firms. One way how FDI speeds up growth is that it facilitates the manufacturing of more sophisticated products by local firms. So far, firm-level evidence is missing on how the presence of multinational firms affects the product sophistication of firms in a developing country. This paper aims to fill this gap. We compile an extensive firm-product-level dataset of Indian manufacturing firms which we complement with information on product sophistication and spillovers from FDI. We then explore different channels through which spillovers from multinationals to local Indian firms foster the manufacturing of sophisticated products. We find evidence that spillovers through supplier linkages strongly increase the manufacturing of sophisticated products in India.

JEL-Classification: F23, O1, O3
Keywords: Multinational Firms, Spillovers, Sophistication, Technological Change

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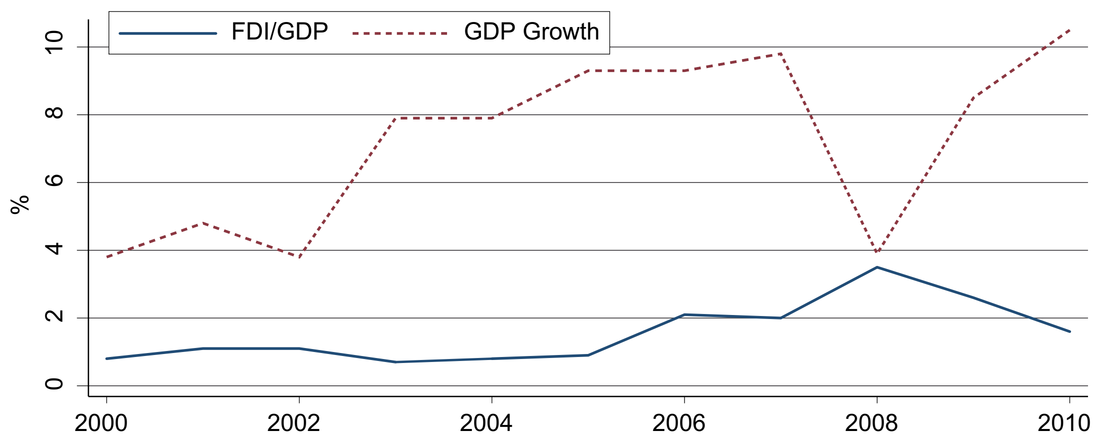
1 Introduction

Politicians give high priority to attracting FDI in developing countries. In India, e.g., foreign investors enjoy tax holidays up to 100% (UNCTAD, 2000) and are entitled to additional depreciation of 20% on new investments (Parekh, Shah, Khivasara, and Dholakia, 2012). According to estimates of the Indian Ministry of Finance (2013), the revenue foregone due to accelerated depreciation adds up to about 5 billion USD in 2011–12. The main argument in favor of generous fiscal incentives to foreign investors usually is that FDI spurs economic development in the host country. Foreign investors not only inject fresh capital but also bring new knowledge and technologies which can spill over to host country firms. One way how FDI speeds up growth is that it facilitates the manufacturing of more sophisticated, i.e. technologically advanced, products by local firms. Country-level evidence from China and India also suggests that FDI is a major driver of technological upgrading and economic growth (Woo, 2012).

At the firm-level, an extensive body of literature analyzes how spillovers from FDI affect the productivity, export, and wage setting decisions of host country firms (Görg and Greenaway, 2004). However, little is known on how the presence of multinational enterprises (MNEs) affects the manufacturing of sophisticated products by firms. This is surprising given that technological upgrading through FDI is considered an important source of growth in developing countries. The main contribution of this paper is to explore this particular spillover channel in order to provide micro-level evidence on how technological upgrading can be achieved. For a sample of Indian manufacturing firms, we empirically investigate how spillovers from FDI influence the product sophistication of firms. Due to our rich dataset, we can differentiate between horizontal and vertical transmission channels for spillovers. This allows us to identify industries in which the attraction of FDI is particularly beneficial. Our results suggest that the presence of multinational downstream firms increases the product sophistication of local Indian firms via vertical backward linkages. In contrast, a higher presence of multinational upstream firms can have an adverse effect on product sophistication via vertical forward linkages. We do not find robust evidence of positive horizontal spillovers.

India is an appropriate setting to tackle our research question. India's economy was liberalized during the 1980s and 1990s by, among others, dismantling the License Raj system that regulated entry and production activity in the registered manufacturing sector (Aghion, Burgess, Redding, and Zilibotti, 2008). As a consequence, India experienced high growth rates and large inflows of FDI over the past few years. Figure 1 shows that FDI as a percentage of total GDP has steadily increased up to almost 4% by 2008 in India. Total GDP annually grew between 4 and 10%. Therefore, insights on the relationship between FDI and technological upgrading from a large growing market can also be interesting for other developing economies.

To investigate the impact of FDI on product sophistication at the firm-level, we combine data from three different sources. Data on Indian manufacturing firms come from the Prowess database. Prowess collects annual data on the financial performance of publicly listed and unlisted Indian firms. Most importantly, it also reports detailed information on the products manufactured by each firm. Moreover, we employ data on the industry-wise sale and purchase relationships from the OECD (2012) input-output tables for India to construct spillover measures at the industry-level. Horizontal spillovers are proxied by the intensity of contact between local firms and MNEs within an industry. Vertical spillovers are captured by the intensity of contact between local firms and MNEs across industries. Finally, we exploit disaggregated data on country-level export flows from CEPII-BACI to obtain a product-specific sophistication index which was developed in Hausmann, Hwang, and Rodrik (2007). The idea of the index is to proxy the technology level of a product by the average technology level (GDP per capita) that a country needs to have in order to successfully export a particular product. Thus, a product is more sophisticated if it is exported by richer countries.



Source: World Bank Development Indicator Database.

Figure 1: FDI inflow as share of GDP and annual GDP growth in India

For our analysis, we consider two dimensions of product sophistication at the firm-level. Our first measure is a dummy variable indicating whether a firm manufactures at least one product belonging to the top quartile of the sophistication distribution. Thereby, we capture the manufacturing of highly sophisticated products (HSPs) by firms. Second, we measure the extent of firm-level product sophistication by calculating the average sophistication level of all products manufactured by a firm. In the empirical analysis, we regress each measure of firm-product sophistication on the proxies for horizontal and vertical FDI spillovers. We use a firm fixed effects approach to control for unobserved influences on the firm-level. Our findings suggest the existence of strong positive spillovers through vertical backward linkages. An increase in backward spillovers by 10 percentage points raises the probability that a firm manufactures an HSP by about 4% and increases average firm-product sophistication by 16%. In contrast, we do not find evidence of significant horizontal spillovers. These findings support the idea that MNEs try to prevent technology leakage to competitors, but have an incentive to transfer their knowledge to suppliers. Finally, we observe that the presence of multinational upstream firms induces a strong negative effect on firm product sophistication. An increase by 10 percentage points in forward linkages reduces a firm's probability to manufacture an HSP by about 13%

and decreases average product sophistication by about 32%. One explanation for this finding is that the technology gap between foreign inputs and local final goods is too large so that Indian firms cannot make use of foreign inputs and are driven out of the production of highly sophisticated final goods. The negative effect of forward linkages is less strong for more productive Indian firms, though. This indicates that more productive firms are better able to use inputs from MNE's, since the technology gap is smaller for them. Overall, we find the spillover effects to be particularly strong for domestic firms without foreign ownership participation.

This paper is related to two different strands of literature. First, it builds on the literature on product sophistication and economic development. According to the models by Stokey (1988) and Young (1991), the production of sophisticated goods sets free knowledge and learning-by-doing spillovers which spur economic growth. The spillovers are the stronger the more sophisticated the goods are. Consequently, enduring growth requires the introduction of increasingly sophisticated products. Hausmann et al. (2007) develop a model in which the production of highly sophisticated products shifts out the technological frontier of a country and thus spurs growth. They also provide cross-country evidence on the positive impact of product sophistication on growth in developing countries. Jarreau and Poncet (2012) confirm the relationship between product sophistication and growth for Chinese provinces. Our study complements the literature by providing micro-level evidence on the manufacturing of sophisticated products. We are aware of only one study by Hunt and Tybout (1998) that portrays the manufacturing of sophisticated products by Colombian and Moroccan plants. This study, however, uses the number of technicians employed by a plant to proxy for firm-level product sophistication. We, instead, directly infer the sophistication level of a product. Our measure of product sophistication reflects differences in technological requirements of products and is thus unrelated to firm characteristics.

Second, we relate to the literature on spillovers from FDI. Rodriguez-Clare (1996) and Markusen and Venables (1999) provide a theoretical foundation for the impact of MNEs on host country development. In both models, firm productivity and host country welfare improve if MNEs create strong backward linkages with host country firms. Lin and Saggi (2007) and Carluccio and Fally (2013) show that a vertical technology transfer can also entail adverse welfare effects if it is directed to only a subgroup of local suppliers. In Lin and Saggi (2007), exclusive contracts between MNEs and local suppliers prevent that technology transfers benefit all suppliers. Carluccio and Fally (2013) account for firm heterogeneity and show that only the most productive firms are able to adopt foreign technologies when technology adoption is costly. Liu (2008) differentiates between short-term level effects and long-term growth effects. In his model, FDI spillovers reduce productivity levels in the short term due to a reallocation of ressources but in the long run, productivity growth increases. A large part of the empirical literature focuses on the impact of FDI on firm-level outcomes such as productivity. Evidence on productivity gains through contact to multinational firms remains ambiguous and critically hinges on the data available.[1] An early investigation is Caves (1974) who observes positive horizontal spillovers for Australian firms. Other studies that only consider horizontal spillovers

[1] See Görg and Strobl (2001) for a meta-analysis on the subject.

from FDI often find negative or insignificant effects on the productivity of domestic firms (e.g. Harrison and Aitken (1999) for Venezuelan firms and Konings (2001) for Romania, Bulgaria, and Poland). One exemption is Haskel, Pereira, and Slaughter (2007), who observe a positive relationship between the presence of MNEs and total factor productivity growth of UK firms. Schoors and Van Der Tol (2002), Javorcik (2004), Blalock and Gertler (2008), Lin et al. (2009), and Liu (2008) differentiate between horizontal and vertical FDI spillovers and provide evidence of positive spillovers via backward linkages in Hungary, Lithuania, Indonesia, and China, respectively.[2] The only study that addresses the effect of FDI on product sophistication does so at the product-country level. For a sample of 105 countries, Harding and Javorcik (2012) find that the unit values of export products increase if these products belong to sectors targeted by FDI promotion. However, with their cross-country empirical setup with disaggregated international export data they fail to find the same effect if product sophistication is measured via the Hausmann et al. (2007) index.

Our analysis contributes by providing evidence on a further micro-level channel through which FDI promotes economic growth. We show that the presence of multi-national firms not only allows local firms to become more efficient or upgrade the quality of their products, but that it also helps firms to produce more technologically advanced products. This is in line with the macroeconomic evidence by Woo (2012) who shows that FDI is an important driver of technological upgrading in China and India.

The remainder of this paper is organized as follows. Section 2 provides an overview on how spillovers from FDI influence firm product sophistication through different linkages. Section 3 describes the data. In Section 4, we portray product sophistication of Indian firms. Section 5 discusses our empirical strategy and presents the corresponding results. Section 6 concludes.

[2] For an extensive overview of the empirical evidence on FDI spillover effects at the firm-level, refer to Görg and Greenaway (2004).

2 Potential channels of FDI spillovers and their effect on product sophistication

To guide our empirical analysis, we elaborate on the potential channels through which spillovers from FDI can influence product sophistication of firms. Our discussion relies on the theoretical framework by Hausmann and Rodrik (2003) that describes the production choice of an entrepreneur. In the model, entrepreneurs can choose whether to invest in the production of a traditional sector good or a modern, technology intensive sector good. The traditional sector consists of a homogeneous good whose cost of production is commonly known. The modern sector consists of differentiated goods, each of which requires the adoption of a particular technology that is already used in developed countries. The cost of producing a modern sector good is discovered only after production. Uncertainty about the production cost of a modern sector good stems from the technology of the modern sector good which is unknown to the entrepreneur. Moreover, she may have to make certain changes in order to establish the product in the local market, for example adjustments due to different raw materials or the introduction of additional quality controls. Thus, the entrepreneur has to engage in a costly learning process to discover whether she is able to successfully produce and market the good. If the new product is introduced successfully into the economy, it is prone to emulation from other entrepreneurs.[3] This reduces the profitability to the original entrepreneur. Briefly, the returns from introducing a more sophisticated good cannot completely be internalized by an entrepreneur whereas she bears the full costs of the new investment. Consequently, entrepreneurs may choose too little investment in more sophisticated goods.

The presence of MNEs in developing countries can impact on a firm's choice whether to manufacture a more sophisticated product. FDI changes the access to foreign knowledge and technologies since MNEs usually employ more advanced technlogies and have already engaged in the cost discovery process of new products (Harding and Javorcik, 2012). If knowledge on the use of more sophisticated technologies spills over to local firms, cost uncertainty is reduced and the production of more technologically advanced products is facilitated.

Spillovers from MNEs to local firms can evolve through three different channels. First, spillovers can flow from multinationals to local firms within the same industry. Well-cited examples for positive horizontal spillovers are learning-by-observation and worker turnover. Local firms learn how to produce a more sophisticated product by simply observing the production techniques of MNEs in the same industry. Furthermore, workers that have previously been employed by multinationals can transfer their acquired knowledge when switching to a local firm. The effect of horizontal spillovers is limited, though, since MNEs have an incentive to prevent technology leakage via patenting their technologies or via paying higher wages to limit the knowledge outflow. Within-industry presence of multinationals can also lead to a negative competition effect on local firms. MNEs are usually assumed to be more skill-intensive

[3] Emulation is justified by the assumption that the original entrepreneur is not able to secure her adoption of the modern good via patents since the adjustment usually is too small to receive patent protection (Evenson and Westphal, 1995).

and more productive than local firms and thus they are better able to produce more sophisticated goods. Consequently, competition can crowd out local firms from the production of more sophisticated products.

Second, vertical backward spillovers can occur between multinational downstream firms and local upstream firms via supplier linkages. Even though preventing technology leakage is preferable within the own industry, MNEs have an incentive to transfer their knowledge to local suppliers.[4] Consider for example an Indian steel manufacturer that is selling steel bars for the use in water pumps. An MNE engaging in the construction of airplane wings requires flat rolled steel sheets instead. Producing steel sheets is more technologically advanced since it requires the handling of special steel rolling machines. In order to source the flat steel sheets locally, the multinational company can provide training services to suppliers on how to use the specific machines and on how to combine existing production techniques. The magnitude of the effect of backward spillovers depends on the extent to which multinationals source locally. If inputs are predominantly acquired from abroad, positive backward spillovers are limited in size (Javorcik, 2008).

Third, knowledge spillovers can flow from multinational suppliers to local customers via vertical forward linkages. Access to highly sophisticated inputs from MNEs allows local downstream firms to produce highly sophisticated outputs. Flat steel sheets can only be produced if the specific rolling machines are available to Indian firms. In addition, multinational upstream firms can provide training to downstream customers on how to use the machines. However, as Javorcik (2008) notes, the effect of positive forward spillovers depends on the availability of sophisticated inputs prior to the entry of multinational downstream firms. If highly sophisticated inputs are accessible via imports, forward spillovers are limited in size. Moreover, the technological gap between local and multinational firms plays a decisive role. If the technological gap is too large, local firms cannot make use of inputs provided by multinationals in their production process. This can also entail a negative effect if local inputs are crowded out by multinational inputs and local final good producers no longer have access to suitable inputs (see e.g. Carluccio and Fally, 2013).

[4] See for example Lin and Saggi (2007) or Pack and Saggi (2001) for a theoretical framework on vertical technology transfer by MNEs.

3 Data and summary statistics

In order to conduct our empirical analysis we combine three datasets. Data on Indian manufacturing firms come from the Prowess database. To construct the spillover measures, we use data on the industry-wise sale and purchase relationships from the OECD (2012) input-output tables for India. Finally, we exploit disaggregated data on country-level export flows from CEPII-BACI to calculate the product sophistication index.

3.1 Firm-level data – Prowess

The Prowess database is compiled by the Centre for Monitoring the Indian Economy (CMIE) and provides firm-level information on listed and unlisted Indian enterprises.[5] The database performs quite well in terms of comprehensiveness. According to CMIE, the output of manufacturing firms covered in the database accounts for about 80% of total Indian manufacturing output. Identity indicators comprise *inter alia* the incorporation year, the ownership type, the share of equity held by foreign investors, and the place of business. The industry classification is based on ISIC Rev.4 up to the 4-digit level. Data on financial statements include total sales, exports, the wage bill, total assets, and raw material expenditures. One drawback is that information on the number of employees per firm is available for very few firms only. Essential for our analysis is that Prowess provides information on the products manufactured by Indian firms. Due to the 1956 Companies Act, Indian firms have to make information available on the sales, capacities, and production quantities of their products.

We compile a firm-level panel data set of 5,539 manufacturing firms for the period 2001 to 2010. We choose 2001 as a start year since data on the equity capital held by foreign investors is available only from 2001 onwards. The panel is unbalanced and the number of firms observed in each year ranges between 3,000 and 4,000. The total number of firm-year observations amounts to 36,238. On average, a firm is present in the dataset for 7 out of 10 years. A list of all variables included throughout the analysis can be found in Table 1. Table 2 provides average firm characteristics for the entire sample period. Data on income and expenditures are in million Rupees and deflated by either the Indian industry specific wholesale price index (sales and exports) or the Indian overall wholesale price index (all other) following Goldberg, Khandelwal, Pavcnik, and Topalova (2010). The average firm age is 25 years and firms produce 3 products on average.[6]

Information on exports is only available for firms that export a positive amount (18,209 firm-year observations). More than 90% of all firms are privately Indian owned, about 6% are foreign-owned and the remaining part is state owned.[7] For publicly listed companies, Prowess

[5] The Prowess database has already been used in various research projects. See for example Goldberg, Khandelwal, Pavcnik, and Topalova (2009) for evidence on how trade liberalization affects the import of new inputs by Indian firms or Franco and Sasidharan (2010) for evidence of FDI spillovers on the export participation of Indian firms.

[6] For an in-depth discussion about Indian multi-product firms and their characterstics, we refer to Goldberg et al. (2010) who provide a detailed portrait on multi-product firms from the Prowess database.

provides the share of equity held by foreign investors which is on average 6%. We perform a consistency check on ownership information by comparing the ownership type, as indicated by Prowess, with the share of equity held by foreign investors. For government and Indian owned listed firms, the average share of equity held by foreigners is below 10% and for listed firms classified as foreign-owned, the average share lies above 50% (data not reported in Table 2).

$LogTFP$ denotes firm total factor productivity and is calculated using the superlative index number approach (Caves, Christensen, and Diewert (1982), Griffith, Redding, and Simpson, 2009). For further details on the calculation of the productivity measure please refer to the appendix.[8]

Table 1: Description of variables

Outcome variables	
HSP	Dummy equal to 1 if firm produces at least one product from the top quartile of the sophistication distribution and 0 otherwise
LogEXS	Log average product sophistication level of firm
Spillover measures	
Horizontal	Extent of presence of multinational companies in own industry
Backward	Extent of presence of multinational companies in downstream industries
Forward	Extent of presence of multinational companies in upstream industries
Other variables	
ForeignOwned	Dummy equal to 1 if firm is owned by a foreign entity and 0 otherwise
ForeignShare	Share of equity held by foreign investors
HHI	Herfindahl index of industry concentration
LogAge	Log age of firm
LiqRatio	Liquidity ratio of firm, defined as current assets less current liabilities over total assets
LogIncome	Log of total income of a firm
LogTFP	Log total factor productivity of firm based on the superlative index number approach (Caves, Christensen, and Diewert (1982) and Griffith, Redding, and Simpson, 2009)
Variables used in the calculation of $LogTFP$	
LogGroFixAss	Log gross fixed assets of firm
LogRawMatExp	Log raw material expenditures of firm
LogSales	Log sales of firm
LogWagebill	Log wage bill of firm

[7] Prowess makes use of internal information to classify firms according to their ownership status, but does not provide further information on the classification system.

[8] We also experimented with a semi-parametric productivity measure obtained via the Levinsohn-Petrin algorithm (Levinsohn and Petrin, 2003) that corrects for endogeneity in the firm's choice of production inputs due to unobserved shocks. Our main results remain unchanged when we use a more sophisticated measure of productivity. However, the Levinsohn-Petrin measure is more data-demanding and relies on the assumption that there is no entry and exit of firms. Since our panel is unbalanced, we decided to use the superlative index number approach.

Table 2: Summary statistics, 2001 – 2010

Variable	Mean	Std. Dev.	Observations
Age	25.22	17.83	36,238
Number of products	2.34	2.00	36,238
Exports	5.87	68.06	18,209
HHI	350.47	303.61	36,238
LiqRatio	0.24	0.32	36,189
LogGroFixAss	0.34	1.81	36,238
LogIncome	0.97	1.89	36,238
LogRawMatExp	0.04	2.14	36,238
LogSales	1.06	1.92	36,238
LogTFP	−0.11	1.9	36,238
LogWagebill	−2.18	1.84	36,238
Privetaly Indian owned (%)	0.9	0.29	36,238
Foreign Owned (%)	0.06	0.24	36,238
State Owned (%)	0.03	0.18	36,238
Foreign equity share (%)	6.3	16.87	15,378

Sales, the wage bill, gross fixed assets, raw material expenses, and exports are in million Rupees. Sales and the export volume are deflated by the Indian industry specific wholesale price index and all other monetary values are deflated by the Indian overall wholesale price index.

3.2 Industry linkages – OECD input-output tables

We use data from the OECD (2012) input-output tables for India to construct measures of FDI linkages. The input-output tables describe economy-wide consumption and supply relationships between producers and consumers. For India, data are available for two time periods, the early 2000 and the mid 2000 period.

We follow Javorcik (2004) in constructing proxies for horizontal and vertical spillovers from FDI. Horizontal spillovers within each industry are defined as

$$Horizontal_{jt} = \left[\sum_{i,i\in j} ForeignShare_{it} * Y_{it}\right] / \sum_{i,i\in j} Y_{it}. \tag{1}$$

$ForeignShare_{it}$ is the percentage of equity held by foreign investors in firm i at time t and Y_{it} denotes the total sales of the firm. $Horizontal_{jt}$, thus, is the sales weighted average of foreign equity held in industry j at time t. It proxies spillovers from the intensity of contact between foreign investors and local firms in industry j. Foreign presence in industry j rises if the average foreign equity share in the industry or the output of firms with foreign participation increases.

Vertical backward spillovers stem from the intensity of contacts between suppliers and multinational customers in downstream industries. They are proxied by the degree of foreign presence in industries to which firms in industry j supply. $Backward_{jt}$ is defined as

$$Backward_{jt} = \sum_{k,k\neq j} \alpha_{jk} * Horizontal_{kt}, \tag{2}$$

where α_{jk} denotes the share of output of industry j that is supplied to industry k and is calculated from the OECD input-output tables for India. Following Javorcik (2004), we calculate

α_{jk} excluding output of industry j that is used for final consumption but including intermediate products. Moreover, the within-industry supply share α_{jj} is not included in (2) since within-industry spillover effects are already taken up by $Horizontal_{jt}$. Increases in backward spillovers to industry j can stem from a rise in relative supply to downstream industries with foreign presence or from a rise in foreign presence in downstream industries.

Last but not least, vertical forward spillovers originate from the contact between local downstream firms and multinational suppliers in upstream industries. They are proxied by the degree of foreign presence in industries from which industry j consumes inputs. $Forward_{jt}$ is defined as

$$Forward_{jt} = \sum_{m, m \neq j} \sigma_{jm} \left[\frac{\left[\sum_{i, i \in m} ForeignShare_{it} * (Y_{it} - X_{it})\right]}{\left[\sum_{i, i \in m} (Y_{it} - X_{it})\right]} \right], \quad (3)$$

where σ_{jm} is the share of inputs that industry j consumes from industry m. The within-industry consumption share σ_{jj} is not included in (3). Firm-level exports X_{it} have to be subtracted from firm-level output since exports cannot be consumed by industry j. Forward spillovers to industry j increase if relative consumption from industries with foreign presence rises or if foreign presence in upstream industries rises.

Three remarks on the calculation of the FDI linkage measures are in order. First, note that we use the industry-wise supply and consumption shares from the early (mid) 2000 period to construct our spillover variables for the years 2001 to 2005 (2006 to 2010). Our spillover measures vary at the industry-year level because firm-year specific information on $ForeignShare_{it}$, Y_{it}, and X_{it} is added. Second, since the OECD input-output tables are based on ISIC Rev.3, we convert the 24 2-digit manufacturing industries at ISIC Rev.4 in Prowess to the corresponding ISIC Rev.3 categories.[9] Table A.1 in the appendix provides the correspondence between both classifications and the share of firms in each industry. Third, data on $ForeignShare_{it}$, the equity participation by foreign investors, is available for publicly listed firms only (16,452 firm-year observations). If we use information from publicly listed firms only, we disregard almost two thirds of our observations. In order to calculate consistent spillover measures, we supplement $ForeignShare_{it}$ by information on the ownership type of firms as defined by Prowess. We consider firms that are classified as privately Indian or government owned to have 0% foreign equity and privately foreign-owned firms to have 100% foreign equity. We provide a robustness check of our main results with regard to this assumption.

Table 3 reports summary statistics on the share of foreign equity in each industry and the spillover measures for the year 2010. Our measures strongly vary across industries. The average share of foreign equity held in firms is highest in the motor vehicles industry (34.6%) and lowest in the textile industry (1.3%). If we weigh foreign equity held in each industry by output, the ranking is slightly different. Horizontal spillovers are highest in the motor vehicles industry and lowest in manufacturing and recycling. Backward spillovers are comparatively smaller in

[9] The rather high aggregation level of industries is due to data constraints when matching the Indian and the OECD data. This makes it harder to trace significant spillover effects and therefore, we consider our estimates as rather conservative.

size and range from a high 9.1% in fabricated metal products to a low 1.0% in food, beverages, and tobacco products. In other words, firms in the fabricated metal (food) industry supply to industries in which the average share of foreign equity held is 9.1% (1.0%). They have the most (least) intense contact to multinational downstream enterprises. In contrast, forward linkages are highest in the rubber and plastics product industry (5.6%) implying that these firms very intensively consume inputs from multinational upstream enterprises. Very low contact to multinational upstream firms can be observed in the coke and petrol industry (0.3%).

Table 3: Summary statistics on FDI spillovers by industry in 2010

Code	Industry	ForeignShare (%)	Horizontal (%)	Backward (%)	Forward (%)
C15,16	Food, beverages, tobacco	3.64	7.85	1.01	0.69
C17,18,19	Textiles, textile products, leather and footwear	1.27	2.22	1.83	1.64
C23	Coke, refined petroleum products and nuclear fuel	11.19	1.07	1.90	0.31
C24	Chemicals and chemical products	6.49	11.33	2.25	0.73
C25	Rubber and plastics products	4.60	6.78	6.98	5.59
C26	Other non-metallic mineral products	8.68	7.98	1.20	1.15
C27	Basic metals	2.03	4.64	8.24	1.08
C28	Fabricated metal products, exc. machinery and equipment	3.85	6.62	9.06	3.49
C29	Machinery and equipment n.e.c.	13.31	15.14	5.77	3.26
C30,32,33	Office, accounting and computing machinery; Radio, television and communication equipment; Medical, precision and optical instruments	9.42	23.42	2.73	3.95
C31	Electrical equipment	8.38	24.07	5.34	4.00
C34	Motor vehicles, trailers and semi-trailers	34.56	40.87	1.44	4.01
C35	Other transport equipment	7.23	13.26	2.13	4.08
C36,37	Manufacturing n.e.c; recycling	1.79	0.55	3.37	2.96

The code in column 1 corresponds to the classification in the input-output database of the OECD. The industries C30, C32, and C33 are combined in to one industry since they correspond to one ISIC Rev.4 industry at the 2-digit level.The industries C20 and C21, 22 are not represented in our database.

3.3 Product sophistication

To determine the sophistication level of products, we adapt the product-specific sophistication index from Hausmann et al. (2007).[10] The index measures the average implied technology level of a product k which is proxied by the weighted average GDP per capita of those countries that export product k. The weights reflect the revealed comparative advantage that each country has in product k. A product is associated with a higher (lower) sophistication level if on average richer (poorer) countries have a revealed comparative advantage in the product. Put differently, the index represents the technology requirements that a country must meet in order to successfully export the product. The level of sophistication of product k is defined as

[10] The sophistication index in Hausmann et al. (2007) is called $PRODY$ and has been used by Jarreau and Poncet (2012) and Harding and Javorcik (2011), for example.

$$SOPH^k = \sum_i \underbrace{\left(\frac{x_i^k / X_i}{\sum_i \left(x_i^k / X_i \right)} \right)}_{weight\ \varphi_i^k} Y_i, \tag{4}$$

where Y_i is the GDP per capita of country i. x_i^k denotes country i's export volume of product k, and X_i is the total export volume of country i. The weights φ_i^k are variants of Balassa's Revealed Comparative Advantage (RCA) Index and add up to one. The weights ensure that the sophistication ordering of the products is not biased by country size.[11] Data on GDP per capita in constant 2005 USD stem from the World Development Indicators database. Data on product-level exports come from the CEPII-BACI database which is constructed from UN-Comtrade data. We use disaggregated export data at the 3-digit SITC Rev.3 level which comprises 259 product categories. To get a time consistent indicator, we take the average level of GDP per capita and exports by each country over the time span of 2000 to 2010. This diminishes disturbing influences from wars and business cycle fluctuations, as well as industrial and technological developments over time. Consistent data on GDP per capita and the corresponding export flows are available for 175 countries. Table 4 provides the three most and least sophisticated products according to $SOPH^k$. The top sophisticated product is organo-inorganic compounds with an average sophistication level of 26,309 USD. Organo-inorganic compounds are intensively exported by Ireland, for example. In contrast, the least sophisticated product is uranium ores with an average sophistication level of 976 USD. Uranium ores make up a substantial share of Nigerian exports, one of the world's poorest countries.

Table 4: Top and bottom sophisticated products

Top products

SITC code	$SOPH$ in USD	Description
515	26,309	Organo-inorganic compounds, heterocyclic compounds, nucleic acids and their salts, and sulphonamides
344	26,049	Petroleum gases and other gaseous hydrocarbons, n.e.s.
514	23,356	Nitrogen-function compounds

Bottom products

SITC code	$SOPH$ in USD	Description
286	976	Uranium or thorium ores and concentrates
284	1,103	Nickel ores and concentrates; nickel mattes, nickel oxide sinters and other intermediate products of nickel metallurgy
264	1,357	Jute and other textile bast fibres, n.e.s., raw or processed but not spun; tow and waste of these fibres (including yarn waste and garnetted stock)

SITC categories are defined at the Rev.3 3-digit level.

[11] Assume for example that both the US and Ecuador export bananas. Since the US is larger in market size than Ecuador, its export volume of bananas is probably larger than that of Ecuador. However, bananas certainly take a larger share in Ecuador's exports than in the US exports. Not controlling for a country's RCA in exporting bananas might thus lead to a higher sophistication level for bananas simply because they are exported (to a small extent) by a rich country.

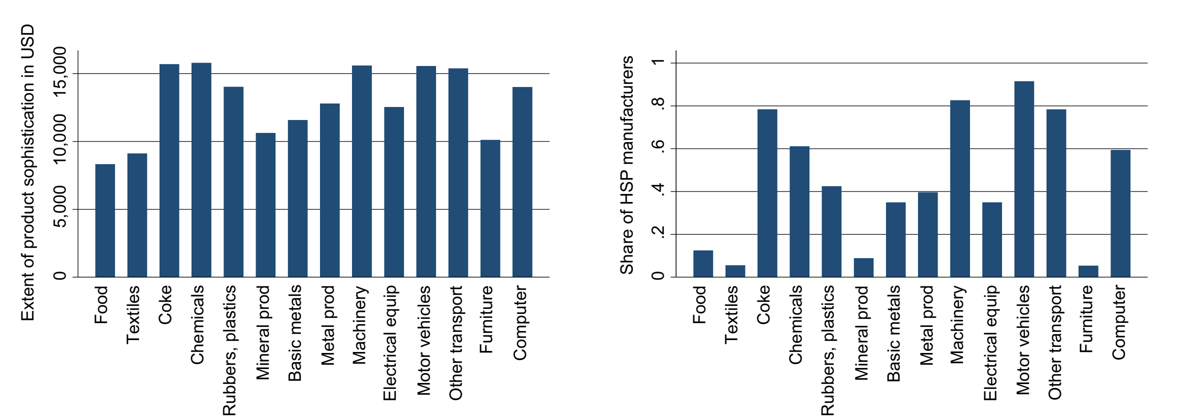
We use the index to determine the sophistication level of the products manufactured by the Indian firms. The product classification of CMIE cannot directly be linked to any standard international classification. Therefore, we reclassify all products according to the SITC 3-digit classification. We manage to identify 82% of all firm-product-year observations which account for 88% of total output. For the remaining share, the information provided on the products is not sufficient in order to assign a sophistication level. We also experimented with a more disaggregated classification at the 4- and 5-digit level. However, as products become more disaggregated the reclassification becomes more imprecise and we managed to identify less than half of all observations. Although the 3-digit level is comparatively aggregate, we are confident that the 259 different product categories still provide sufficient scope for variation in the activities of firms. A more detailed description of the product reclassification to SITC Rev.3, 3-digit, can be found in the appendix.

4 Portrait of product sophistication in India

In this section, we describe the economic prevalence of product sophistication of Indian firms. To capture different dimensions of product sophistication at the firm-level, we employ two measures. The first is a dummy variable HSP indicating whether a firm produces a highly sophisticated product. HSP is equal to 1 if a firm produces at least one product that belongs to the top quartile of the sophistication distribution. This allows us to capture firms' manufacturing of the most sophisticated products. Second, we calculate, EXS_{it}, the extent of product sophistication per firm:

$$EXS_{it} = \sum_{k}^{K} \frac{Sales_{it}^{k}}{\sum_{k}^{K} Sales_{it}^{k}} SOPH^{k}. \tag{5}$$

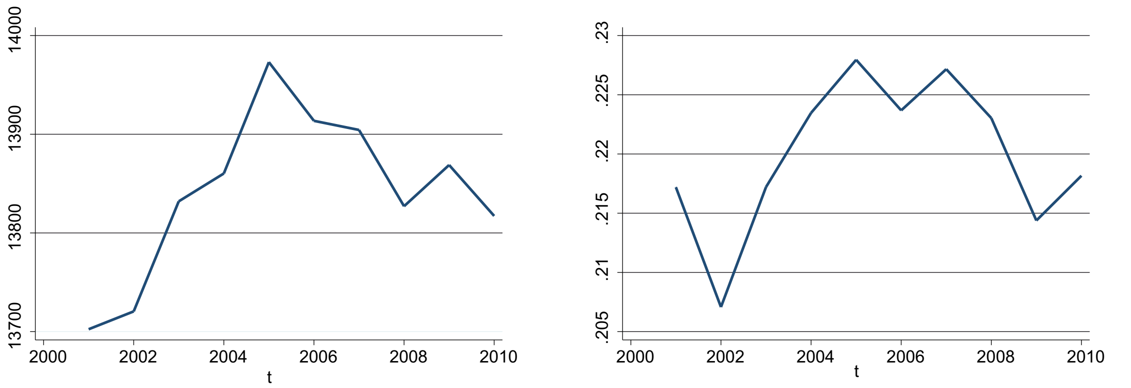
EXS is defined as the average sophistication level of all products, $k = 1, ...K$, that are produced by a firm. The sophistication level $SOPH^k$ of each product k is weighted by its share in total firm sales. A higher value of EXS_{it} indicates that the firm manufactures products with a higher sophistication level or that a higher share of its sales stems from more sophisticated products.



(a) Extent of product sophistication, *EXS* (b) Share of HSP manufacturers

Figure 2: Product sophistication across industries, 2001–2010

We first illustrate the industry-wise distribution of product sophistication in Figure 2. There is substantial variation in EXS across different industries (Subfigure 2a). The lowest average sophistication level per firm is found in food (USD 8,312) and textiles (USD 9,102), the highest average sophistication level is exhibited by firms in the chemicals industry (USD 15,779). Subfigure 2b displays the share of firms that produce at least one HSP in each industry. HSP manufacturers are present in each industry, but they are not homogeneously spread across industries. The share of HSP manufacturers ranges from about 5% in the textiles and furniture industry to about 90% in the motor vehicles industry.



(a) Average level of product sophistication over time, sales weighted

(b) Share of output generated by the sale of HSPs over time

Figure 3: Product sophistication and the share of output over time

Studying the evolvement of product sophistication over time, we also observe substantial variation. Subfigure 3a displays the development of the average sophistication level of all products, weighted by the sales share, within our sample period. The average sophistication level of products increased from USD 13,700 in 2001 to almost USD 14,000 in 2005. During the crisis years, average product sophistication declined to about USD 13,800.

Since the manufacturing of very sophisticated products is associated with a higher growth potential for developing countries (Hausmann et al., 2007), we shed more light on the production of top sophisticated products by Indian firms. As Panel A of Table 5 shows, less than half (43%) of all firms produce an HSP at least once over the entire sample period. Interestingly, these firms together generate almost three quarters (74%) of total sample output and they also produce on average a larger number of products than firms that never manufacture an HSP. Half of all products produced by HSP manufacturers actually are HSPs, the other half is made up of less sophisticated products. Although these firms dominate manufacturing output, less than one third of their output stems from HSPs (Panel B of Table 5). The bulk of output is generated from the sale of less sophisticated products. Hence, less than a quarter of total sample output is derived from the sale of HSPs. This is also depicted in Subfigure 3b. The share of output that is generated from HSPs increases from 21.7% in 2001 to about 23% in 2005 and then drops to its starting level in the aftermath of the financial crisis. Generally, the manufacturing of HSPs seems not only to be rather low but also very persistent over time. Panel C of Table 5 reports the unconditional sample probabilities of adding and dropping an HSP. The unconditional sample probability of adding an HSP only, for example, is the number of firm-year observations in which an HSP was added only (no simultaneous dropping of another HSP) divided by total firm-year observations. Over the whole sample period, HSP adding was observed in 5% of all observations whereas dropping an HSP (without adding another HSP) was observed in 2% of all cases. The unconditional probability of doing both, adding and dropping HSPs is 0.3%. The probability that firms that produce HSPs stick to their HSP mix is about 39%. These findings clearly indicate that manufacturing HSPs is not yet very prevalent among Indian manufacturing firms. One explanation is the high uncertainty in the profitability of these products. Since they require the investment in unknown technologies and are attractive to emulators, only few firms engage in their production. A further issue is that the demand for HSPs in India may still be low. This could also explain why rather large firms produce HSPs: only firms that generate sufficiently high returns from other activities can bear the risky investment because they can better cover potential losses from HSPs by other income generating products.

Table 5: Prevalence of HSP manufacturing in India

Panel A: Output by HSP manufacturers vs. never-HSP manufacturers

Type of firm	# of firms	Share of firms (%)	Share of output (%)	Mean # of products	Mean # of HSPs
Never-HSP manuf.	3,134	56.6	26.0	1.9	0
HSP manuf.	2,405	43.4	74.0	2.8	1.5
Total	5,539	100	100		

Panel B: Output of HSP manufacturers by product type

Type of product	Share of products (%)	Share of output (%)
No HSP	46.4	70.1
HSP	53.6	29.9
Total	100	100

Panel C: HSP adding and dropping by firms

Activity	Unconditional probability (%) of
Adding HSP only	4.8
Dropping HSP only	2.1
Adding and dropping of HSP	0.3
Not changing HSP mix	38.8

In Panel A, a firm is classified as an HSP manufacturer if it produces at least one highly sophisticated product at least once over the whole sample period. Never-HSP manufacturers are firms that never produce a highly sophisticated product. Panel B splits product output of HSP manufacturers by product type. In Panel C, unconditional probabilities of changes in firms' HSP mix are reported.

We next explore whether producing more sophisticated products is related to certain firm characteristics. In doing so, we run simple OLS regressions of the following type:

$$Char_{ijst} = a_0 + by_{ijst} + a_t + a_j + a_s + e_{ijst}. \tag{6}$$

$Char_{ijst}$ denotes the respective firm characteristic. y_{ijst} is one of our two measures of firm product sophistication, either HSP or $LogEXS$. If we employ HSP as sophistication measure, the coefficient b gives us the percentage differential in firm characteristics between HSP manufacturers and non-HSP manufacturers. For $LogEXS$, b can be interpreted as the percentage difference in firm characteristics for a 1% difference in average product sophistication. In addition, we control for time, industry, and state fixed effects.

The results in Panel A of Table 6 suggest the existence of HSP manufacturer premia: firms that produce an HSP are distinctly different in almost all reported firm characteristics. They are significantly older (11%), larger in terms of sales (33%) and the wage bill (50%) and they are more productive (31%). These findings are in line with the theoretical predictions by Bernard, Redding, and Schott (2009) who derive that firms sort into the production of more complex goods according to their productivity. We also observe that these firms have a significantly higher probability to export (10%) and they are more often foreign-owned (1%).[12] In Panel B of Table 6, we test whether differences in firm characteristics also exist with regard to average product sophistication. We find that except for the age of a firm, all differences are statistically significant. A b-coefficient of 14% in row 4 of Panel B, e.g., signifies that the productivity premia for firms with a 1% higher level of average product sophistication is 14%.

Table 6: Differentials in firm characteristics according to product sophistication

Panel A: HSP manufacturers vs. non-HSP manufacturers (Soph. measure: HSP)

Firm characteristic	b	(se)	R^2	Obs.
LogAge	0.1112***	(0.0083)	0.07	36,238
LogSales	0.3302***	(0.0235)	0.07	36,238
LogWagebill	0.5016***	(0.0225)	0.10	36,238
LogTFP	0.3146***	(0.0236)	0.05	36,238
ForeignOwned	0.0119***	(0.0031)	0.05	36,238
ForeignShare (%)	0.3703	(0.2630)	0.05	36,238
Export Prob. (%)	0.0981***	(0.0062)	0.09	36,238

Panel B: Average sophistication (Soph. measure: LogEXS)

Firm characteristic	b	(se)	R^2	Obs.
LogAge	–0.0029***	(0.0023)	0.07	36,237
LogSales	0.1253***	(0.0086)	0.08	36,237
LogWagebill	0.0976***	(0.0071)	0.09	36,237
LogTFP	0.1410***	(0.0099)	0.05	36,237
ForeignOwned	0.0053***	(0.0006)	0.05	36,237
ForeignShare (%)	0.3969***	(0.0574)	0.05	36,237
Export Prob. (%)	0.0166***	(0.0016)	0.08	36,237

Panel A display results from regressing firm characteristics on HSP, time, industry, and state fixed effects. Panel B displays results from regressing firm characteristics on $LogEXS$, time, industry, and state fixed effects. Heteroskedasticity-robust standard errors are in parentheses. ***, **, and * denote significance at 0.01, 0.05, and 0.10 levels, respectively.

To summarize, we find strong evidence that firms that manufacture more (or highly) sophisticated products outperform less sophisticated firms. In addition, HSP manufacturers dominate manufacturing output although the output by HSPs is rather low. This may be due to the higher

[12] One might be concerned that our classification of firms in HSP and non-HSP manufacturers simply reflects the distinction between multi-product and single-product firms. Naturally, manufacturing an HSP and being a multi-product firm is highly correlated since HSP manufacturers produce on average more than one product (Table 5). However, in our data more than half of all firms that never produce an HSP sell more than one product and are thus multi-product firms. Therefore, we are confident that we do not simply capture multi-product firm characteristics when classifying firms according to the sophistication of their activities.

costs and uncertainty associated with producing more complex products. In the following, we analyze whether contact to MNEs can foster the manufacturing of more sophisticated products by firms via spillovers through horizontal and vertical linkages.

5 The impact of FDI spillovers on product sophistication

To examine the relationship between product sophistication and spillovers from FDI, we choose two different approaches. In subsection 5.1, we first use a binary model to estimate the effect of horizontal and vertical spillovers on a firm's decision whether to produce an HSP. In subsection 5.2, we then test for spillover effects on the extent of product sophistication using fixed effect estimation. The first part of the analysis allows us to infer how the presence of MNEs affects firms' engagement in manufacturing products with the highest sophistication level. The second part identifies driving forces behind continuous changes in firm-product sophistication.

5.1 Manufacturing of HSPs

5.1.1 Estimation Strategy

To explore the relationship between spillovers and firms' manufacturing of an HSP, we estimate the following equation:

$$\begin{aligned} Prob(HSP_{ijst} = 1) = \Phi(&\alpha_0 + \beta_1 Horizontal_{jt} + \beta_2 Backward_{jt} + \beta_3 Forward_{jt} \\ &+ \gamma_1 LogTFP_{ijst} + \gamma_2 ForeignShare_{ijst} + \gamma_3 LogAge_{ijst} \\ &+ \delta HHI_{jt} + \alpha_t + \alpha_j + \alpha_s). \end{aligned} \tag{7}$$

As defined above, the dependent variable HSP is a binary indicator equal to 1 if firm i active in industry j and operating in state s produces at least one product in year t that belongs to the top quartile of the sophistication distribution. $Horizontal$, $Backward$, and $Forward$ denote our measures of FDI spillovers. Additionally, we control for firm-level influences such as the share of equity held by foreigners in the firm ($ForeignShare$), the log age of a firm ($LogAge$), and log total factor productivity ($LogTFP$). We expect a positive influence of the firm-level controls on the manufacturing of HSPs. Foreigners that possess a higher stake in a local firm may have a higher incentive to share their technologies with the firm in order to produce a more sophisticated output and to earn higher profits. Older and more productive firms are better able to cover the higher fixed costs and to bear the higher risk of producing more complex products. Additionally, we include the Hirschman-Herfindahl-Index HHI to control for industry concentration. HHI is defined as the sum of squared market shares of all firms operating in a particular industry. A higher value indicates a higher level of concentration and thus weaker competition. The effect of HHI on product sophistication is ambiguous: on the one hand, stronger concentration generates larger profits which can be reinvested in the production of more sophisticated products. On the other hand, weaker competition can impede the manufacturing of HSPs since incentives to innovate and produce very sophisticated products decrease.

Standard errors are clustered at the industry-year level because our key regressors vary at the industry-year level (Moulton, 1990). Moreover, we include time, industry, and Indian state fixed effects. By including industry and state dummies, we rule out that the effect of our spillover measures on HSP manufacturing is driven by the presence of multinational enterprises in more (or less) attractive industries and states. We abstain from including firm fixed effects because the within variation in our dependent variable is very low. As reported in Panel C of Table 5, only few firms add and drop HSPs over time. We thus estimate equation (7) via a pooled probit model for all observations between 2001 and 2010. In addition, we reestimate our baseline specification for domestically owned firms only since we expect spillovers to be particularly important for firms without intra-firm access to foreign technologies. To identify domestically owned firms, we use the ownership classification provided by Prowess.

5.1.2 Results

Table 7 provides the results from estimating equation (7) for the full sample (column 1) and the sample of domestically owned firms only (column 2). We report average marginal effects instead of the parameter coefficients since the latter are less informative in terms of magnitude. We find a positive but statistically insignificant effect of $Horizontal$ on the likelihood of a firm to produce an HSP (column 1). Consequently, firms do not benefit from the presence of MNEs within their own industry in terms of product sophistication. This contradicts intra-industrial spillovers and hints at strong protection against technology leakage within an industry. In contrast, the effect of $Backward$ is positive and highly significant: This provides supportive evidence of positive vertical spillovers via supply chains. Specifically, an increase by 10 percentage points in foreign presence in downstream industries raises the likelihood of a firm to produce an HSP on average by 4%. Thus, while MNEs try to prevent spillovers to competitors, they have an incentive to transfer their knowledge to upstream local suppliers in order to receive highly sophisticated inputs. One concern is that the effect of $Horizontal$ could be flawed due to measurement error. If vertical and horizontal linkages are identified at the 2-digit industrial level, vertical linkages at the 4-digit level are potentially misclassified as horizontal linkages. This is the case if MNEs consume inputs from local suppliers that are located in a different industry at the 4-digit level but in fact belong to the same 2-digit industry as the multinational firm (Alfaro and Charlton, 2009). Since we observe a strong positive effect of vertical backward FDI spillovers at the 2-digit level, we would actually expect the coefficient of $Horizontal$ to be upward biased if the variable also covers vertical FDI at a more disaggregated level. Therefore, the effect of $Horizontal$ exclusive of vertical spillovers should be even smaller which strongly denies a horizontal spillover channel.

Interestingly, the effect of $Forward$ is negative and twice as large as the effect of backward spillovers. Firms that consume from industries with a 10 percentage points higher foreign presence have a 13% lower probability of manufacturing an HSP. At first glance, this seems counterintuitive given that access to better inputs from foreign firms is supposed to lead to more sophisticated outputs (Rodriguez-Clare, 1996). One explanation for the negative impact of $Forward$ is that intermediate inputs provided by multinational firms are probably not fit for use by local firms. If the technology gap between multinational firms and local Indian firms is too large, Indian firms are not able to successfully transform more sophisticated inputs

Table 7: Effect of FDI Spillovers on the Probability to Manufacture a HSP

HSP	(1) Probit	(2) Probit	(3) LPM	(4) LPM
Horizontal	0.00027 (0.00034)	0.00010 (0.00036)	0.00028 0.00040)	0.00008 (0.00042)
Backward	0.00424*** (0.00159)	0.00409** (0.00173)	0.00427** (0.00166)	0.00413** (0.00175)
Forward	–0.01310*** (0.00438)	–0.01171*** (0.00452)	–0.01534*** (0.00492)	–0.01380*** (0.00498)
LogTFP	0.01399*** (0.00208)	0.01392*** (0.00217)	0.00937*** (0.00299)	0.00910*** (0.00314)
ForeignShare	0.00002 (0.00009)	0.00019 (0.00030)	0.00002 (0.00010)	0.00029 (0.00032)
LogAge	0.03887*** (0.00345)	0.03202*** (0.00353)	0.03743*** (0.00312)	0.03056*** (0.00318)
HHI	–0.00000 (0.00002)	0.00000 (0.00002)	–0.00001 (0.00002)	–0.00000 (0.00002)
LogTFP*Forward			0.00233** (0.00100)	0.00236** (0.00107)
Observations	36,238	34,022	36,260	34,042
Time-FE	YES	YES	YES	YES
State-FE	YES	YES	YES	YES
Industry-FE	YES	YES	YES	YES
Sample	All firms	Domestic	All firms	Domestic
Pseudo R^2	0.253	0.252		
R^2			0.302	0.300

Columns 1and 2 provide average marginal effects from a pooled probit model. Columns 3 and 4 provide the coefficients from a pooled linear probability model including the interaction between *Forward* and *LogTFP*. Time, industry, and state fixed effects are included. Standard errors are clustered at the industry-year level. ***, **, and * denote significance at 0.01, 0.05, and 0.10 levels, respectively.

into more sophisticated outputs. The crowding-out effect is aggravated if intermediate inputs from multinational firms replace other inputs. In that case, local Indian firms do not have access to suitable inputs anymore and cease the production of sophisticated final goods. A second explanation for the negative impact of $Forward$ is that MNEs strategically might try to prevent local firms from accessing their inputs: MNEs that have offshored intermediate stages of production to an Indian firm in order to access inputs at a lower cost may induce the Indian firm to charge a mark-up for its input to local competitors.[13]

The average marginal effect of $ForeignShare$ is positive as expected but insignificant. The weak influence of foreign intra-firm presence is counterintuitive but could be due to the presence of cost-saving FDI motives. Foreign investors that have cost-saving motives in mind invest abroad in order to produce less sophisticated, intermediate products at a lower cost which are then exported back to the home country of the investor. This could reduce the positive effects that are usually associated with foreign presence within a firm. Cost-saving motives of FDI do not contradict positive backward spillovers, though. A downstream multinational textile firm still requires highly sophisticated textile machines from local suppliers even though it produces a less sophisticated output (e.g. t-shirts). The other firm-level covariates have the expected

[13] See e.g. Bartels, Buckley, and Mariano (2009) and Harrison and Rodríguez-Clare (2010) for a description on strategic firm behaviour in complex, global production systems.

effect on HSP manufacturing: older and more productive firms are more likely to produce an HSP. For example, an increase in $LogTFP$ by 10% increases a firm's probability to produce an HSP by 14%. A higher industry concentration is associated with a lower probability of manufacturing an HSP, but the effect is not significantly different from zero.

Comparing the results for all firms and domestic firms only (column 2), we find that the marginal effects are very similar in magnitude. This finding supports our guess that spillover effects seem to be mainly driven by domestically owned firms which should react more strongly to the presence of MNEs.

In columns 3 and 4, we include an interaction term between $Forward$ and $LogTFP$ to test whether spillovers through forward linkages depend on a firm's productivity level. As Carluccio and Fally (2013) argue, more productive firms are better able to adopt foreign inputs into their production process and are thus less harmed by the presence of multinational firms. In order to interpret the interaction term, we neglect the binary nature of our dependent variable and use a linear probability model instead. The interaction term is indeed positive and highly significant whereas the base effect of $Forward$ remains negative. This supports the notion that the effect of access to foreign inputs depends on a firm's productivity level. The more productive the firm, the less it is affected by the technology gap to foreign multinationals. In terms of magnitude, the positive effect from a 1% increase in productivity outweighs the negative impact of a 1 percentage point higher presence of multinational suppliers. Thus, very productive firms actually benefit from access to inputs from multinational upstream firms.

5.2 Extent of Product Sophistication

5.2.1 Estimation Strategy

By classifying firms into HSP and non-HSP manufacturers, we face two limitations. First, we do not observe continuous sophistication upgrades by firms. FDI and its spillover effects may not only induce firms to produce one product of the top of the sophistication distribution, but also to gradually upgrade their production from less to more sophisticated products. As Goldberg et al. (2010) note, product churning in India is lower than in other countries, probably due to industrial licensing and rigid labor market regulations. This, however, does not prevent firms from adjusting the sales share of their product mix. Therefore, we expect to see more variation in the average sophistication level of all products a firm produces. Second, in the above analysis we could not control for unobserved factors that could drive both the decision of a firm whether to produce an HSP and the location decision of foreign investors, such as firm specific effects. The effect of $Backward$, e.g., is upward biased if multinational firms decide to locate in industries which predominantly consume from firms that have a high management quality and thus produce more sophisticated products. To take both concerns into account, we test for spillover effects on gradual sophistication upgrading ($LogEXS_{it}$) and control for firm fixed effects (α_i):

$$\begin{aligned} LogEXS_{ijst} = & \alpha_0 + \beta_1 Horizontal_{jt} + \beta_2 Backward_{jt} + \beta_3 Forward_{jt} + \gamma_1 LogTFP_{ijst} \\ & + \gamma_2 ForeignShare_{ijst} + \gamma_3 LogAge_{ijst} \\ & + \delta HHI_{jt} + \alpha_t + \alpha_i + \epsilon_{ijst}. \end{aligned} \tag{8}$$

Another concern is that idiosyncratic shocks can stimulate a firm's capability to manufacture more sophisticated products. If multinationals tend to locate close to firms experiencing such a shock in order to gain access to better inputs or to realize increased selling opportunities, the effects of our spillover measures are also biased. However, it is unlikely that multinationals are able to react to short term shocks experienced by Indian firms given that foreign investment usually involves tedious preparation and high transaction costs and fees (Blalock and Gertler, 2008). To take the within-industry correlation into account, we estimate all specifications with industry-time clustered standard errors (Moulton, 1990).[14]

5.2.2 Results

Table 8 reports the corresponding results from estimating equation (8). In line with our previous results, we find that backward linkages strongly foster the manufacturing of more sophisticated products. An increase in the presence of multinational downstream firms by 1 percentage points increases the average product sophistication level of a firm by 1,6% (columns 1 and 2). Likewise, a higher presence of multinational suppliers, $Forward$, induces a significantly negative effect on average product sophistication. A 1 percentage point increase in upstream foreign presence reduces average firm product sophistication in downstream industries by 3,2–3,6%. As before, there is no evidence for intra-industry spillovers. Moreover, we confirm that more productive firms manufacture more sophisticated products on average. A 1% increase in firm productivity leads on average to a 13% rise in firm product sophistication. In contrast to the results above, we do not observe a heterogenous effect for more productive firms. The interaction term between $LogTFP$ and $Forward$ is positive but insignificant (columns 3 and 4). Surprisingly, the estimated coefficient of $LogAge$ turns negative. Albeit the probability of producing an HSP is higher for older firms, it is predominantly younger firms that have a higher sophistication level on average. As above, the extent of industry concentration does not affect product sophistication.

In addition, we apply a model in first and second differences as a robustness check. The fixed-effects approach is more efficient under the assumption that the idiosyncratic errors ϵ_{ijst} are serially uncorrelated, while the differences approach is more efficient when ϵ_{ijst} follows a random walk. We follow Haskel et al. (2007) and additioanlly include industry, and state fixed effects ($\alpha_j + \alpha_s$). Industry and state fixed effects account for a different average level of product sophistication across industries. This allows us to control for the fact that foreign investors gra-

[14] We also experimented with block-bootstrap techniques (Cameron, Gelbach, and Miller, 2008). The results do not differ significantly.

vitate towards industries that are supplied by or sell to industries with an increasing level of product sophistication. The identification of β_1 to β_3 then comes from the deviation of within-industry changes in spillovers from the respective year and industry means.

The results stay qualitatively the same. $Backward$ induces a highly significant and positive effect on the average product sophistication of a firm. The magnitude of the effect increases slightly to 2,1–2,3% for the full sample of firms (columns 5 and 7) and 1,8–1,9% for the sample of domestic firms (columns 6 and 8). A notable difference to our previous results is the highly significant and negative effect of $Horizontal$ when applying the model in second differences (columns 7 and 8). Consequently, if we allow for a longer time horizon we observe that firms in industries with a high presence of multinational investors produce on average less sophisticated products than firms in industries with a lower presence. This result clearly points to within-industry crowding out effects by competition from multinational companies. Since multinational firms usually tend to be not only more skill-intensive but also more productive, they crowd out less efficient Indian firms which are prevented from product upgrading. A second difference is that the significant negative effect of vertical forward linkages vanishes.

Summing up, our findings provide evidence of strong spillovers between local firms and MNEs through vertical backward linkages. Contact to multinational downstream firms enables Indian firms to produce a top sophisticated product and it also fosters gradual sophistication upgrading. In contrast, contact to multinational suppliers negatively affects the manufacturing of top / more sophisticated products but the results are less robust across different specifications. We do not find evidence of positive spillover effects through horizontal linkages. If we allow for a longer time horizon, intra-industry presence of MNEs prevents firms from producing more sophisticated products.

5.2.3 Robustness Checks

We next perform a series of robustness checks to test the sensitivity of our main results. In doing so, we rely on our prefered specification including firm fixed effects (column 1 in Table 8). The first set of robustness checks considers the measurement of product sophistication via the sophistication index by Hausmann et al. (2007). Recall that $SOPH$ is a time constant measure of product sophistication since we employ time-averaged values of GDP per capita and export shares for each country. This is a rather conservative approach since it reduces the variation in our dependent variable $LogEXS$. Changes in firm product sophistication can only stem from a reallocation in the firm's product mix and not from a change in sophistication ranking of products over time. If e.g. a productivity shock allows poorer countries to produce more sophisticated products, the sophistication ranking would change. Likewise, the ranking changes if poorer countries become richer due to the production of more sophisticated products. To test whether our results are robust to a time-varying sophistication ranking, we calculate three different versions of $SOPH$. Version 1 is most flexible in the sense that both the GDP per capita levels and country-wise export shares vary over time. In version 2, GDP per capita varies but

Table 8: Effect of FDI Spillovers on the Extent of Sophistication

LogEXS	(1) FE	(2) FE	(3) FE	(4) FE	(5) First Dif.	(6) First Dif.	(7) Second Dif.	(8) Second Dif.
Horizontal	–0.0024	–0.0025	–0.0024	–0.0025	–0.0033	–0.0038	–0.0069***	–0.0078***
	(0.0032)	(0.0036)	(0.0032)	(0.0036)	(0.0023)	(0.0025)	(0.0022)	(0.0024)
Backward	0.0156***	0.0162***	0.0160***	0.0168***	0.0210***	0.0180***	0.0232***	0.0188**
	(0.0049)	(0.0053)	(0.0048)	(0.0053)	(0.0065)	(0.0066)	(0.0072)	(0.0075)
Forward	–0.0318***	–0.0358***	–0.0380***	–0.0415***	–0.0127	–0.0106	–0.0236	–0.0210
	(0.0105)	(0.0111)	(0.0121)	(0.0126)	(0.0174)	(0.0185)	(0.0146)	(0.0153)
LogTFP	0.1288***	0.1299***	0.1113***	0.1120***	0.0683*	0.0841**	–0.0385	–0.0379
	(0.0118)	(0.0119)	(0.0146)	(0.0147)	(0.0347)	(0.0373)	(0.0319)	(0.0333)
ForeignShare	0.0006	0.0020	0.0005	0.0019	0.0006	0.0018	0.0013	0.0037*
	(0.0006)	(0.0013)	(0.0006)	(0.0013)	(0.0005)	(0.0011)	(0.0008)	(0.0019)
LogAge	–0.0578*	–0.0638**	–0.0545*	–0.0603*	0.0379	0.0239	0.0403	0.0451
	(0.0299)	(0.0319)	(0.0301)	(0.0321)	(0.0658)	(0.0666)	(0.0522)	(0.0525)
HHI	–0.0001	–0.0001	–0.0001	–0.0001	–0.0001	–0.0001	–0.0001	–0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
LogTFP*Forward			0.0087	0.0089				
			(0.0057)	(0.0059)				
Observations	36,259	34,041	36,259	34,041	29,422	27,612	23,430	21,981
Time-FE	YES	YES	YES	YES	YES	YES	YES	YES
Firm-FE	YES	YES	YES	YES	–	–	–	–
Industry-FE	–	–	–	–	YES	YES	YES	YES
State-FE	–	–	–	–	YES	YES	YES	YES
Sample	Allfirms	Domestic	Allfirms	Domestic	Allfirms	Domestic	Allfirms	Domestic
Adj.R^2	0.0189	0.0196	0.0193	0.0199	0.00201	0.00238	0.00359	0.00383

Columns 1 to 4 provide coefficients from a firm fixed effects model. Columns 5 and 6 provide the coefficients from estimations in first differences and columns 7 and 8 in seccond differences. Time, industry and state fixed effects are included in columns 1 to 8, but are dropped in columns 1–4 due to collinearity to the firm fixed effects, denoted by "–". Standard errors are clustered at the industry-year level. ***, **, and * denote significance at 0.01, 0.05, and 0.10 levels, respectively.

export shares are kept constant and vice versa in version 3. Table 9, columns 1 to 3 provide the corresponding results for each version. Briefly, we find that our main results are robust to different measurements of $SOPH$.

Since the use of the sophistication index by Hausmann et al. (2007) may seem rather restrictive, we additionally calculate product sophistication using the sophistication index SI developed by Lall, Weiss, and Zhang (2006). The basic concept of SI is similar to Hausmann et al. (2007) since the sophistication level of a product is also derived from the income of its exporters. It differs in the sense that it divides countries into 10 income groups according to their GDP per capita and then uses the average GDP per capita and the average export share of each income group to calculate SI.[15] This has the advantage that outlier countries receive less weight in the calculation of the index. The results, shown in column 4 of table 9, remain basically unchanged.

The second set of robustness check regards the calculation of our spillover measures. $Horizontal$, $Backward$, and $Forward$ hinge on the definition of the share of equity held by foreign investors. Since information on the foreign equity share is available for publicly listed firms only, we assume that firms denoted as Indian owned by Prowess have a foreign equity share of 0% and firms classified as foreign-owned are foreign-owned by 100%. To test the restrictiveness of this assumption, we vary ownership thresholds and calculate alternative spillover measures. In the first version, we assume that firms that are denoted to be foreign-owned are foreign-owned by 50% instead of 100%. In the second version, we set this threshold to 10%. Finally in version 3, we only use the information on foreign equity shares of publicly listed firms. The three linkage variables thus exclusively capture spillovers from publicly listed multinationals. Note that in this version, we do not include the equity share of foreign owners as a control variable since we would lose all observations from unlisted firms. The results are displayed in Table 9 columns 5–7. The point estimates of our spillover variables change only slightly when we alter the method of calculating the spillover measures. However, the estimates become less significant since the precision of the estimates decreases (columns 6 and 7). In column 7, e.g., the variation in the spillover variables is smallest since we only use information from the subset of publicly listed firms to calculate the spillover variables.

Thirdly, we check whether the recent global financial crisis impacts our results. In column 8 of Table 9, we only consider the years from 2001 to 2007 predeceeding the great downturn in GDP and trade. Again, the resulting point estimates do not differ much.

Fourthly, we control for downstream demand of intermediate inputs as suggested by Javorcik (2004). A higher presence of multinational downstream firms can lead to a stronger demand for intermediate inputs supplied by an industry which would be captured in $Backward$ and flaw the effect of supply chain linkages. We therefore include $Demand_{jt}$ which captures the demand of

[15] For a more detailed description of how the index is calculated, please refer to Lall et al. (2006).

downstream industries for intermediate inputs supplied by industry j in each year.[16] As column 9 in Table 9 shows, backward spillovers are not driven by pure demand effects.

Fifthly, in addition to the downstream demand of intermediate inputs in column 9, we consider the financial situation of a firm ($LiqRatio$). We expect more liquid firms to produce more sophisticated products on average since they can better cover higher investment costs. We thus re-estimate our main specification controlling for the liquidity ratio of the firm. $LiqRatio$ is defined as the ratio of current assets less current liabilities over total assets. Since we are worried that reverse causality may run from product sophistication to the financial situation, we include the variable lagged by one period in order to mitigate this problem. Results reveal that controlling for this effect does not greatly change our main findings (column 10).

Sixthly, the effect of spillovers on product sophistication might be driven by certain groups of firms, e.g. firms in the coke and petroleum industry. Due to the construction of the index, products belonging to this industry tend to receive a high sophistication level since petrol exporting countries tend to have a high GDP per capita. However, this does not necessarily reflect a high product technology or sophistication level but is simply endowment-driven. If multinationals tend to locate in India in order to benefit from cheaper access to petrol from Indian suppliers, the positive effect of $Backward$ would not only reflect knowledge spillovers, but also cost saving motives. To rule this out, we re-estimate our main specification excluding firms belonging to the petrol and coke industry. As suggested in column 11 of table 9, our results are basically unchanged in terms of magnitude and significance when excluding petrol and coke producing firms.

Finally, Blalock and Gertler (2008) raise the concern that spillover effects could be mainly driven by exporting firms. Multinational firms probably tend to choose local suppliers that also sell their products to foreign markets assuming that this reflects a higher quality of the goods sold by these firms. Firms that have access to export markets are also more likely to invest in the production of more sophisticated products since they benefit from larger sales opportunities. In order to rule out bias from exporting firms, we re-estimate our main specification with non-exporting firms only. As non-exporting firms, we consider those that sell less than 10% of their sales abroad. Column 12 confirms that our main results hold. We observe a slightly stronger effect of spillovers through supply chain linkages which is plausible since firms without contact to international markets should benefit in particular from the presence of foreign knowledge. In addition to the specifications of Table 9, we ran all regressions with domestic firms only. The results are robust and not displayed here, but are available upon request.

[16] $Demand_{jt}$ for inputs from industry j in time t is calculated as the sum of input requirements of downstream industries k: $Demand_{jt} = \sum_k a_{jk} Y_{kt}$, where a_{jk} gives the number of units from input j that are needed in order to produce one unit of downstream good k. a_{jk} is taken out of the input-output tables. Y_{kt} denotes the output of industry k.

Table 9: Effect of FDI Spillovers on the Extent of Sophistication – Robusness Checks

LogEXS Version	(1) SOPH V.1	(2) SOPH V.2	(3) SOPH V.3	(4) SI-Lall	(5) Foreign 50%	(6) Foreign 10%	(7) Publ.firms	(8) $t < 2008$	(9) Demand	(10) LiqRatio	(11) no coke	(12) no exporter
Horizontal	–0.0015	–0.0019	–0.0017	–0.0013	–0.0056	–0.009*	–0.008*	–0.0031	–0.0020	–0.0014	–0.0023	–0.0043
	(0.0034)	(0.0032)	(0.0034)	(0.0033)	(0.0050)	(0.005)	(0.005)	(0.0032)	(0.0031)	(0.0032)	(0.0032)	(0.0043)
Backward	0.0140**	0.0140***	0.0144**	0.0113**	0.0199***	0.018	0.016	0.0176***	0.0159***	0.0160***	0.0161***	0.0170**
	(0.0064)	(0.0049)	(0.0064)	(0.0045)	(0.0075)	(0.012)	(0.013)	(0.0065)	(0.0049)	(0.0048)	(0.0049)	(0.0069)
Forward	–0.0404***	–0.0344***	–0.0320**	–0.0079	–0.0392***	–0.042***	–0.038**	–0.0205*	–0.0295***	–0.0268**	–0.0160	–0.0265*
	(0.0144)	(0.0104)	(0.0143)	(0.0100)	(0.0137)	(0.015)	(0.015)	(0.0115)	(0.0106)	(0.0105)	(0.0103)	(0.0154)
LogTFP	0.1310***	0.1268***	0.1334***	0.1239***	0.1291***	0.129***	0.129***	0.1285***	0.1291***	0.1292***	0.1172***	0.1546***
	(0.0125)	(0.0125)	(0.0126)	(0.0123)	(0.0125)	(0.012)	(0.012)	(0.0162)	(0.0125)	(0.0153)	(0.0126)	(0.0158)
ForeignShare	0.0006	0.0005	0.0006	0.0004	0.0007	0.001		0.0009	0.0006	0.0005	0.0006	0.0025**
	(0.0006)	(0.0005)	(0.0006)	(0.0005)	(0.0007)	(0.001)		(0.0007)	(0.0005)	(0.0005)	(0.0005)	(0.0011)
LogAge	–0.0363	–0.0503*	–0.0451	–0.0768***	–0.0600**	–0.061**	–0.061**	–0.0606*	–0.0586**	–0.0243	–0.0587**	–0.0877***
	(0.0302)	(0.0273)	(0.0300)	(0.0260)	(0.0273)	(0.027)	(0.027)	(0.0350)	(0.0274)	(0.0358)	(0.0275)	(0.0335)
HHI	–0.0001	–0.0001	–0.0001	–0.0001	–0.0001	–0.000	–0.000	–0.0002	–0.0001	–0.0001	–0.0001	–0.0002**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.000)	(0.000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Demand									–0.0000	–0.0000		
									(0.0000)	(0.0000)		
L.LiqRatio										0.0351		
										(0.0431)		
Observations	37,478	37,478	37,478	37,478	37,478	37,478	37,478	26,650	37,478	33,773	37,109	23,036
Time-FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm-FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Adj. R^2	0.0193	0.0198	0.0197	0.0181	0.0191	0.0187	0.0187	0.0170	0.0187	0.0181	0.0188	0.0283

Standard errors are clustered at the industry-year level. ***, **, and * denote significance at 0.01, 0.05, and 0.10 levels, respectively.

5.2.4 Comparative Statics

Our results suggest that the effect of FDI spillovers on average product sophistication strongly depends on the channel through which spillovers are transmitted. Even though the presence of MNEs generates a positive spillover effect to upstream industries it can also entail a negative crowding out effect to downstream firms. This leads to the question in which industries the attraction of FDI is most beneficial. Intuitively, this are downstream industries which create strong backward linkages that compensate for negative vertical forward effects from multinational suppliers in upstream industries. To identify industries of this type, we perform a comparative statics analysis in the following four-step-procedure. We first calculate the predicted values of firm product sophistication in one specific year, $t = 2010$, using the regression specification in column 1, Table 8. These values serve as our benchmark, $\widehat{LogEXS}^{base}_{ij2010}$. We then artificially increase $ForeignShare$, the foreign equity share, of all firms in one particular industry l by 10 percentage points in $t = 2010$. This leads to a change in the three spillover variables $Horizontal_{j2010}$, $Backward_{j2010}$, and $Forward_{j2010}$ which we recalculate. Next, we calculate $\widehat{LogEXS}^{counter}_{ij2010}$, the predicted change in firm product sophistication due to the change in foreign presence. To do so, we use the new levels of our spillover variables and the coefficients from column 1, Table 8. Finally, we determine for all industries the net change in product sophistication that stems from a change in industry l:

$$\Delta\widehat{LogEXS}_{j2010} = (\widehat{LogEXS}^{counter}_{ij2010} - \widehat{LogEXS}^{base}_{ij2010}) \cdot 100. \tag{9}$$

$\Delta\widehat{LogEXS}_{j2010}$ takes the same value for all firms in industry j since we increase FDI in all firms equally in industry l. These four steps are then iterated for each industry.

Column 1 of Table 10, reports $\Delta\widehat{LogEXS}_{lj2010}$, the predicted net change in product sophistication in each industry j that results from a 10 percentage points increase in FDI in industry $l = 1$ (basic metals). An estimate of –10.7 (column 1, row 3) implies that an increase in FDI by 10 percentage points in the basic metals industry leads to a 10.7% decrease in firm product sophistication in the machinery industry. On the diagonal, the within-industry changes are displayed. A 10 percentage points increase in FDI leads to a 1.82% decrease in product sophistication within the same industry. This is a composite effect of the horizontal spillover ($\hat{\beta}_1 = -0.0024$, Table 8 column 1) and the firms' foreign equity share ($\hat{\gamma}_3 = 0.0006$). Generally, an increase of FDI in more downstream industries, like e.g. the motor vehicles and transport equipment industries, leads to an increase of firm product sophistication in almost all other industries. Increasing FDI in more upstream industries like basic metals and plastics slows down product sophistication growth in almost all industries.

This comparative static can be seen as an exercise and visualization of how to detect industries wherein the presence of MNEs works best for the technological upgrading of a country. However, in order to derive clear policy advice, a more complex general equilibrium model would have to be calibrated which is beyond the scope of this analysis.

Table 10: Comparative statics – Effect of a 10 perecentage points increase in FDI on net change in product sophistication growth

$\Delta Log\widehat{EXS}_{lj2010}$ in industry j	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) Basic metals(C27)	–1.82	–.038	1.78	–1.27	.684	–.526	–.029	.023	–.01	.787	1.6	–.104	.143	.467
(2) Plastics(C25)	–.284	–1.82	.298	–.686	.107	–12.5	.414	.459	–.062	.834	.709	.411	.18	.487
(3) Machinery(C29)	–10.7	–.359	–1.82	–.421	–1.05	–.169	.465	–.285	.752	.447	.213	–.247	.149	1.23
(4) Coke/petroleum(C23)	.572	.047	.075	–1.82	.04	.548	.169	.008	.225	.08	.058	.379	.028	.046
(5) Fab. metal products(C28)	–16.6	–.476	.495	–.437	–1.82	–.721	.031	–.243	.028	.909	.818	–.012	.413	1.48
(6) Chemicals(C24)	0	.639	–.206	–2.28	.022	–1.82	–.886	–.1	.503	.142	.331	–.014	.09	.074
(7) Food products(C15,16)	.018	–.204	–.298	–.381	–.017	.796	–1.82	–.034	–.01	–.011	.037	.001	–.001	.004
(8) Manufact./Recycling(C36,37)	–.898	–.858	–.388	–.16	–.242	–1.16	.038	–1.82	–.016	–1.25	.095	–.065	.143	.111
(9) Textiles(C17,18,19)	–.02	–.107	–.719	–.651	–.037	–2.23	.133	–.121	–1.82	.119	.157	.049	.028	.136
(10) Office machineries(C30,32,33)	–4.26	–.631	–1.03	–.293	–.778	–.978	.022	.106	–.113	–1.82	–1.26	–.366	.053	.318
(11) Electrical machinery(C31)	–10.8	–.672	–.766	–.269	–1.02	–1.88	–.049	–.425	–.193	.638	–1.82	–.167	–.026	.385
(12) Non–metallic minerals(C26)	–.665	–.796	–.018	–3.24	–.107	–.984	–.032	–.169	–.157	.182	.069	–1.82	.005	.008
(13) Transport equipment(C35)	–5.49	–.666	–1.16	–.435	–1.43	–1.68	.01	–1.17	–.12	–.56	–.076	–.118	–1.82	–.386
(14) Motor vehicles(C34)	–5.2	–.769	–3.08	–.346	–2.26	–.716	.048	–.33	–.242	–.952	–.734	–.069	.169	–1.82

This table depicts the net change in product sophistication in each industry that results from an increase in $ForeignShare$ by 10 percentage points in each industry.

6 Conclusion

In this paper, we have shown that knowledge spillovers from MNE to local firms can greatly impact on product sophistication in India. Local firms benefit the most from contact to multinational customers since downstream firms have a higher incentive to transfer their knowledge and technologies to upstream suppliers than to rivals in the same industry. In contrast, a higher presence of multinational upstream firms can lead to a crowding out effect so that less firms manufacture top sophisticated products in downstream industries. Indian firms are probably not able to integrate inputs from MNE into their production process and are driven out of the production of more sophisticated final goods. Therefore, policies should aim at attracting multinational downstream firms in order to foster the structural transformation process from producing less to more sophisticated products.

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Appendix

Following Griffith et al. (2009), the level of $LogTFP$ can be calculated as:

$$LogTFP_{it} = Log(Y_{it}/\overline{Y}_j) - \sum_{z=1}^{Z} \sigma_i^z Log(x_{it}^z/\overline{x}_j^z),$$

where i, j, and t are firm-, industry-, and time-specific subscripts. Y_{it} is the output of firm i in year t in form of total sales and $\overline{Y}_j$ is the corresponding geometric mean in industry j. x_{it}^z denotes the use of factor z. We consider three factors of production, labor, capital, and material input costs. Labour input is measure by the total wage bill, capital by gross fixed assets, and material input costs by raw material expenditures. $\overline{x}_j^z$ captures the industry-wise geometric mean of each factor. $\sigma_i^z = (\alpha_i^z + \overline{\alpha}_j^z)/2$, where α_i^z is the share of the factor z in output. σ_i^z captures the average of the factor share in each firm i and the geometric mean factor share of the corresponding industry j. Similarly, total factor productivity growth $\Delta LogTFP_{it}$ is given by

$$\Delta LogTFP_{it} = \Delta LogY_{it} - \sum_{z=1}^{Z} \tilde{\alpha}_{it}^z \Delta Log(x_{it}^z),$$

where $\tilde{\alpha}_{it}^z = (\alpha_{it}^z + \alpha_{it-1}^z)/2$. The superlative index number approach assumes constant returns to scale which requires $\sum_z \sigma_i^z = 1$ and $\sum_z \tilde{\alpha}_{it}^z = 1$.

Industry correspondence

Table A.1: Correspondence between ISIC Rev. 4 and ISIC Rev. 3 for manufacturing industries

ISIC Rev. 4 (2-digit) Code	Manufacture of	ISIC Rev. 3 (2-digit) Code	Name	I-O cat.	% firms
10	Food products	15	Food products, beverages		
11	Beverages	15	Food products, beverages	C15,16	12.3
12	Tobacco products	16	Tobacco		
13	Textiles	17	Textiles		
14	Wearing apparel	18	Textile products	C17,18,19	13.6
15	Leather and related products	19	Leather and footwear		
16	Wood, wood and cork products, exc. furniture	20	Wood and products of wood and cork	C20	0
17	Paper and paper products	21	Pulp, paper, paper products	C21,22	0
18	Printing and reproduction of recorded media	22	Printing and publishing		
19	Coke and refined petroleum products	23	Coke, refined petroleum, nuclear fuel	C23	1.0
20	Chemicals and chemical products	24	Chemicals and chemical products	C24	21.6
21	Pharmaceuticals, medic., chem., and botan. products	24	Chemicals and chemical products		
22	Rubber and plastics products	25	Rubber and plastics products	C25	6.9
23	Other non-metallic mineral products	26	Other non-metallic mineral products	C26	4.4
24	Basic metals	27	Basic metals	C27	11.3
25	Fabricated metal products, exc. machinery and equipment	28	Fabricated metal products exc. machinery and equipmen	C28	3.7
26	Computer, electronic and optical products	30	Office, accounting and computing machinery	C30	
		32	Radio, television and communication equipment	C32	3.9
		33	Medical, precision and optical instruments	C33	
27 (exc. 2570)	Electrical equipment	31	Electrical machinery and apparatus n.e.c	C31	4.5
2750	Domestic appliances	29	Machinery and equipment n.e.c	C29	7.4
28	Machinery and equipment n.e.c.	29			
29	Motor vehicles, trailers and semi-trailers	34	Motor vehicles, trailers and semi-trailers	C34	0.3
30	Other transport equipment	35	Other transport equipment	C35	7.2
31	Furniture	36	Manufacturing n.e.c		
32	Other manufacturing	36		C36,37	1.9
33	Repair and installation of machinery and equipment	37	Recycling		
Total					100

The industries captured by the OECD input-output tables are based on 23 2-digit ISCI Rev. 3 categories but have already been aggregated to 18 industries. From the 18 industries defined in the OECD input-output tables, we combined industries C30, C32, and C33 into one industry since these three industries correspond to one ISIC Rev.4 industry (code 26).

Description of the product classification

Table A.2: Example of reclassification from CMIE codes to SITC categories

CMIE product code	Name of products	3-digit	SITC description
14040501000000000000	Conveyor systems Conveyors Crusher Feed Conveyor Discharge Conveyor	744	Mechanical handling equipment, and parts thereof, n.e.s.
69907080100000000000	Fishing net Fish net Fish Knitted Fabrics Fishnet Fabrics	657	Special yarns, special textile fabrics and related products

In the database, product names as reported by the firms are assigned a 20-digit code based on an internal classification system by CMIE. In fact, one product code is usually linked to several different product names in the database. We first standardize product names according to their internal code. Since we are only interested in the products a firm actually manufactures, we delete product codes that refer to retail trading activities, rental income and other services performed. In doing so, we eliminate 316 different products. We next allocate each product code to the corresponding SITC 3-digit category in order to determine the sophistication level of a product. This task was performed manually by a research assistant. We double checked the reclassification and sorted out inconsistencies. Table A.2 provides an example of the concordance between the 20-digit internal code and the SITC Rev.3 classification. Product names often differ in spelling (Fishing net vs. Fish net) or are more or less precise (Conveyors vs. Discharge Conveyor). We manage to classify 82% of all firm-product-year observations in our subsample at the 3-digit level. These account for 88% of total product output. For the remaining share of 12% of total output, we cannot determine the corresponding concordance because sufficient information on the type of the product is not available. Assigning products to the 4- or 5-digit level would certainly be more satisfactory and better reflect single products compared to a more aggregate classification. However, given that we only observe the often rather uninformative names of the products, this is infeasible without sacrificing the precision of our concordance.