FDI, Forward Linkages and Services Inputs

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Abstract

This paper provides evidence of spillover effects from foreign direct investment (FDI) through forward linkages, a relatively neglected channel to enhance national competitiveness that is likely to become more important as countries seek to bolster domestic competitiveness and resilience to geo-economic shocks. Using granular information on the universe of firm-to-firm transactions and inward FDI in Rwanda, we find substantial and persistent effects on value-added, employment, and productivity of domestic firms after beginning to source from foreign-owned enterprises. These effects are more pervasive than those associated with selling to foreign-owned firms – the backward linkages emphasised in the literature. Suggestive evidence reveals that foreign-owned firms provide higher-quality intermediate inputs than domestic suppliers, particularly in specialized business and professional services that are difficult to import, and that these inputs complement rather than crowd out domestically sourced inputs.

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1 Introduction

Foreign Direct Investments (FDI) are widely considered to benefit host countries through a variety of channels, including greater competition, higher quality, lower priced or new goods and services that are produced by foreign firms, creation of job opportunities and demand for skilled workers (Javorcik 2015; Alfaro 2017). Benefits from FDI may be particularly large when foreign firms establish linkages with domestic firms, as such relationships raise the possibility for transfers of knowledge and technology. The value of such linkages has long been recognised in the literature. Hirschman (1958) defined *backward* linkages as demand by downstream sectors for specific inputs required for production. He distinguished these from *forward* linkages involving the supply by upstream firms that could be utilized by domestic firms downstream in new ways. The former can be characterized as a demand pull factor, the latter as a supply push factor for local industrial development.

In this paper, we focus on the effects of forward linkages on domestic firms in Rwanda, a small land-locked country in Sub-Saharan Africa that has actively promoted inward FDI and experienced a surge in foreign investment in the past decade. Although Rwanda is a member of a common market, the East African Community (EAC), its land-locked geography and lack of connections to deep-water ports implies that it is a less attractive candidate for export-oriented investment in manufacturing industries that the literature has associated with the presence of backward linkages.[1] Instead, most FDI is intended to access local and regional (EAC) markets, taking advantage of Rwanda's attractive and stable domestic business environment. We show that this kind of investment is prevalent in the country, and that it is likely to generate benefits to domestic firms located downstream via forward linkages, rather than via backward linkages.

Backward linkages have long been central to development strategies—first through import-substitution and local-content approaches and later through policies aimed at attracting FDI and fostering domestic supplier upgrading. Backward linkages are also relatively straightforward to conceptualize and measure because they reflect multinationals' procurement and thus a clear demand channel for domestic upstream firms. Forward linkages, by contrast, can be broader in scope—potentially affecting many downstream sectors through access to new inputs, higher quality, or improved reliability—but their effects are often more heterogeneous, since they depend on downstream firms' capacity and choices to adopt, adapt, and expand production (Hirschman 1958). This distinction is reflected in the empirical literature on FDI spillovers: while evidence on gains from becoming suppliers of multinationals (backward linkages) is substantial (e.g., Amiti et al. 2024; Alfaro-Urena et al. 2022), the effects of sourcing from foreign firms (forward linkages) have received less attention (Garetto

[1]The few export-oriented FDI projects in Rwanda focus on commodities – including tin, tungsten, niobium, coffee – or services. Exporting services is an element of Rwanda's development strategy, reflected in support for investment in tourism and conference and convention facilities that target the global market (RDB 2014).

et al. 2025), in part because evidence suggests that spillovers to suppliers tend to be economically sizeable whereas spillovers to buyers are smaller on average.[2] In this paper we show that in the case of economies that face constraints on the availability of intermediate inputs in domestic markets, forward linkages can be the dominant channel through which foreign investment can lead to domestic growth and development. This insight may also prove valuable against the backdrop of geopolitical tensions and policy-driven geo-economic fragmentation. As governments increasingly pursue "economic security" objectives that emphasize resilience and domestic capacity in strategic sectors, understanding whether and when access to foreign-provided inputs translates into downstream performance gains is of broader interest beyond the development context.

One important reason to focus on forward linkages in a low-income country like Rwanda is that channels for FDI spillovers are influenced by country contexts and the motivation of foreign investors. If foreign investments are motivated by selling into local or regional markets (so-called *market-seeking* FDI), foreign firms may build different relationships with local suppliers and customers than if FDI is export-oriented, or more generally motivated by the availability of local input factors such as cheap labour. Such *efficiency-seeking* FDI may be associated with incentives to create relationships with local suppliers and share – tacitly or explicitly – knowledge to improve suppliers' performance so as to reduce production costs. Such relationships are well documented in the cases of export oriented emerging economies, where domestic firms take advantage of connections to foreign firms that establish production facilities to export and participate in global value chains (Amendolagine et al. 2019; Alfaro-Urena et al. 2022). In contrast, market-seeking FDI is mainly concerned with meeting local demand for products and services, some of which will be intermediate inputs. Analogous to the literature emphasizing the positive effects of input trade liberalization in which products that were previously unavailable in the local markets, of inferior quality and/or higher cost become more readily available or cheaper (e.g., De Loecker and Goldberg 2014), FDI is an instrument through which similar mechanisms may apply. If so, market seeking FDI may generate knowledge spillovers that improve the performance of domestic firms that buy intermediate inputs from foreign-owned firms.

Forward linkages are particularly relevant to access services, including those typically used as inputs by other firms. Some production services, e.g. financial services, ICT, consulting, logistics or other business services, are unlikely to be provided locally at international standards. Such services inputs may be particularly important for economic performance (Arnold et al. 2011; Bloom et al. 2013; Hjort and Poulsen 2019; Bijnens et al. 2025). The trade literature has documented that FDI is an important "mode of supply" for firms to provide services to foreign clients. The intangibility and nonstorability of many services implies there is "proximity burden" requiring seller and buyer (provider and consumer) to be in the same place (Francois and Hoekman 2010). FDI in services is therefore often market seeking

[2]See for instance Javorcik (2004), Havranek and Irsova (2011), Damijan et al. (2013) and Jude (2016).

in nature (Kolstad and Villanger 2008). Even if the proximity constraint is not binding, e.g., because a service can be supplied digitally, firms may prefer to establish a local presence in the market for business reasons.[3]

In addition to providing an ideal setting to study forward linkages associated with FDI, Rwanda offers a rich set of information sources that are needed for our analysis. We take advantage of data on the universe of B2B transactions based on VAT declarations provided by the Rwanda Revenue Authority (RRA). These data are matched with registries listing inward foreign investors provided by the Rwanda Development Board (RDB), the national investment promotion agency, using a common anonymized tax ID. This permits us to identify all transactions involving domestic and foreign firms, both as buyers and suppliers, and to distinguish between purchases of goods and services. Our treatment of interest is the first time a domestic firm buys inputs from a foreign firm, thus establishing a forward linkage. To understand whether buying from foreign firms has implications for future performance, we match the VAT transactions data with (a) financial information from Corporate Income Tax (CIT) declarations; (b) employment data from the Pay As You Earn (PAYE) database; and (c) export and import transactions from the Rwanda customs authorities. The data span the period 2013-2022.

Domestic firms entering into a relationship with foreign firms, either upstream or downstream, may differ from the pool of existing firms. This results in a potential endogeneity concern, mostly reflecting selection bias, a common issue in the FDI literature. To address this concern we follow the recent literature analysing the effect of FDI linkages in a similar setting to ours (i.e., Alfaro-Urena et al. 2022; Amiti et al. 2024) and employ an event study approach, paying specific attention to the issue of staggered treatment and pre-trends. To do this, we leverage the large pool of "untreated" firms in the VAT data and use the Synthetic Control Difference-in-Difference approach developed by Arkhangelsky et al. (2021) for estimation.[4] Since our panel is unbalanced and focusing on a balanced panel would mean dropping a large number of observations, we extend their approach to be applicable to an unbalanced setting. We do this by collecting cohorts of treated units with the same data availability and identify for each cohort the set of valid control units under the staggered treatment setting. We apply the method in Arkhangelsky et al. (2021) to this subset of data and aggregate the treatment effects into horizon-specific effects by weighting them by the number of treated units used in every cohort.

Our results indicate that forward linkages are not only more frequent than backward linkages in Rwanda, but are the dominant channel through which FDI generates spillovers for domestic firms. Firms that begin to source from foreign-owned suppliers see an average

[3]For example, Stalkamp et al. (2023) document that even "born digital" firms have incentives to engage in FDI in target markets. WTO (2024) shows that sales through foreign affiliates (FDI or "mode 3" in WTO speak) continue to be much larger than cross border trade in services.

[4]Bijnens et al. 2025, using data similar to ours, but with a specific focus on consulting services, adopt a similar methodology.

increase in value-added and employment by around 20% and 10%, respectively. These increases are persistent. We also document that forward linkages are stronger for interactions with foreign firms providing services, especially those with high skill content, such as consulting (business and professional services), and for interactions with foreign wholesalers – a channel for domestic firms to acquire foreign intermediate inputs and technologies. Overall, we show that sourcing from foreign firms is more conducive to improvements in performance relative to sourcing solely from domestic suppliers – even when restricting attention to the most productive domestic firms – or from supplying to foreign firms. Results are robust to a battery of checks, including (i) alternative methods to define the control group; (ii) alternative definitions of the treatment, such as new foreign firm entries or repeated relations; and (iii) restricting attention to linkages with newly entering foreign firms to mitigate concerns about endogenous timing. We further address selection by implementing a network-based propensity score approach and show that results are not driven by firms simply adding any larger or more productive suppliers. Additional checks confirm that findings are robust to alternative exposure thresholds and are unlikely to reflect changes in firms' reporting behaviour following the establishment of a linkage with foreign suppliers.

In the final part of the paper, we explore some potential mechanisms that could explain this relationship. We focus on the availability and quality of inputs provided by foreign firms relative to domestic suppliers, and whether foreign and domestic inputs are complementary. Using unit value indices for products at the 8-digit level of disaggregation obtained from the customs data, we show that the mix of goods offered by foreign firms is of higher quality relative to domestic suppliers. We also provide evidence of a positive correlation between foreign ownership and the share of skilled workers at the sector level within the services sector. Furthermore, we show that foreign firms dominate in several sectors in providing specific skill-intensive intermediate services – notably data centres, web portals and accounting and management consulting services. Such services are difficult to import, are typically needed by domestic firms and may not be available or of sufficient quality domestically in low-income contexts. Finally, and importantly, we demonstrate that inputs sourced from foreign firms complement domestically-sourced inputs, as they do not seem to crowd-out domestic suppliers.

Contribution to the literature. We contribute to the extant research on FDI spillover effects in developing countries (Alfaro 2017; Garetto et al. 2025). We add to this research by exploiting firm-to-firm transaction data to provide robust evidence on the occurrence and the effects of linkages between domestic and foreign firms. As noted, much of the literature focuses predominantly on measuring and evaluating the implications of backward linkages, finding evidence of positive spillovers on different dimensions of domestic firm performance (e.g. Alfaro-Urena et al. 2022; Kee 2015; Masso and Vahter 2023; Carballo et al. 2023; Amiti et al. 2024)[5]. Evidence on forward linkages is largely qualitative. For instance, a

[5]Evidence on the effects of FDI in Africa has so far mostly focused on horizontal spillovers on domestic

survey of multinationals and domestic firms in African and Asian countries by Newman et al. (2019) shows that forward linkages are as, if not more, frequent than backward linkages. An exception is Newman et al. (2015), who find evidence for positive forward linkages in the case of Vietnam. Consistent with these stylized facts, we document that forward linkages between foreign and domestic firms are widespread in Rwanda and that their effects on domestic firms are generally positive.

By showing that FDI in services spur domestic firm performance via forward linkages, we also contribute to the literature on FDI as a mode of supply for services, complementing earlier work on more developed economies. Services differ from FDI in manufacturing or natural resource based sectors insofar as many services cannot be easily exported. As mentioned, FDI in the service sector is therefore market-seeking to a much greater extent than in goods-producing activities (Kolstad and Villanger 2008). Many services are specialised intermediate inputs used in other economic activities. This implies that in the context of countries receiving FDI in services, spillovers through forward-linkages can be expected to play a larger role than spillovers through backward-linkages, which is what we find.

This finding accords with growing evidence on the effects of (producer) services on private sector development and economic growth. Consistent with this literature, which focuses inter alia on services trade liberalization episodes, we provide suggestive evidence that this can be due to new or better services being introduced through FDI (Fernandes and Paunov 2012; Arnold et al. 2016). We show that this is particularly the case for high-skilled business and professional services, such as consulting, that act as a source of knowledge on business processes, management practices and use of new technologies, consistent with empirical research by Bloom et al. (2013) and Bijnens et al. (2025).[6]

Finally, the paper makes a methodological contribution by extending the Synthetic Control (SC) difference-in-difference method (Arkhangelsky et al. 2021) to unbalanced panels without gaps. It applies the SC method with a normalisation term in presence of a large number of potential control units (firms) as discussed in Abadie and l'Hour (2021). This yields a data-driven way to find useful control-units for the treated without relying on explicit matching functions.

The remainder of the paper proceeds as follows. Section 2 describes the data sources, including foreign investment activity in Rwanda. Section 3 describes our estimation procedure and presents the main results by contrasting spillovers through forward-linkages against spillovers through backward linkages from FDI. Section 5 explores several potential mechanisms driving these results. Section 6 concludes.

firms and workers. See e.g., Abebe et al. (2022), Toews and Vezina (2022), Hoekman et al. (2025), Olurotimi et al. (2025)

[6]In a sample of African countries Hoekman et al. (2025) find that the entry of foreign firms in business and professional services contributes to shifts in the composition of the labour force towards more skilled workers.

2 Data

We use administrative data to construct a panel of the universe of formal firms in Rwanda from 2013 to 2022. The data contains firm-level information on firms' balance sheets from Corporate Income Tax (CIT) data and Value-Added Tax (VAT) data, which allows us to identify firms' income, production costs and value-added at an annual frequency. It also covers data on formal employment and wage bills from Social Security Pay-As-You-Earn (PAYE) data. Further information at the firm-level includes the economic sector at the 4-digit ISIC4-level and geographic location of the firm from the tax register. Additionally, we utilize price-and quantity information for firm-level imports and exports of goods obtained from customs statistics. Firms are identified across datasets using a common anonymised tax ID.

Crucially, we observe the universe of B2B transactions from VAT sales- and purchase annexes. This permits us to identify the interactions between all domestic firms during the observation period and serves as our main tool of identifying interactions between domestic and foreign firms.[7] We aggregate transactions between firms at the annual level.

We identify foreign firms using two strategies. First, we have access to a register of FDI projects from the One Stop Centre managed by the Rwanda Development Board (RDB), the country's investment promotion agency. Registration as an FDI project is voluntary for foreign firms starting operations in Rwanda but is a prerequisite to access investment incentives outlined in the Law on Investment Promotion and Facilitation.[8] The second source to identify foreign firms is a dataset on foreign ownership of firms maintained by the RDB and the Registrar General of Rwanda. This dataset comprises the ownership structure of all firms registering for operations in Rwanda with at least one shareholder who is a foreign national or company. Both datasets can be linked to our data using the tax ID. For our main specification, we rely on the broader definition of foreign ownership as captured by the ownership structure recorded by the RDB and the Registrar General. We provide robustness checks considering only the more restricted set of foreign-owned firms that went through the voluntary registration process.

Our sample covers those firms for which we are able to successfully link the CIT and PAYE datasets with information on firm-sectors, and VAT-annexes. Overall, we are able to link either information on value-added or employment for around 18,600 domestic firms. Since our analysis relies on within-firm variation in exposure to foreign-owned suppliers or customers and a substantial amount of firms appears in the data only once, the effective sample-size is reduced to around 7,000 for the regression-based results. Our identification

[7]Data includes information on sales and purchases between businesses in terms of transaction values but does not provide reliable information on quantities or the nature of goods and services traded.

[8]This law defines access to several incentives that apply to any registered investor, including exemptions from capital gains tax, VAT exemptions and refunds, time-bound corporate or property income tax holidays or rate reductions, accelerated depreciation for investments in priority sectors, as well as visa-related and employee work permit provisions.

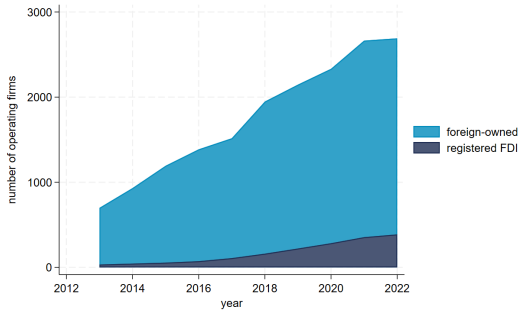
strategy relies on similar patterns of outcome variables pre-treatment. Therefore, the main results of the paper are based on a further reduced sample that contains sufficiently long pre-treatment information for treated units. Table A1 in the appendix provides a break-down of sample-sizes for different layers of data-requirements. The main results of the paper are calculated using the restricted sample but regressions on the larger sample are reported for robustness.

2.1 Foreign Investment in Rwanda

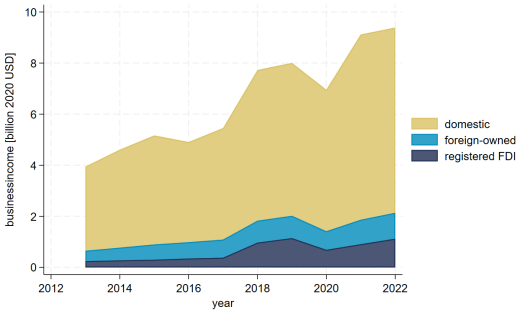
Rwanda has experienced a strong influx of FDI in recent years. Figure 1 reports the trend in the number and business income of foreign firms active in Rwanda for the sample period.The number of foreign firms increased threefold during the period – roughly mirroring the growth in the number of formal firms reporting positive business income in Rwanda. The business income generated by foreign firms has also increased, comprising 21% of business income reported by all formal businesses in Rwanda in 2022 compared to 12% in 2013.

Figure 1: Foreign firms in Rwanda

(a) Number of foreign-owned operating firms



(b) Business income of all operating firms



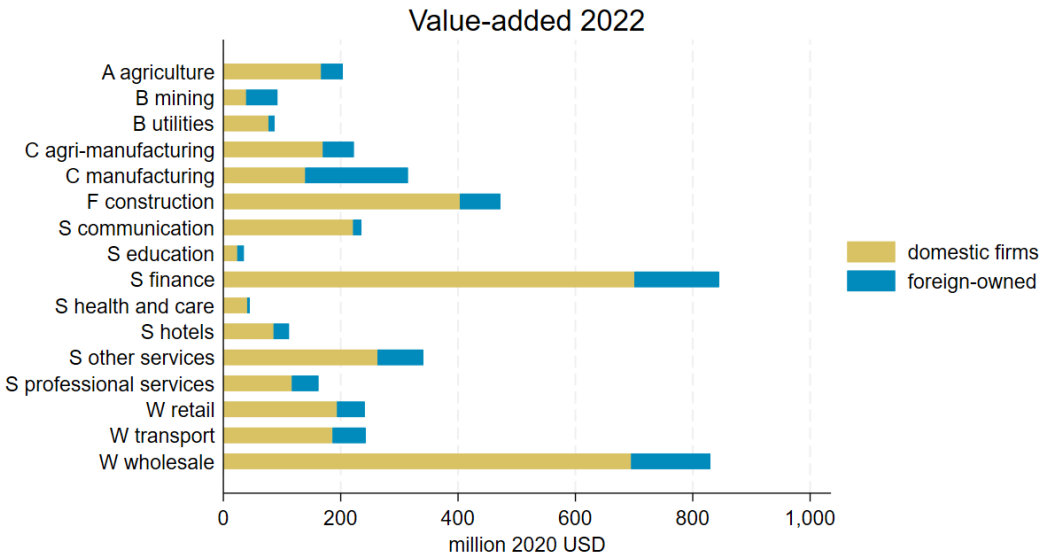
Note: Authors' calculation based on Rwandan tax register and Corporate Income Tax data. Conversion to 2020 USD based on IMF data.

Figure 2 reports the value-added of active firms in 2022 by economic sector and ownership status. About 300 of the more than 2,600 foreign firms active during the sample period were engaged in manufacturing activities. These firms generate over half of manufacturing value added and about one quarter of total foreign-owned value-added. While FDI in manufacturing is important, most of value-added from foreign firms is in the services, where also a majority of FDI firms in Rwanda are active.

FDI in Rwanda is mostly focused on the domestic and regional market rather than producing intermediate inputs for further use in Global Value Chains. While it is difficult to support this claim via direct evidence, several patterns of firm-behaviour support the view that most FDI in Rwanda is market-seeking rather than efficiency-seeking and oriented to exporting to global markets.[9] FDI in services sectors overwhelmingly enters to serve local

[9]An exception to this are mineral and agricultural commodities that are exported in large quantities by

Figure 2: Active firms in 2022 by economic sector and ownership



Note: Authors' calculation based on Rwandan tax register and Corporate Income Tax data. Conversion to 2020 USD based on IMF data.

demand, reflecting the limited tradability of many of the associated services.[10] For FDI in manufacturing, foreign firms' trade patterns suggest a similar conclusion. Of the 300 foreign firms in the manufacturing sector that directly engage in international trade, only 30 ever export larger values than they import. Figure A2 in the Appendix further explores the export destinations of foreign-owned firms in Rwanda. Foreign manufacturing firms almost exclusively export to other countries in the EAC. This supports the view that the intention for FDI in the manufacturing sector predominantly is to access local and regional markets rather than producing intermediate inputs for GVCs, which would lead to more value added in exports and greater diversity in destinations, including the Global North.[11]

Forward linkages are much more prevalent for FDI in Rwanda than backward linkages. Figure 3 plots the value of firm-to-firm interactions in intermediate inputs by sector during the 2013-2022 period. The leftmost and rightmost panels comprise only domestically owned firms in Rwanda. The central panel covers all foreign-owned firms active within Rwanda. Flows from the left panel to the middle panel represent the sum of business-to-business sales

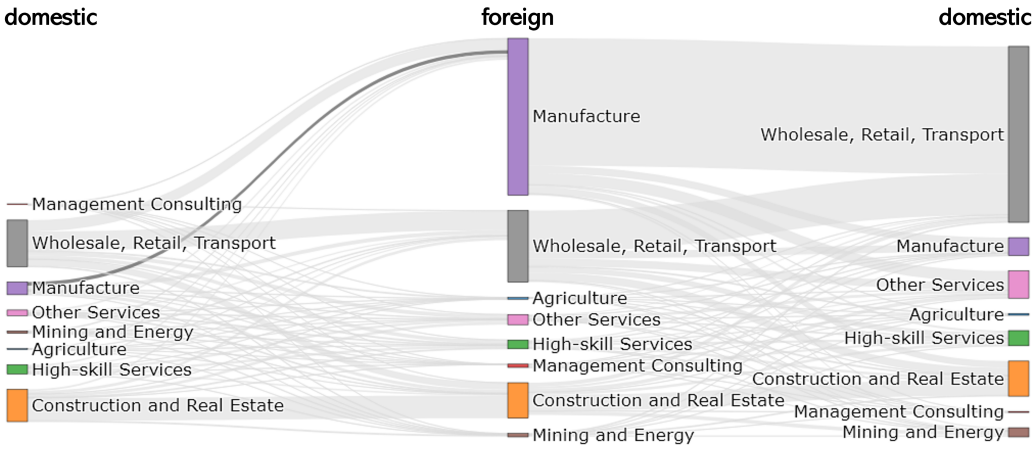
a few foreign-owned firms in the mining and wholesale sectors. The most important of these commodities are tin, tungsten, niobium, coffee, and to a lesser extent pepper.

[10] While some of these domestically provided services may be associated with sales to foreign persons (i.e., services exports) reflected in tourism-related activities (e.g., international conventions or sports events) – service firms entering the Rwandan market and providing intermediate inputs as observed via the VAT annexes manifestly enter in order to serve local demand.

[11] Appendix Figure A3 breaks down these exports by BEC categories. Whereas most exports to OECD countries are composed of commodities, exports to the EAC (and other Sub-Saharan African countries) are more diverse, encompassing substantial shares of processed industrial supplies and consumption goods. These patterns support the view that export-oriented foreign activity towards the global North is mostly extractive, whereas a substantial amount of FDI in manufacturing aims to access regional markets.

from domestically owned to foreign-owned firms within Rwanda broken down by economic sector. Flows from the middle to the rightmost panel represent the sum of sales from foreign-owned firms active in Rwanda to domestic firms in Rwanda. All other sales and purchases (final sales to individuals, sales between domestic firms, imports and exports) are omitted from the figure. The interactions most prone to spillover effects from FDI through backward-linkages emphasised in the literature are highlighted in a darker shade. Figure 3 makes evident that sales by domestic suppliers of intermediate inputs to foreign firms (backward linkages) account for a small fraction of interactions between domestic and foreign firms. Especially within the manufacturing sector, a larger fraction of interactions with the domestic economy plays out through forward linkages. Overall, during the sample period the nominal value of forward-linkages is more than twice that of backward linkages, although the share of backward linkages has risen over time.[12]

Figure 3: Aggregate transactions between domestic and foreign firms 2013-2022



Note: The Sankey chart depicts the volume of all transactions between foreign-owned and domestic firms from VAT sales and purchase annexes between 2013 and 2022. The width of the flows from the left-hand to the center block corresponds proportionally to the sum of all sales from domestic firms to foreign-owned firms and therefore reflects the volume of backward linkages by economic sector. The width of the flows from the center to the right-hand block reflects proportionally the sum of all purchases by domestic from foreign-owned firms in Rwanda and therefore reflects the volume of forward linkages by economic sector. Backward linkages for manufacturing, emphasized in the recent literature, are plotted in a darker font to highlight that these are quantitatively small in Rwanda.

In Appendix Table A2 and Figure A1 we report descriptive statistics and distributions for firm-level outcome variables for domestic firms not exposed to foreign-owned firms via sales transactions, firms that will become a buyer from a foreign-owned firm, and foreign-owned firms themselves. Firms beginning to interact with foreign-owned firms are larger and more productive on average than firms that never interact. They are also more likely to engage in

[12]In 2022, forward linkages amounted to foreign-owned firms selling approximately USD 575 million in goods and services to domestic firms and sourcing approximately USD 350 million from domestic firms. This compares to a nominal GDP of approximately USD 13.3 billion.

trade at least indirectly via sales relations with importing or exporting firms. Foreign-owned firms themselves are younger than domestic firms eventually interacting with foreign-owned businesses. Although on average they are not larger or more productive than eventually treated domestic firms, the median foreign-owned firm is larger than and as productive as the median domestic and eventually treated firm. The size and productivity distributions of foreign-firms are also shifted to the right when examining the center of the distribution – both in raw numbers and when focusing on within-industry variation. This indicates that foreign-owned firms are under-represented in the right tail of the firm size-distribution but that most foreign firms are relatively large and productive, both overall and within their respective industry. Foreign-owned firms are also more integrated into international trade both in terms of imports and exports. Finally, whereas foreign-owned firms on average source a lower fraction of their inputs domestically - instead exhibiting a higher reliance on imports in intermediate inputs – they do sell a larger fraction of their output on the intermediate-goods market domestically. These descriptive patterns confirm the insight from Figure 3 that the main channel of interaction between domestic and foreign-owned firms in the economy is through forward linkages.

3 Forward and Backward Linkages

3.1 Descriptive Analysis

We begin the analysis of spillovers from FDI using two-way fixed-effect (TWFE) regressions. Using the VAT firm-to-firm transactional data, we compute the sales shares from firm i to firm j as $s_{ij,t} = \frac{sales_{ij,t}}{\sum_j sales_{ij,t-1}}$. Note that we use previous year's sales in the denominator. We then define a threshold of 10% in the baseline results and consider a domestic firm as exposed to a foreign firm through backward linkages if in a given year at least 10% of its sales scaled by previous year's total sales were directed at a foreign firm i.e.

$$Z_{it}^{\text{backward}} := \text{any}_{j \in \text{foreign}, l \leq t}(\mathbb{1}\{s_{ij,l} \geq \text{threshold}\})$$

where $\mathbb{1}$ denotes the indicator function. We then add a refinement to ensure that first-time exposure is not triggered by marginal increases in sales shares (e.g. from 9.9% pre-treatment to 10.1%) but reflects substantive increases. To this end, we consider a firm as already exposed if its sales shares exceeded the 10% threshold in the following year and the difference in sales shares between the current and following year was below a second threshold (we use 5%).

$$Z_{it}^{backward} = \begin{cases} 1 & \text{if } Z_{it+1}^{backward} == 1 \ \& \ \text{any}_{j \in \text{foreign}}(\mathbb{1}\{(s_{ij,t+1} \geq 0.1) \& (s_{ij,t+1} - s_{ij,t}) < .05\}) \\ Z_{it}^{backward} & \end{cases}$$

Similarly, we define the same objects for purchases $b_{ji,t} = \frac{sales_{ji,t}}{\sum_j sales_{ji,t-1}}$ and define exposure to a foreign firm through forward linkages as

$$Z_{it}^{\text{forward}} := \text{any}_{j \in \text{foreign}, l \leq t}(\mathbb{1}\{b_{ji,l} \geq \text{threshold}\})$$

with the refinement

$$Z_{it}^{forward} = \begin{cases} 1 & \text{if } Z_{it+1}^{forward} == 1 \text{ \& any}_{j \in \text{foreign}}(\mathbb{1}\{(b_{ji,t+1} \geq 0.1) \& (b_{ji,t+1} - b_{ji,t}) < .05\}) \\ Z_{it}^{forward} \end{cases}$$

We interpret exposure to a foreign firm to be an absorbing state. This means that once a domestic firm has been exposed to a foreign firm over the observation period, we consider it to be treated for the remainder of our observation period. This view of exposure to foreign firms reflects the notion that interaction with foreign firms yields benefits that go beyond the immediate transactional value from selling to or sourcing from the firm but rather imply some persistent effects on the domestic firm. We restrict our sample of analysis to domestic firms in Rwanda. We also exclude firms that are exposed to foreign firms for the entirety of their observed spell (always-treated). We then estimate the following TWFE specification using OLS.

$$Y_{it} = \beta_0 + \beta_1 Z_{it}^{\text{backward}} + \beta_2 Z_{it}^{\text{forward}} + \beta_3 \mathbf{X}_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{1}$$

where $\mathbf{X_{it}}$ includes additional firm controls, α_i and γ_t are firm- and year fixed effects, respectively. Table 1 reports the results of the regression for log value-added, log number of employees, the log wage bill per employee and log value-added per employee respectively.[13] The first column is computed on the full sample whereas the latter three requires reducing the sample to those firms paying into the social security system for employees.

This regression provides suggestive evidence consistent with the presence of spillovers through both forward and backward linkages. On average, value added is about 25–30% higher for domestic firms that begin interacting with a foreign-owned supplier or customer. Moreover, increases in formal employment and worker remuneration are observed in connection with forward linkages but not with backward linkages. The last column indicates that the higher value added among domestic firms does not necessarily coincide with a larger scale of operations or higher profitability. Instead, the increase in value added per employee is consistent with improvements in efficiency associated with interactions with foreign firms.

The TWFE strategy suffers from two key identification issues. First, the staggered adoption of treatment in our setting implies that the criticism raised by Goodman-Bacon (2021) applies to the TWFE estimator in our setting. This means that the OLS-TWFE

[13]We measure value-added as the difference between business-income and cost-of-goods-sold from the Corporate Income Tax (CIT) data. Employees are formal full-time employees as reported in the PAYE-dataset. The wage bill comprises both direct wages and indirect labour costs via contributions to social security and in-kind remunerations as reported in the PAYE data. Reported zero-employment and value-added is dropped from the analysis.

Table 1: TWFE regression of forward and backward linkages from foreign-owned firms

	log value-added	log employees	log wagebill /employee	log value-added / employee
foreign supplier	0.243***	0.062***	0.080***	0.155***
	(0.033)	(0.015)	(0.014)	(0.041)
foreign buyer	0.309***	0.028	0.029	0.117
	(0.058)	(0.035)	(0.027)	(0.077)
observations	32592	42754	41963	14187
firms	7626	7254	7167	3036
treated firms	6035	5026	4991	2510

Note: Firm-and year fixed effects included. We control for number of observed buyers and suppliers in the previous period. Standard-errors (in parentheses) are clustered at firm-level. We exclude always-treated firms from the analysis. * p<.1 ** p<.05 *** p<.01

estimator includes invalid comparisons between treated units. Second, the TWFE estimator only identifies an interpretable effect if parallel trends can be assumed between those firms that began interacting with foreign-owned companies and all control units that did not do so. Since we are using the full dataset comprising the universe of formal firms in Rwanda and interaction between domestic and foreign firms is a choice made by firms, this is a very strong assumption to make in our present context. Selection, i.e. the correlation between some measurable and not measurable characteristics of domestic firms, may affect the decision to interact with foreign suppliers (see also Appendix Table A2). This is a well-known issue in the FDI literature. In the rest of this Section we discuss an identification strategy that is grounded on existing work using a similar setting as ours (Alfaro-Urena et al. 2022; Amiti et al. 2024).

3.2 Identification Strategy

To address the above-mentioned issues, we employ the Synthetic Control Difference-in-Differences approach developed by Arkhangelsky et al. (2021). This approach uses a weighted average of valid control units in such a way that parallel trends between treated and control units hold in the pre-treatment period *by construction*. The identifying assumption is that the synthetic control unit that mirrored the outcome pre-treatment continues to be unbiased for the counterfactual potential outcome of treated units after treatment occurs. This approach effectively yields a data-driven way to select control units from our large pool of possible control units in such a way that the treated firms are best mirrored by these control units. Arkhangelsky and Hirshberg (2023) discuss how the creation of a synthetic control can overcome selection bias present in Difference-in-Difference settings. The use of a synthetic control replaces the parallel trends assumption with the weaker assumption that treatment is independent of the counterfactual potential outcomes when conditioning on permanent unobserved firm-characteristics and the observed pre-treatment information.

Synthetic control group estimators in the literature have been defined only for balanced panels. Since our panel is unbalanced, using this methodology therefore would force us

to drop a large number of observations arguably in a non-random fashion. To overcome this issue, we extend the Synthetic Control methodology to be applicable to unbalanced panels without gaps. Appendix C presents formally how this is achieved. We partition our observations of treated units observed at different horizons into cohorts of unit-horizon observations with the maximum number of pre-treatment observations available for this cohort. We then select the control units comprised of never-treated and the valid sample of not-yet-treated units for this cohort that are observed over at least the same time-period. We use this cohort to compute a synthetic-control group and retain the effect of the Synthetic-Control Difference-in-Difference estimator for the treatment horizon under investigation. Finally, we average the horizon-specific effects from different cohorts weighting them by the number of treated units in the cohorts. The retention of only the last horizon for each cohort ensures that no treated unit enters our horizon-specific post-treatment estimates multiple times.

4 Results

Figure 4 presents the event-study estimates of forward linkages using the unbalanced-panel SCDID estimator for our full sample. Confidence intervals are computed using a clustered studentized bootstrap at the 95% confidence-level. The sample is restricted to those treated firms for which at least 3 pre-treatment observations are available, since the synthetic control method crucially relies on pre-treatment information to compute the synthetic control unit[14]. The estimates show sizeable and persistent spillovers on firm-performance through forward linkages. Domestic firms that become customers of foreign-owned firms persistently increase their value-added by around 20% following the first sourcing event. Some firms experience persistent growth in later periods to around 30% increases but this effect is subject to larger variation. Likewise, employment of these firms increases by roughly 10%. This adjustment is strongest the year following the first interaction indicating the presence of persistent changes to firms' operations. Estimates for the wage bill and value-added per employee are less precisely estimated, but they indicate that at least some of this effect is due to improvements in domestic firms' productivity rather than simply an expansion of scale. Average compensation per employee rises significantly and persistently by about 5% at least in the year of the interaction and the following year. Value-added per employee experiences an imprecisely estimated initial increase and long-term upward trend but is subject to more heterogeneity.

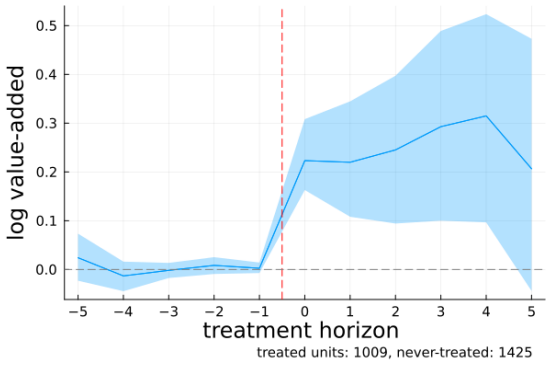
Evidence for backward linkages in Rwanda, on the other hand, is less clear. Figure 5 indicates that in the year where domestic firms sell to a foreign-owned firm their value-added increases by about 20%. However, in the years afterwards, the average effect drops to zero

[14]Table A1 in the Appendix reports the number of observations that are used for the different estimation samples, and after the restrictions imposed to the data.

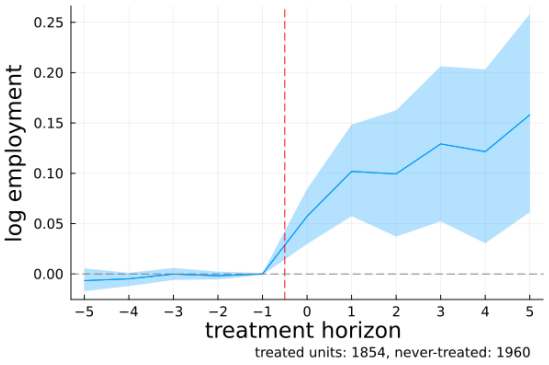
and there is much more heterogeneity in the trajectory of value-added from then on. The jump in value-added in the year of sales to foreign firms is almost a mechanical result if sales to foreign firms are on average larger in scale than domestic firms' usual operations. Since value-added reverts back to pre-exposure levels quickly, this may imply that backward linkages from FDI in Rwanda do not provide a major channel for productivity spillovers. This view is supported by the other variables analysed. Exposure to foreign firms has only short-term significant effect on firms' employment and employees do not become more productive after their firm sells to foreign-owned firms, except for the same spike in value-added per employee that drives results for overall value-added.

Figure 4: Synthetic Control Difference in Difference, foreign supplier

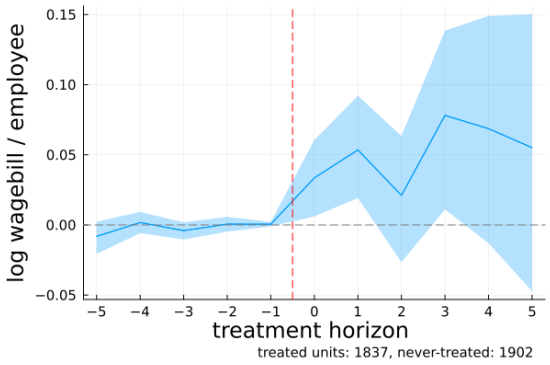
(a) Value-added



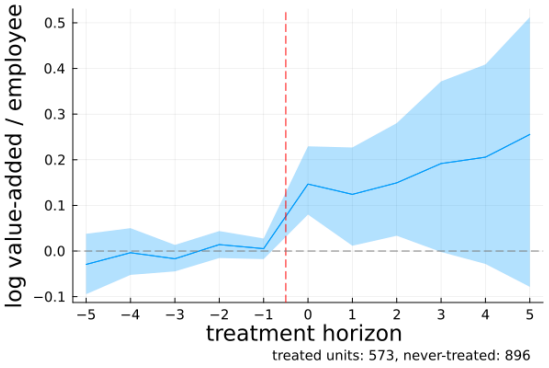
(b) Employment



(c) Wagebill per employee



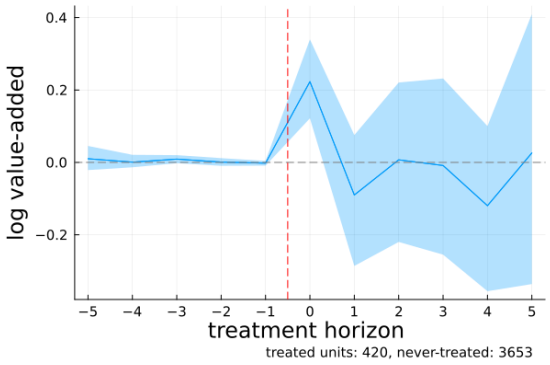
(d) Value-added per employee



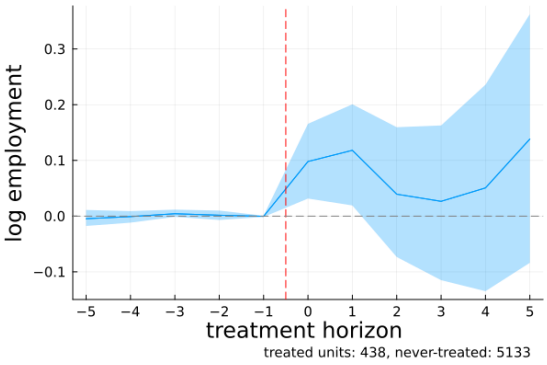
Note: The event-study graphs report the results of Synthetic Control Difference-in-Differences estimates for the unbalanced panel without gaps as described in Appendix C. In case of gaps in the panel, any spell containing a treatment event is retained and other spells are dropped from the analysis. For never-treated units, the longest consecutive spell is retained. The treatment is defined as a domestic firm starting to source from a foreign-owned supplier (forward linkage) as described in section 3.1. The threshold used to define a substantial interaction is 10% of previous year's purchases. The sample consists of domestic firms where never-treated units contain a spell of at least 4 non-missing observations and treated units have at least 3 non-missing observations pre-treatment. The overall number of treated and never-treated units is reported below the graph. The effective number of control units is higher however since not-yet treated units are used in the pool of controls for eligible causal contrasts. A synthetic control unit is computed for each treated unit and individual-level effects are then aggregated. The shaded area reports 95% studentized bootstrap confidence intervals computed with 90 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

Figure 5: Synthetic Control Difference in Difference, foreign buyer

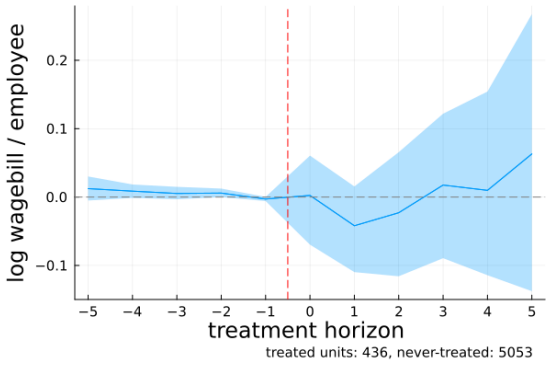
(a) Value-added



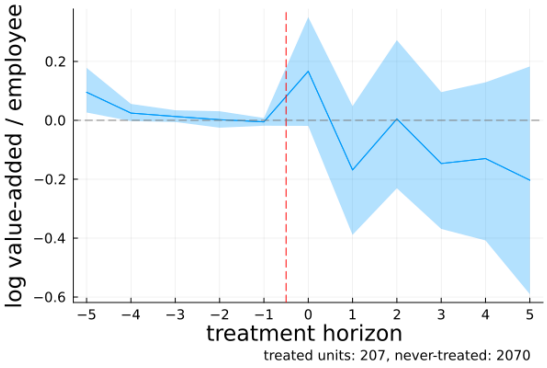
(b) Employment



(c) Wagebill per employee



(d) Value-added per employee



Note: The event-study graphs report the results of Synthetic Control Difference-in-Differences estimates for the unbalanced panel without gaps as described in Appendix C. In case of gaps in the panel, any spell containing a treatment event is retained and other spells are dropped from the analysis. For never-treated units, the longest consecutive spell is retained. The treatment is defined as a domestic firm starting to supply to a foreign-owned customer (backward linkage). The threshold used to define a substantial interaction is 10% of previous year's sales. The sample consists of domestic firms where never-treated units contain a spell of at least 4 non-missing observations and treated units have at least 3 non-missing observations pre-treatment. The overall number of treated and never-treated units is reported below the graph. The effective number of control units is higher however since not-yet treated units are used in the pool of controls for eligible causal contrasts. A synthetic control unit is computed for each treated unit and individual-level effects are then aggregated. The shaded area reports 95% studentized bootstrap confidence intervals computed with 90 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

4.1 Robustness Checks

4.1.1 Entry of foreign firms

We analyse exposure to a sub-sample of foreign suppliers that have entered the economy earliest in the year before the exposure is observed. This strategy – employed also in Amiti et al. (2024) – ensures that the option to source from the foreign firm in question was not available in periods prior to treatment such that the ability to begin sourcing can be seen as an exogenous shock to the domestic firm under investigation. Appendix Figure B1 reports the results for beginning to source from a foreign owned firm that has begun its operations in the year or the year before the first observed interaction. The treatment group and control groups are constrained to not have interacted with any other foreign-owned firms prior to treatment and the control group is constrained not to source from foreign-owned firms at all during the period of observation. These restrictions evidently reduce the sample and omit a lot of substantial interactions between foreign and domestic firms observed in the data.

Nonetheless, the persistent spike in increased value-added after sourcing from a foreign-owned firm is maintained, although the bootstrap confidence intervals increase due to the substantial reduction in sample size.

4.1.2 Alternative Methods: Propensity Score and Heterogeneous treatment

The Synthetic-Control method we employ has been shown by Arkhangelsky and Hirshberg (2023) to offer some robustness to endogenous selection into treatment. However, their results are asymptotic in the number of pre-treatment periods. Since we have available a large number of firms and a small to moderate number of pre-treatment periods, we complement our baseline results by estimating a treatment model. Given the rich network data available to us, we calculate the propensity to enter into a sales- or purchase relationship with a foreign-owned firm based on the full profile of sales interactions. This approach has been developed by Wang (2023) and computes the network of probabilities that any two firms in the network enter into a sales relationship based on the sales and purchase profiles of its neighbours on the network. Some relatively weak assumptions on the underlying network formation process then allow us to compute the joint propensity score to be exposed to any foreign supplier or customer.[15] The propensity score thus estimated is a generalisation of logit-estimation of propensity to be treated if the covariates of the logit-model only include network statistics at the firm-level (and not at the firm-dyad-level). In this sense, it nests the propensity-score based approach in Alfaro-Urena et al. (2022). We follow the approach

[15]The theoretical justification to treat the estimated probabilities of a link between any two firms as independent when calculating propensity scores is based on the theory of the deconfounder (Wang and Blei 2019). The estimated propensity score therefore not only conditions on observed variables, but also on unobserved confounders that are correlated with the process of selecting buyers and suppliers. A key assumption is that any confounding variable affects the potential sales interaction between multiple firms at once and never just a single dyadic relationship between two firms.

in Wang (2023) to compute the propensity scores of interaction with any foreign-owned firm and compute Inverse Probability Weighted (IPW) estimates using a TWFE estimator as well as the estimator proposed in Callaway and Sant'Anna (2021). This approach is consistent under the assumption that the propensity score we compute achieves covariate-balance on all relevant (observed or unobserved) confounding variables. Appendix Figure B2 confirms that our method achieves overlap in the propensity score between treated and control units.[16] The results reported in Appendix Figure B3 are qualitatively similar to our baseline results, although the TWFE estimates do not lead us to confidently rule out the existence of pre-trends leading us to favour our Synthetic-Control-Difference-in-Difference results. In Figure B4 we finally introduce the propensity score as a covariate to the entropy-regularised synthetic control estimator studied in Arkhangelsky and Hirshberg (2023). This implies that the synthetic counterfactual for each treated firm is chosen such that covariate balance is achieved not only over pre-treatment outcomes but also over pre-treatment interaction behaviour as measured by the probability to be exposed to a foreign supplier over the firm-to-firm interaction network. The results are comparable to the baseline figures.

4.1.3 Unique treatment

A potential concern for our analysis is that units in the control group for any of the estimates might be exposed to a different treatment. In Appendix Figure B5 we therefore repeat the analyses for the main outcomes from Figure 4 but restricting the control units to not being exposed to either forward or backward linkages from any foreign firm. For the first two columns, we also exclude observations from both treated and control units that do not appear in the firm-to-firm transaction data such that we ensure the effects observed are not driven by first-time entering into a formal supplier-buyer relationship.[17] In Figure B6 we restrict the treated and the control group for forward linkages to firms importing throughout the observed period to ensure that the interaction with foreign-owned firms active in Rwanda exerts effects beyond the pure exposure to inputs available on the world markets. The reduction in sample size preserves the significant effects on value-added. Effects for employment are no longer statistically significant due to the reduced sample size but point estimates are in line with the baseline findings.

4.1.4 Foreign supplier or productive supplier premium

The median foreign-owned firms is larger and more productive than domestic firms. Therefore, the results in the baseline estimates may be driven by treated firms adding a large or productive supplier as opposed to effects specific to foreign-owned firms. To address this

[16]Since we employ weighting strategies, we drop units with extreme propensity scores of below 1% and above 99%.

[17]Note that for firms selling to foreign-owned firms, this additional restriction decreases sample size beyond acceptable levels since most sellers to foreign-owned firms do source from foreign-owned firms at some point in the observed period.

ambiguity, in Appendix Figure B7 we restrict the control groups for each treated firm starting to source from a foreign-owned supplier to firms that in the same year added at least one domestic supplier from the upper quartile of the firm size- or productivity distribution.[18] Therefore, the causal contrast is with control firms that are comparable with respect to pre-treatment observables and also expanded their set of suppliers selectively towards larger or more productive firms. The results confirm the presence of a premium for sourcing from a foreign-owned firm beyond any premium of adding a productive supplier. For the effect on value-added the increase in the year of sourcing is reduced from 20% at baseline to 10% but the effect then gradually aligns with or even exceeds the baseline results. For employment, the restriction on the control group also reduces the effect after two years from a 10% increase at baseline to a 5% increase converging to the 10-15% increase in the baseline results after 3 years.

4.1.5 Persistence of sourcing relationships

A further cause of concern might be that effects of establishing a persistent supplier-relationship with a foreign-owned firm differ from those comprising a one-shot sourcing event. Although in both cases there are channels that might lead to the persistent positive effects on firm outcomes previously observed, our methodology confounds these channels by treating interactions with foreign-owned firms as an absorbing state. In Appendix Figure B8 we therefore plot the distribution of spell-lengths of interactions between (foreign and domestic) suppliers with local firms. Although we find that interactions with foreign-owned suppliers are on average slightly more persistent than interactions with domestic firms, almost 80% of these interactions are only observed for a single year. In Figure B9 we therefore conduct robustness checks by splitting the sample among firms that source from a foreign-owned supplier in only a single-year (on-off interaction) and those that begin sourcing from foreign-owned firms more persistently. The Synthetic Control event study reveals that firms that persistently source from foreign-owned suppliers experience stronger and growing increases in their value-added whereas the effects for one-off sourcing are smaller and subject to greater variation in the years following the event. The contrast is starker for employment.

4.1.6 Alternative definition of FDI

Figure B14 reports the effects of first-time exposure via forward linkages to a firm registering for FDI incentives with the Rwanda Development Board's Onestop Centre. The results are largely similar to those using the broader definition of foreign-owned firms used in the main section of the paper.

[18] We define an interaction with a domestic supplier as a meaningful interaction using the same threshold as for exposure to foreign-owned suppliers.

4.1.7 Homogeneous sample of firms

To ensure that the differences between the effects for different variables and treatments are not driven by the differing samples of available data as outlined in Section 2 and Table A1 in the appendix, we also construct a common reduced sample for all variables. The Synthetic Control Difference-in-difference estimates for this reduced sample are reported in Figure B10 The results resemble the headline results although the effect on value-added after exposure to a foreign supplier takes place more gradually than in the baseline results.

4.1.8 Alternative thresholds

We also investigate whether our results are robust to variations in the threshold of sales or purchase shares to foreign-owned firms used to define treatment exposure Z_{it}. Appendix Figures B15 and B16 show how the thresholds place in the distribution of firm-to-firm sales and purchase shares as used in the definition of treatment. Sales and purchase shares are approximately log-normally distributed. The distribution of purchase shares on input sourced from foreign-owned firms are slightly shifted to the right whereas the same is not true for sales shares to foreign-owned customers. The threshold strategy filters out a large number of very small transactions as measured by the expenditure share. Tables B1 and B2 report the same Synthetic-Control Difference-in-Difference estimates as in our baseline configuration in Figure 4 for different thresholds ranging from 0.1% to 20% of purchases (sales) made with a foreign-owned firm in order to qualify as treated. The results are robust across specifications confirming that our results are robust to variation in the definition in exposure to foreign-owned firms through sales-interactions.

4.1.9 Misreporting

The change in firm outcomes that we observe in our analysis might reflect a change in their reporting behavior when they start interacting with foreign suppliers. There is evidence that a significant share of firms make costly reporting errors in low-income countries (Almunia et al. 2024). Firms may improve their reporting standards after engaging with foreign firms, which has a bearing on their VAT disclosures.

To check whether part of our results are affected by reporting behavior, we apply a methodology used in the tariff evasion literature (Fisman and Wei 2004). Specifically, we construct a proxy for misreporting defined as the difference between seller i's reported sales (s) to domestic buyer j in month–year m and buyer j's reported purchases (b) from seller i in the same period, both measured in logs (after adding a small constant). We treat non-reporting by either party as zero.[19]

We then take the average of the discrepancies across all buyers who report purchases to construct a seller's misreporting measure in a given year:

[19]We exclude observations where one party reports zero while the other has a missing value.

$$d_{ijm} \;=\; \log\big(s_{ijm}\big) \;-\; \log\big(b_{jim}\big), \tag{2}$$

$$\bar{d}_{it} \;=\; \frac{1}{J_{it}} \sum_{j=1}^{J_{it}} \left(\frac{1}{M_t} \sum_{m \in \mathcal{M}_t} d_{ijm} \right) \tag{3}$$

Some buyers may fall below the VAT registration threshold and therefore never report purchases; in such cases, discrepancies may reflect tax exemption rather than misreporting (for evidence on this issue in the context of Rwanda, see Mascagni et al. 2023). To address this concern, we construct an alternative measure that excludes buyer–seller pairs involving buyers that never report any purchases throughout the sample period.

Appendix Figure B11 plots the distribution of the misreporting measure ($\bar{d}_{it}$), showing that a large share of discrepancies is driven by non-reporting by one of the trading partners. We then estimate whether sourcing from foreign firms affects domestic firms' misreporting, capturing both discrepancies arising from differences in reported transaction values and discrepancies due to non-reporting. Appendix Figure B12 presents results from the synthetic difference-in-differences estimation, showing no evidence of a change in reporting behavior when firms begin sourcing from foreign suppliers. Appendix Figure B13 reports estimates after excluding buyer–seller pairs involving buyers that never report purchases. While the point estimates suggest that firms tend to report higher sales relative to purchases reported by their buyers in later years, they remain statistically not different from zero. Further, since sourcing from foreign firms has an immediate effect on reported value added, these results suggest that atleast the short-term increase in firms' productivity is unlikely to be driven by changes in reporting behavior when firms begin buying from foreign suppliers.

4.2 Forward Linkages by Sector

FDI in Rwanda are spread across a variety of sectors. In the context of forward linkages, it is of interest to analyse the effects of interacting with foreign firms from different industries in some more detail. This may provide some indications regarding the mechanisms at play. There is an important conceptual difference of domestic firms purchasing from foreign manufacturing firms and purchasing from foreign service firms. That is because many services are less tradable internationally than manufacturing goods that can either be purchased from local producers or imported. Nayyar et al. (2021) emphasise the heterogeneity of services introducing a distinction between skill-intensive and less skill-intensive services.[20] Following their classification, we investigate the exposure to foreign firms in manufacturing, skill-intensive service sectors,[21] and wholesalers separately. We also include estimates for

[20]Baccini et al. (2023) analyse the rising role of services in African structural transformation, highlighting sectoral and skill heterogeneity across services sector employment trends over time.

[21]Skill-intensive services firms are classified under sections M (professional, scientific and technical activities), J (Information and communication), or P (education) of the ISIC rev.4 classification.

firms purchasing the services of foreign management consultancies. This is motivated by the notion that improved management practices offer the opportunity of large efficiency gains in developing countries (Bloom et al. 2013).

To separate the effect of sourcing from a domestic firm from the effect of sourcing from a foreign-owned firm in a sector, we control for exposure variables to the domestic sector of interest defined the same way as exposure to foreign firms. Next, we define an indicator variable for exposure to either foreign firms in the sector under investigation, domestic firms in the sector or both and repeat the regression from equation 1 with this new indicator variable. We include controls for backward linkages, as well. We conduct a Wald test for equality of the three coefficients associated with the indicator variable for forward linkages. Rejection of the null hypothesis of equal coefficients implies a significant difference between the forward linkages from exposure to domestic and foreign-owned firms in the sector under investigation. The results for log value-added are presented in Table 2 and those for employment in Table 3. Note that the comparisons reported in both tables are constrained to be within the same sector as described in the headings.

Table 2: TWFE of forward and backward linkages: log value-added

	manufacture	service			wholesalers		
		all	skill-intensive	consulting	all	input importers	capital importers
domestic supplier	0.238***	0.212***	0.229***	0.264***	0.162***	0.154***	0.196***
	(0.029)	(0.032)	(0.035)	(0.048)	(0.037)	(0.034)	(0.033)
foreign supplier	0.281***	0.286***	0.249***	0.325***	0.093	0.152**	0.165***
	(0.060)	(0.058)	(0.052)	(0.074)	(0.083)	(0.059)	(0.060)
foreign & domestic supplier	0.434***	0.495***	0.491***	0.480***	0.372***	0.431***	0.435***
	(0.044)	(0.050)	(0.059)	(0.110)	(0.044)	(0.042)	(0.040)
foreign buyer same sector	0.297***	0.287***	0.344***	0.357***	0.377***		
	(0.072)	(0.076)	(0.088)	(0.130)	(0.072)		
Wald test	13.87	21.12	12.07	2.04	30.66	46.25	36.81
p	0.000	0.000	0.000	0.131	0.000	0.000	0.000
observations	56516	56422	56625	58776	51533	53765	53178
firms	12487	12406	12455	13069	11242	11743	11604
treated firms	3632	2643	2259	506	6950	6144	6386
foreign treated	512	760	1077	281	120	351	376
both treated	3120	1883	1182	225	6830	5793	6010

Note: Controls include overall number of suppliers and customers in the previous year, sourcing from and selling to foreign-owned firms in different sectors, firm-and year fixed effects. Standard-errors (in parentheses) are clustered at firm-level. The Wald-test is for equality of the first three coefficients reported. We exclude always-treated firms for the current sector from the analysis. Treated firm means buying from a foreign-owned firm. Services are firms classified under sections J (Information and communication services), M (Professional, scientific and technical activities), N (Administrative and support service activities), O (Public administration and defence), P (Education), Q (Human health and social work), R (Arts, entertainment and recreation), and S (other service activities). We deliberately exclude financial and real estate services. Skill-intensive services are firms classified under sections J (Information and communication), M (Professional, scientific and technical activities), or P (Education) of the ISIC rev.4 classification. Input and capital importing wholesalers are those wholesalers that over the period actively imported industrial inputs or capital goods according to the BEC classification of goods.* p<.1 ** p<.05 *** p<.01

The results confirm that exposure to foreign firms is associated with higher levels of value-added and employment. The positive coefficient of exposure to domestic firms active in the same sectors indicates that a part of the correlation is due to the composition of goods and services offered by foreign firms and not only due to superior quality of these inputs. However, the significant Wald tests point towards some differences in the extent to which

Table 3: TWFE of forward and backward linkages: log employment

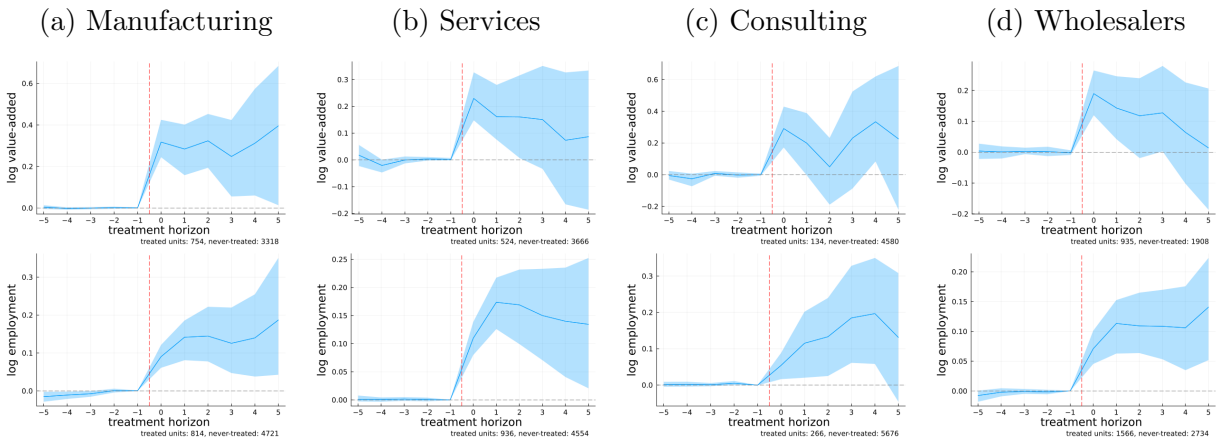
	manufacture	service			wholesalers		
		all	skill-intensive	consulting	all	input importers	capital importers
domestic supplier	0.081***	0.071***	0.085***	0.073***	0.106***	0.065***	0.105***
	(0.016)	(0.018)	(0.018)	(0.027)	(0.019)	(0.018)	(0.017)
foreign supplier	0.132***	0.082***	0.074***	0.117**	0.130***	0.073***	0.052**
	(0.033)	(0.031)	(0.028)	(0.054)	(0.036)	(0.027)	(0.026)
foreign & domestic supplier	0.175***	0.218***	0.176***	0.108*	0.158***	0.145***	0.161***
	(0.032)	(0.028)	(0.031)	(0.059)	(0.022)	(0.023)	(0.023)
foreign buyer same sector	0.032	-0.003	0.065	0.184*	0.015		
	(0.056)	(0.060)	(0.064)	(0.105)	(0.057)		
Wald test	5.59	18.06	5.58	0.32	4.35	8.66	8.41
p	0.004	0.000	0.004	0.725	0.013	0.000	0.000
observations	47975	48025	48202	49126	44652	45868	45798
firms	8320	8304	8338	8569	7596	7832	7813
treated firms	1845	1914	1610	494	4248	3803	3806
foreign treated	287	438	643	271	122	292	307
both treated	1558	1476	967	223	4126	3511	3499

Note: Controls include overall number of suppliers and customers in the previous year, sourcing from and selling to foreign-owned firms in different sectors, firm-and year fixed effects. Standard-errors (in parentheses) are clustered at firm-level. The Wald-test is for equality of the first three coefficients reported. We exclude always-treated firms for the current sector from the analysis. Treated firm means buying from a foreign-owned firm. Services are firms classified under sections J (Information and communication services), M (Professional, scientific and technical activities), N (Administrative and support service activities), O (Public administration and defence), P (Education), Q (Human health and social work), R (Arts, entertainment and recreation), and S (other service activities). We deliberately exclude financial and real estate services. Skill-intensive services are firms classified under sections M (Professional, scientific and technical activities), J (Information and communication), or P (Education) of the ISIC rev.4 classification. Input and capital importing wholesalers are those wholesalers that over the period actively imported industrial inputs or capital goods according to the BEC classification of goods. * p<.1 ** p<.05 *** p<.01

sourcing from foreign firms is related to superior benefits than sourcing from domestic firms. This is particularly evident in the service sector and for wholesalers that import capital goods or processed intermediate inputs. In the latter cases, in fact, the Wald test consistently and strongly rejects equality of coefficients for both value-added and employment. Interestingly, sourcing from foreign-owned wholesalers appears statistically significant only for those engaged in the importation of capital goods and processed inputs.

We complement the TWFE regression results with synthetic control event-studies of sourcing from firms in manufacturing, services, and consulting specifically. Figure 6 presents the results for sourcing from foreign-owned firms in manufacturing, services and after purchasing management consulting services with 95% bootstrap confidence intervals for exposure to foreign firms. The results indicate the presence of forward linkages in both services and manufacturing.

Figure 6: Forward linkages from exposure to foreign firms by sector



Note: The event-study graphs report the results of Synthetic Control Difference-in-Differences estimates for the unbalanced panel without gaps as described in Appendix C. All graphs report the effect after a domestic firm sources from a foreign-owned supplier classified in the economic sector described in the sub-heading. The threshold used to define a substantial interaction is 10% of previous year's purchases. Manufacturing firms are those classified under sections C (Manufacturing) or D (Electricity, gas, steam or air conditioning supply). Services are firms classified under sections J (Information and communication services), M (Professional, scientific and technical activities), N (Administrative and support service activities), O (Public administration and defence), P (Education), Q (Human health and social work), R (Arts, entertainment and recreation), and S (other service activities). We deliberately exclude financial and real estate services. Consulting are firms classified under ISIC classes 6910, 6920, 7020, 7320, or 7490. Wholesalers are firms classified under sections G (Wholesale and retail) and H (Transport and storage). The sample consists of domestic firms where never-treated units contain a spell of at least 4 non-missing observations and treated units have at least 3 non-missing observations pre-treatment. The shaded area reports 95% studentized bootstrap confidence intervals computed with 66 bootstrap iterations that account for the sampling procedure, collection of cohorts, and aggregation of effects.

5 Mechanisms

In this section we provide suggestive evidence for the transmission mechanisms governing the positive spillovers for domestic firms sourcing from foreign-owned companies.

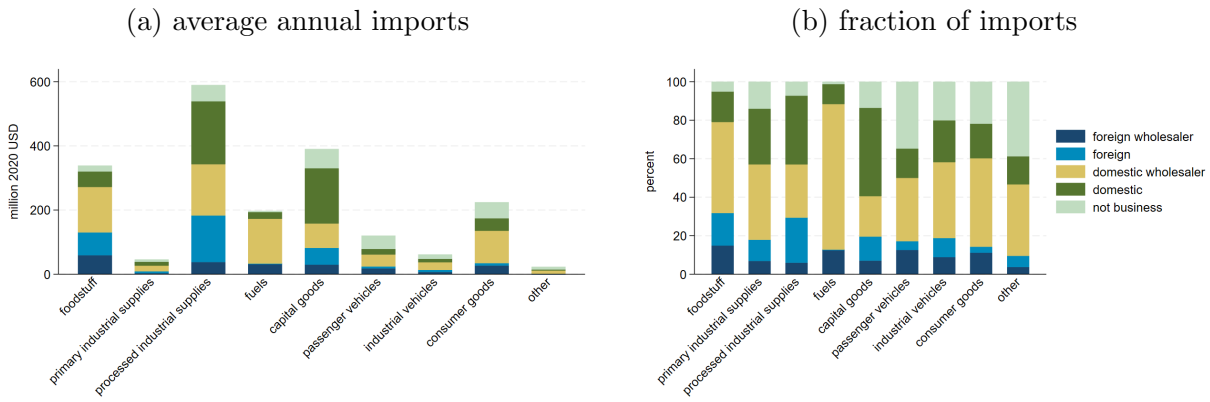
5.1 Quality of intermediate inputs

One possible channel through which sourcing from foreign-owned firms may increase domestic firms' economic performance is that foreign-owned firms provide intermediate input goods of higher value and/or quality than domestic firms can offer. Part of this effect may come from access to intermediate inputs imported from abroad. If so, this would be reflected in detailed customs data on imports by foreign-owned firms.

Figure 7 summarises the fraction of Rwanda's imports conducted by foreign-owned firms. Especially within the categories of food products and industrial intermediate inputs – both primary and processed – foreign-owned firms account for a sizeable share of overall imports to Rwanda.

To get a sense of quality differences in the imports of domestic and foreign-owned firms, we

Figure 7: Structure of imports by foreign-owned firms



Note: Imports to Rwanda 2013-2022 based on customs data summarised by Broad Economic Categories (BEC). Most goods are classified at the 1-digit level. Industrial supplies and vehicles are summarised at the 2-digit level. The identity of the importer is split between domestic and foreign-owned firms according to the firm register and further split by wholesale and retail firms according to ISIC4 classification and other firms. Imports by entities associated with a non-business TIN (individuals, non-governmental organisations, etc.) are summarised as not business.

analyse import-prices of all importing firms between 2014 and 2022. Within each Harmonized System 8-digit category, we standardise prices (unit values) for monthly imports across all importers. We then regress these standardised prices on the ownership type of the importer. Table 4 presents the results where imports by domestic firms are the baseline. Some of the regressions control for a slope of import-quantity in order to capture discounts for large-scale importers. Columns 1 through 4 report regressions on all monthly standardised import prices. Columns 5 through 8 instead compute the mean standardised prices for firms within HS-8 categories such that frequent importers do not appear in the data at a higher rate than infrequent importers. Columns 3, 4, 7, and 8 report the regressions only for imports of industrial inputs as defined by the United Nations Classification by Broad Economic Categories (BEC).

Overall, these results provide suggestive evidence that foreign-owned firms import goods at higher unit-prices than domestic firms. This finding is particularly salient when controlling for imported quantities. The relatively higher price of imports amounts to 0.05 and 0.09 standard deviations of within-month import prices of the same 8-digit HS category of goods. For imports of industrial inputs the import price difference for foreign-owned firms is slightly less pronounced.

5.2 Sectoral composition and input availability

Foreign firms may offer intermediate inputs that are not or not sufficiently provided by domestic firms. This is particularly salient for services, which are much more difficult to

Table 4: Regressions of standardised import-prices on importer type

	firm-month level				firm level			
	all	all	industrial	industrial	all	all	industrial	industrial
foreign	0.048**	0.073***	0.030	0.059**	0.050***	0.088***	0.037**	0.069***
	(0.022)	(0.021)	(0.026)	(0.023)	(0.014)	(0.014)	(0.015)	(0.014)
individual	-0.035*	-0.011	-0.070***	-0.045**	-0.049***	-0.017	-0.083***	-0.057***
	(0.021)	(0.019)	(0.025)	(0.022)	(0.013)	(0.012)	(0.014)	(0.013)
quantity controls	no	yes	no	yes	no	yes	no	yes
observations	2093951	2093943	1006702	1006698	880038	880030	428968	428964
importers	76112	76112	35658	35658	76112	76112	35658	35658

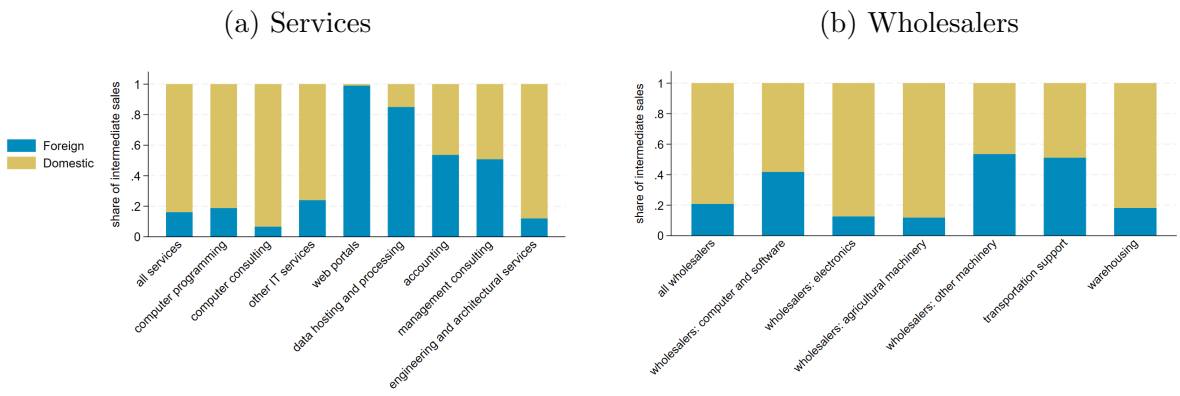
Note: Standard-errors (in parentheses) are clustered at firm-level. The baseline are domestic firms. Quantity controls means that the regression controls for 8-digit HS-code specific slopes with respect to quantity of goods imported by the firm. Columns 1 to 4 regress on standardised import-prices at the firm-month level (computing import prices at the firm-month-HS-code level and then standardising at the month-HS-code level). Columns 6 to 8 regress on standardised import-prices aggregated at the firm-level. Columns 1, 2, 5, and 6 report results for all imports. Columns 3, 4, 7, and 8 report results for standardised import-prices only for industrial input goods according to the BEC (Broad Economic Categories), restricting the analysis to BEC categories 21 (Industrial supplies nes, primary), 22 (Industrial supplies nes, processed), 41 (Capital goods (except transport equipment)), and 42 (Parts and accessories of capital goods (except transport equipment)).* p<.1 ** p<.05 *** p<.01

import than physical goods and are typically provided within a local economy. This is either because a certain service cannot be supplied from afar or because it requires contextual knowledge of local laws and customs (as is the case for accounting and consulting activities). Foreign firms may play an important role in supplying these inputs to domestic firms if there are not enough local firms with the necessary capacity and skills to provide them. We expect that this services input-channel will be more important for services with a higher intensity in specialised skills.

Figure 8 plots the share of foreign firms' sales for a selection of skill-intensive services at the 4-digit ISIC classification. Intermediate sales by foreign firms of services such as computer programming and other IT related services are not more concentrated than services overall. In others, such as data hosting capacities and the operation of web portals, supply is almost entirely dominated by foreign-owned companies. This is also observed in accounting and management consulting. This suggests that foreign firms provide certain types of services to the local economy that either cannot be supplied by domestic firms or that domestic firms cannot supply at the same level of quality or sufficient quantity to satisfy demand. Similarly, for wholesalers and transport-related services, some specialised distribution activities such as provision of machinery and equipment and logistical support services remain strongly dominated by foreign-owned firms, again suggesting that purchasing from foreign firms gives domestic firms access to types of products that are not supplied by domestic competitors.

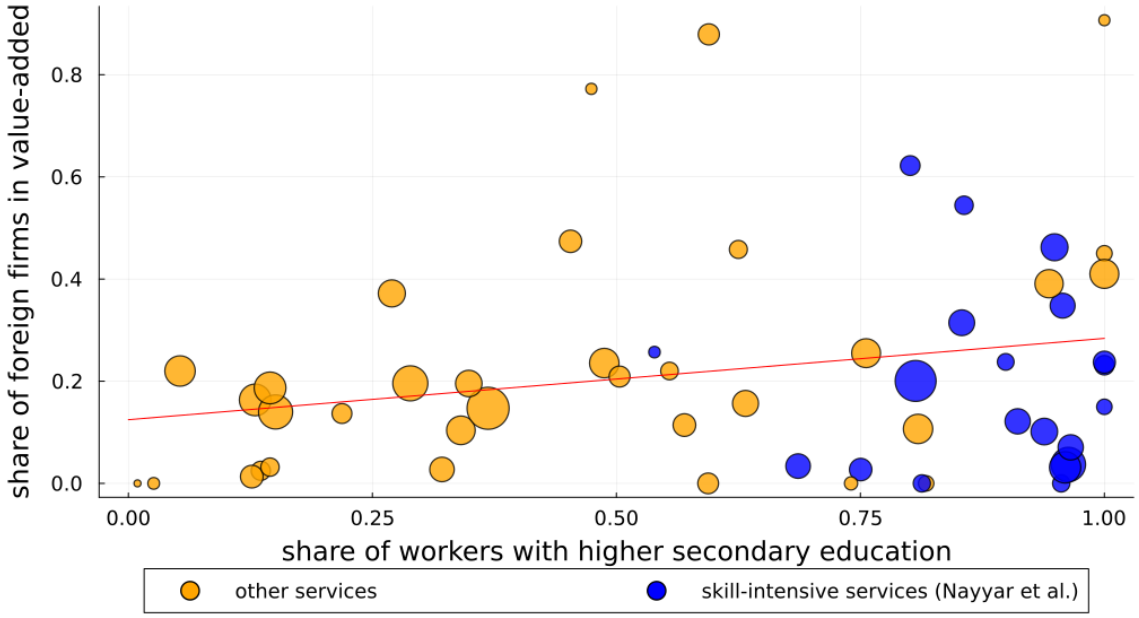
Relatedly, in Figure 9 we correlate the share of foreign-owned firms in all 2-digit ISIC4 service sectors with the education-level of workers in this sector, which we measure from nationally representative individual data from the Labour Force Survey. It unveils a positive correlation between skill-intensity of services and the fraction of value-added provided by foreign-owned firms in this sector. Notably, the work-force of service sectors dominated by foreign-owned firms have higher shares (around 50% or more) of skilled employees. Appendix Figure A4 indicates that this correlation does not hold true in the manufacturing sector.

Figure 8: Foreign firms' sales shares of intermediate inputs



Note: Intermediate sales are all business-to-business transactions to other firms recorded by firms within the sector during the period 2013-2022 and normalised to 1. All services comprises firms in ISIC Rev.4 sections G through S. All wholesalers are divisions 45 and 46. The fine-grained sectors are ISIC classes: Computer programming (6201), consulting (6202), other IT services (6209), web portals (6312), data hosting and processing (6311), accounting (6920), management consulting (7020), engineering and architectural services (7110), wholesalers for computers (4651), electronics (4652), agricultural machinery (4653) and other machinery (4659), transportation support (5229), and warehousing (5210).

Figure 9: Fraction of foreign-owned firms by skill-intensity in services, 2022



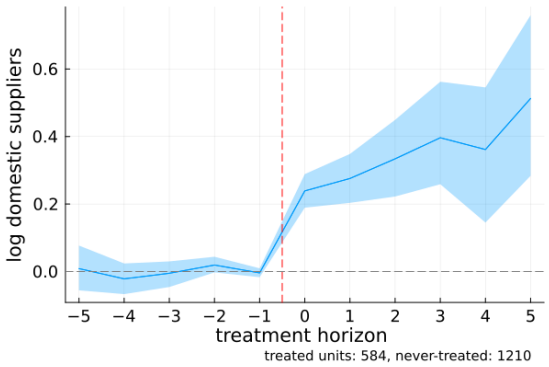
Note: Each dot represents a 2-digit ISIC4 sector within the service sector in Rwanda based on value-added calculated from Corporate Income Tax (CIT) filings in 2022. The size of the dot reflects (non-proportionally) the overall size of the sector. The skill-intensity is calculated from Rwanda's 2022 National Labour Force Survey as the percentage of employed workers in a 2-digit ISIC4 industry that have completed at least higher secondary school education. This fraction is calculated on the sample of working-age employees as reported in the NLFS and applying the sampling weights provided with the survey. Industries colored in Blue are those classified as skill-intensive in Nayyar et al. (2021), namely ISIC4 sections J (Information and communication), K (Financial and insurance activities), M (Professional, scientific and technical activities), P (Education), and Q (Human health and social work activities). The four service categories with over 90% skill-intensity not captured by Nayyar et al.'s classification and a large foreign presence are (in increasing order of foreign-owned share) ISIC divisions 92 (Gambling and betting activities), 79 (Travel agencies and tour operators), 78 (Employment activities), and 39 (Remediation activities and other waste management services). The red line fits a simple linear model to the data. The slope is significantly different from zero at the 90% confidence level.

5.3 Complementarity with domestic suppliers and customers

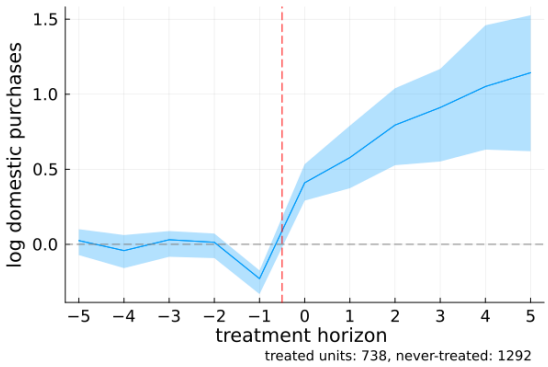
Figure 10 plots the change in the amount of inputs sourced from domestic firms in Rwanda at the extensive and the intensive margin after sourcing from a foreign-owned firm. Interaction with a foreign supplier is also associated with an increase in sourcing from domestic suppliers at both the intensive and the extensive margin. This suggests that foreign enterprises provide inputs to the Rwandan economy that are complementary in production to domestic inputs – in line with the observation that foreign-owned firms especially in services tend to supply intermediate inputs that are are not supplied at all or in sufficient quantity by domestic firms. The results strengthen the view that forward linkages are at least partially driven by alleviating supply shortages of certain skill-intensive inputs or high-quality supplies that when sourced by domestic firms are combined with local inputs to increase the domestic value-added of firms. These positive effects of forward linkages may then propagate further downstream in the local economy. Figure A5 in the appendix shows that firms exposed to foreign-owned buyers also increase their sales of intermediate goods and number of domestic B2B customers.

Figure 10: Synthetic Control Difference in Difference event studies

(a) Number of domestic suppliers



(b) Value of domestic input-purchases



Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The synthetic control is chosen to minimise the distance between the pre-treatment outcome and pre-treatment log value-added with equal weights assigned to each variable. In case of gaps in the panel, any spell containing a treatment event is retained and other spells are dropped from the analysis. For never-treated units, the longest consecutive spell is retained. The treatment is defined as a domestic firm starting to source from a foreign-owned supplier (forward linkage) as described in section 3.1. The threshold used to define a substantial interaction is 10% of previous year's purchases. The sample consists of domestic firms reporting at least one supplier in the firm-to-firm VAT annexes where never-treated units contain a spell of at least 4 non-missing observations and treated units have at least 3 non-missing observations pre-treatment. The overall number of treated and never-treated units is reported below the graph. The effective number of control units is higher however since not-yet treated units are used in the pool of controls for eligible causal contrasts. A synthetic control unit is computed for each treated unit and individual-level effects are then aggregated. The shaded area reports 95% studentized bootstrap confidence intervals computed with 66 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

Figure A6 in the appendix suggests that backward linkages in Rwanda are not associated

with the same kind of complementary effects and provide a more mixed picture. After some years, selling to a foreign-firm via backward linkages crowds out sales to domestic firms. Following a brief increase up to the year after the first sales, interaction with a foreign firm through backward linkages, the number of domestic customers and value of intermediate sales to domestic firms is permanently reduced. These findings differ with dynamics surrounding domestic sales interactions found by Alfaro-Urena et al. (2022). They suggest that in the context of Rwanda interactions with foreign-owned customers are subject to capacity constraints crowding out sales to previously existing domestic customers.

6 Conclusions

We find sizeable and persistent positive spillovers on Rwandan enterprises from the entry of foreign-owned firms. Consistent with the expectation that the type of FDI spillovers in a small, poor, landlocked economy are less likely to be associated with export-oriented FDI, we find that these effects are stronger and more prevalent for firms interacting with foreign-owned businesses through forward linkages. Spillovers through forward linkages are due to interactions with foreign firms operating in both manufacturing and service sectors. As predicted by the literature on trade in services, FDI in services is a channel for domestic firms to obtain access to services inputs that are not available from domestic enterprises or are of lower quality. Purchases of high-skill business services from foreign-owned firms have pronounced positive effects on domestic firms value-added and employment.

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A Additional Results

A.1 Sample composition

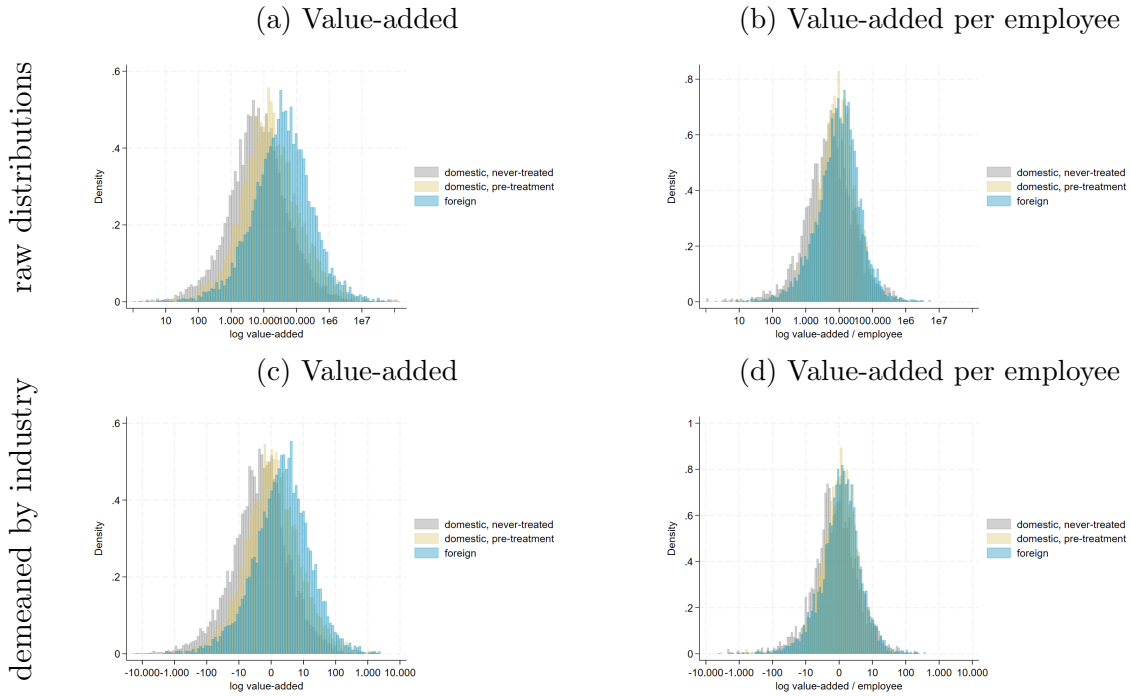
Table A1: Sample sizes for different data requirements

firms (N)	total observations	no singleton observations	domestic firms only	no always-treated		>3 observations, no always-treated	
				foreign supplier	foreign buyer	foreign supplier	foreign buyer
CIT	19982 (63255)	13214 (56487)	11364 (48517)	8591 (37499)	10232 (44244)	2434 (21622)	4073 (36208)
PAYE	14276 (71714)	12230 (69668)	10090 (59102)	8390 (50697)	9601 (56729)	3814 (31033)	5571 (45527)
overlap	7358 (27413)	5352 (25407)	4172 (19920)	3269 (15817)	3854 (18602)	1138 (10644)	2126 (19611)

Note: The table summarises the sample-sizes for different sample restrictions. Cells report the number of unique firms in the first row and the overall number of observations in brackets. The sample consists of firms for which either the Corporate Income Tax data reports non-negative value-added, the PAYE data records non-negative employment, or both conditions hold true. In addition, data must have successfully been merged with the VAT annex data. The columns from left to right impose (cumulatively) increasingly strict requirements on the data. The 4th and 5th column corresponds to the data requirements of the TWFE regressions. The last two columns correspond to the data requirements of the Synthetic Control event studies.

A.2 Descriptive statistics

Figure A1: Firm size and productivity distributions



Note: The size-distributions plot the distribution of firm sizes and productivities for domestic and foreign-onwed firms. For domestic firms, results are separated between firms that never source from foreign-owned firms over the sample-period and those that begin sourcing at some point between 2012 and 2022. For the latter, observations are restricted to the period before sourcing from a foreign-owned firm. The bottom panel depicts the residual size distribution after absorbing 2-level ISIC industry means thus focusing on within-industry differences.

Table A2: Descriptive statistics for domestic and foreign-owned firms

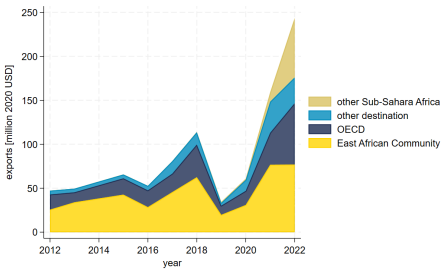
mean (sd) *median*	domestic never-treated	 pre-treatment	foreign
age	5.175	5.087	4.191
	(3.888)	(4.247)	(2.979)
	4	*4*	*3*
businessincome [thsd USD]	141.401	368.421	382.729
	(2360.003)	(3118.629)	(3069.966)
	5.000	*13.682*	*16.425*
value-added [thsd USD]	192.468	218.508	169.209
	(3444.922)	(2560.243)	(1579.624)
	5.340	*12.507*	*16.721*
employees	8.914	20.419	12.622
	(47.069)	(115.487)	(55.335)
	2	*4*	*3*
value-added/employee [thsd USD]	18.785	19.956	17.464
	(70.522)	(205.316)	(46.147)
	4.819	*7.903*	*7.714*
wagebill/employee [thsd USD]	40.474	89.463	223.924
	(446.948)	(720.291)	(8546.220)
	4.033	*6.989*	*5.317*
suppliers	5.794	6.371	5.779
	(124.508)	(17.719)	(17.076)
	1	*1*	*1*
buyers	6.064	10.610	10.351
	(50.637)	(76.073)	(56.189)
	0	*1*	*1*
importer	0.109	0.240	0.373
	(0.311)	(0.427)	(0.484)
	0	*0*	*0*
indirect importer	0.391	0.497	0.496
	(0.488)	(0.500)	(0.500)
	0	*0*	*0*
exporter	0.012	0.029	0.047
	(0.110)	(0.168)	(0.212)
	0	*0*	*0*
indirect exporter	0.077	0.151	0.175
	(0.266)	(0.358)	(0.380)
	0	*0*	*0*
intermediate inputs / expenditure	0.355	0.209	0.163
	(0.378)	(0.314)	(0.281)
	0.210	*0.036*	*0.021*
imports / expenditure	0.131	0.243	0.418
	(0.315)	(0.395)	(0.454)
	0.000	*0.000*	*0.123*
intermediate sales / income	0.227	0.365	0.422
	(0.371)	(0.429)	(0.437)
	0.000	*0.006*	*0.271*
exports / income	0.063	0.132	0.232
	(0.225)	(0.311)	(0.386)
	0.000	*0.000*	*0.000*
firms	9684	7745	1652

Note: The table displays the mean, standard deviation (in parentheses), and *median (in italics)* of domestic and foreign-owned firms in the sample. Domestic never-treated and foreign firms include all observations whereas for domestic firms that are eventually treated only pre-treatment periods are displayed. Always-treated domestic firms are omitted. Suppliers and buyers refers to the number of B2B suppliers and customers in a given year. Importer and indirect importer display the fraction of firms that directly engaged in importing or sourced from a firm that did.

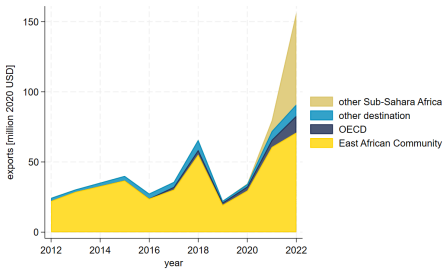
A.3 Export composition of foreign-owned firms by destination

Figure A2: Non-mineral exports of foreign firms by destination

(a) all foreign-owned firms



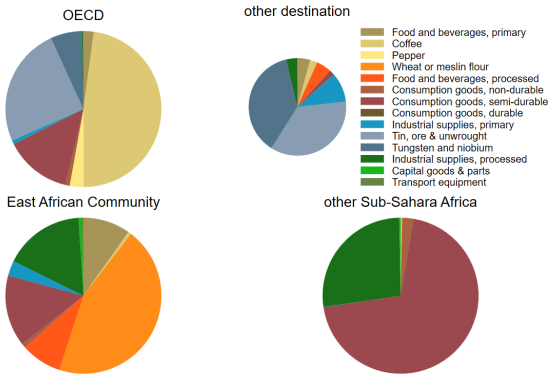
(b) foreign-owned manufacturing firms



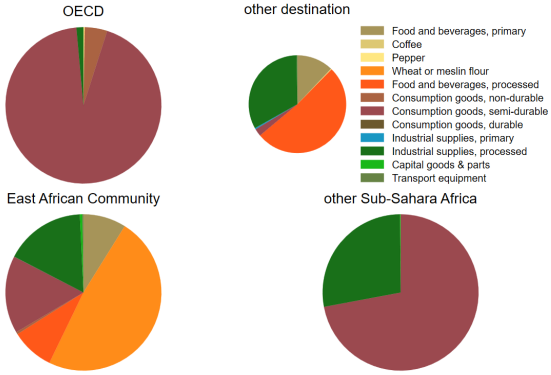
Note: Exports from Rwanda by foreign-owned firms from customs data. The figure excludes the export of mineral commodities.

Figure A3: Export composition of foreign-owned firms by destination, 2022

(a) All foreign-owned firms



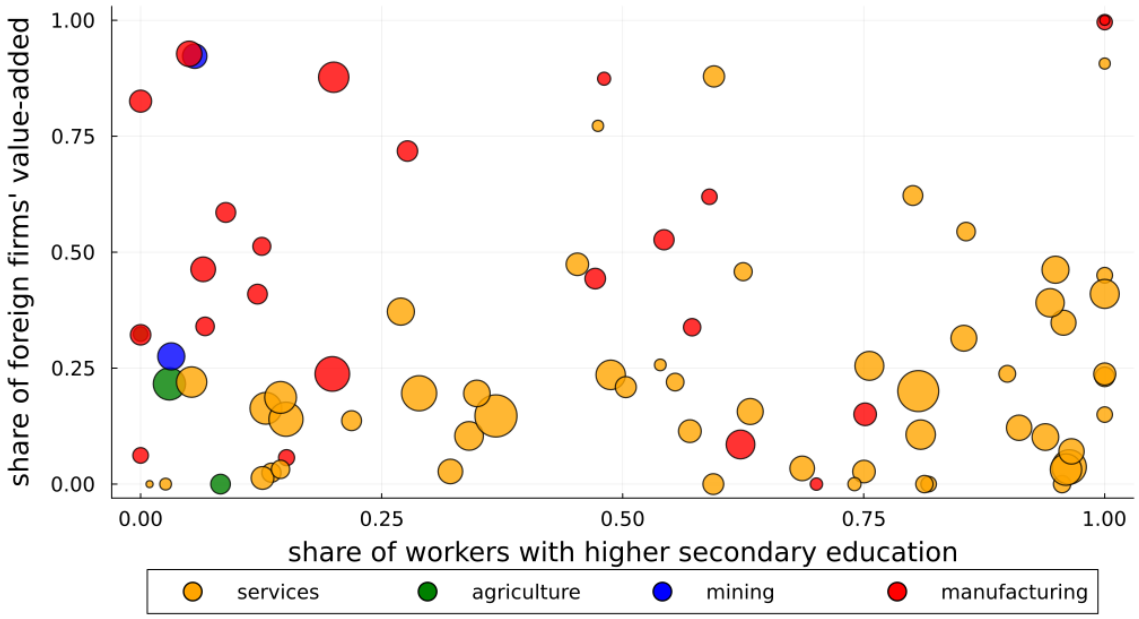
(b) foreign-owned manufacturers



Note: The pie-charts display the composition of direct exports in 2022 by foreign-owned firms in Rwanda to different destinations. Categories follow an aggregation of BEC categories with large volumes of selected commodities displayed separately. Exports of certain commodities that occur in large quantities in the neighbouring Democratic Republic of Congo (namely gold, silver, and precious stones) are excluded. Tin ore, tungsten, and coltan/niobium occur in large quantities in both Rwanda and in the DR Congo.

A.4 Skill-intensity of all sectors

Figure A4: Fraction of foreign-owned firms by skill-intensity, 2022

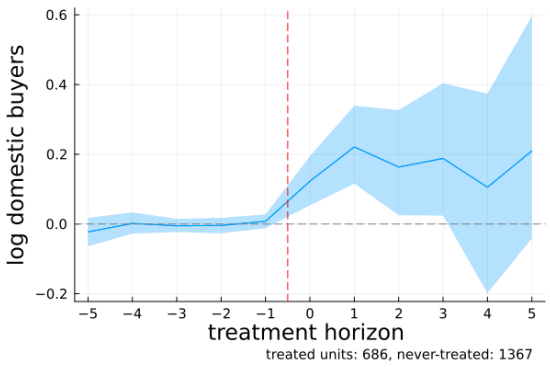


Note: Each dot represent a 2-digit ISIC4 sector within in Rwanda based on value-added calculated from Corporate Income Tax (CIT) filings in 2022. The size of the dot reflects (non-proportionally) the overall size of the sector. Notice that sector sizes are computed from CIT-filings. Therefore, sectors featuring strong informality such as agriculture are under-represented in this dimension. The skill-intensity is calculated from Rwanda's 2022 National Labour Force Survey as the percentage of employed workers in a 2-digit ISIC4 industry that have completed at least higher secondary school education. This fraction is calculated on the sample of working-age employees as reported in the NLFS and applying the sampling weights provided with the survey.

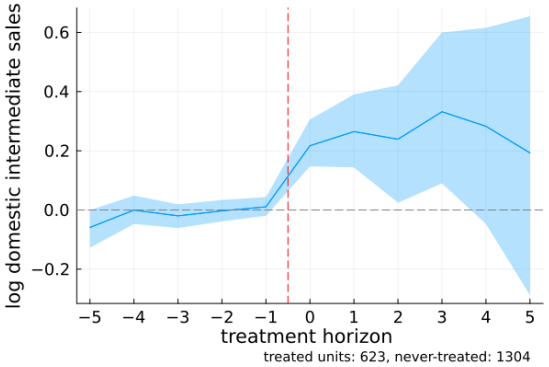
A.5 Synthetic control results for complementarity of inputs

Figure A5: Synthetic Control event studies for domestic sales after exposure to foreign supplier

(a) Number of domestic customers



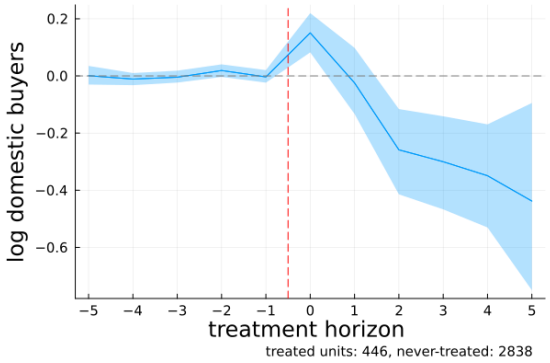
(b) Value of domestic B2B-sales



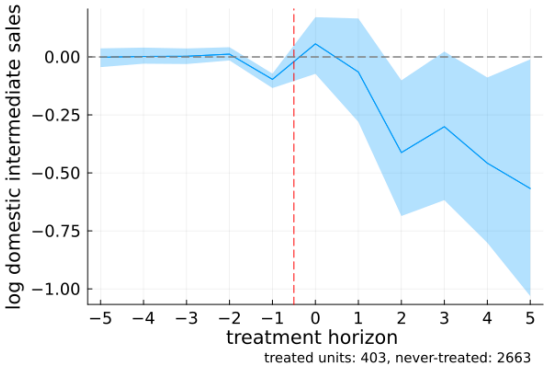
Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The treatment is defined as a domestic firm starting to source from a foreign-owned supplier (forward linkage) as described in section 3.1. The threshold used to define a substantial interaction is 10% of previous year's purchases. The shaded area reports 95% studentized bootstrap confidence intervals computed with 66 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

Figure A6: Synthetic Control event studies for domestic sales/purchases after exposure to foreign buyer

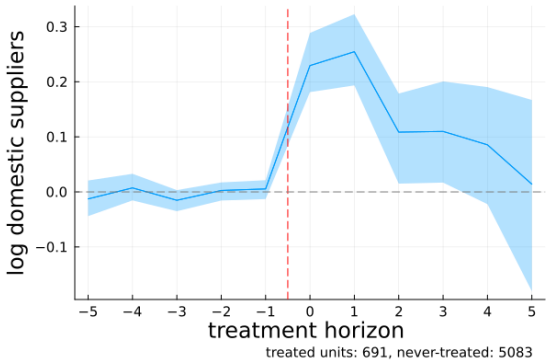
(a) Number of domestic customers



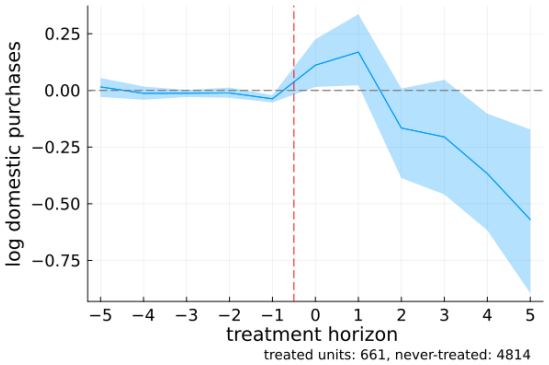
(b) Value of domestic B2B-sales



(c) Number of domestic suppliers



(d) Value of domestic input-purchases



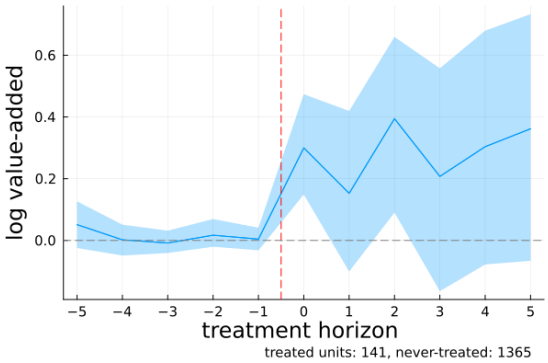
Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The treatment is defined as a domestic firm starting to supply to a foreign-owned buyer (backward linkage) as described in section 3.1. The threshold used to define a substantial interaction is 10% of previous year's purchases. The shaded area reports 95% studentized bootstrap confidence intervals computed with 66 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

B Robustness checks

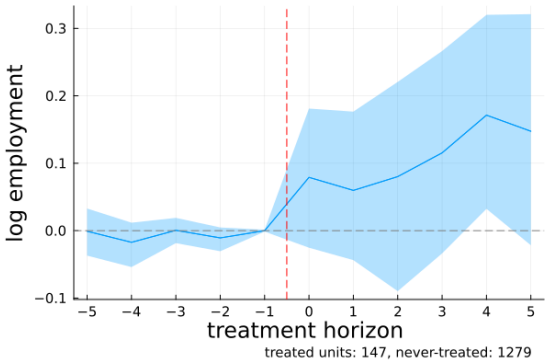
B.1 Exposure to foreign entrants

Figure B1: Synthetic control event studies of forward linkages to new entrants

(a) Value-added



(b) Employment



Note: The event-study graphs report the results of Synthetic Control Difference-in-Differences estimates for the unbalanced panel without gaps as described in Appendix C. The treatment is a domestic firm sourcing for the first time from a foreign-owned firm if this foreign-owned firm entered the market in the same or in the previous year. Firms sourcing from incumbent foreign-owned firms are excluded from both treatment and control groups. The threshold used to define a substantial interaction is 10% of previous year's purchases. The shaded area reports 95% studentized bootstrap confidence intervals computed with 66 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

B.2 Alternative specification using network-based propensity score

To compute the network-based propensity score as outlined in Wang (2023), we compute the annual networks of extensive firm-to-firm interactions defined over the $N \times N$ temporal adjacency matrix A_t with elements $a_{ji,t} = \mathbb{1}\{b_{ji,t} > 0.1\}$ where $\mathbb{1}\{\cdot\}$ is the indicator function. We rely on the network at the extensive margin and compute a matrix of firm-to-firm link-probabilities based on the network connections of indirect neighbours. To achieve this, we use the neighbourhood smoothing algorithm described in Zhang et al. (2017). This algorithm first identifies for each firm i a set of neighbours $\mathcal{N}_{i,t}$ based on a distance score of firms' purchase (or sales) profiles, i.e. the columns (or rows) of A_t. It then estimates the probability $\widehat{p}_{ji,t}$ of a sale from j to i as the share of a firm i's neighbours purchasing inputs from j such that

$$\widehat{p}_{ji,t} = \frac{1}{|\mathcal{N}_{i,t}|} \sum_{k \in \mathcal{N}_{i,t}} a_{jk,t}$$

Under the assumptions outlined in Wang (2023) and Wang and Blei (2019), this yields an independent estimate $\widehat{p}_{ji,t}$ for the link-probability of any two firms in the network. The propensity to be exposed to any foreign-owned firm via forward linkages can therefore be

computed as

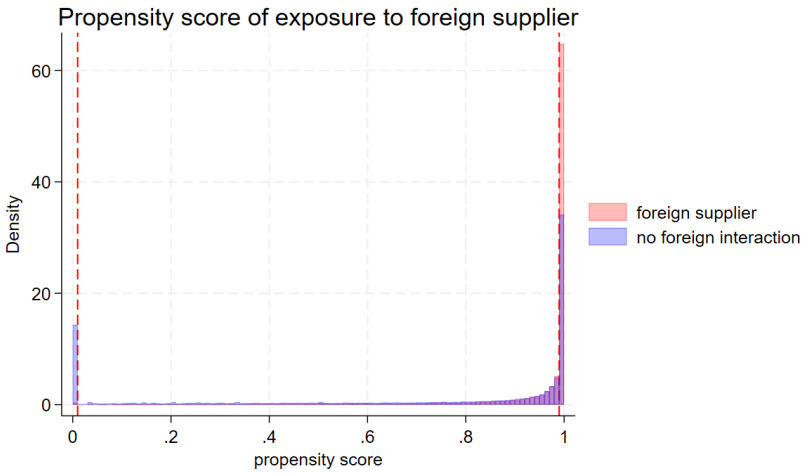
$$\widehat{e}_{it} = 1 - \prod_{j} (1 - \widehat{p}_{ji,t}) \mathbb{1}\{j \in \mathcal{F}\}$$

where $\mathcal{F}$ denotes the set of foreign-owned firms. Since the network of sales-relations is directed, we can distinguish between similar firms according to common suppliers or common buyers by applying the neighbourhood smoothing algorithm over either the columns (in case of forward linkages as above) or the rows (for backward linkages) of the network of firm-to-firm linkages. This yields separate link-probability matrices for the link probabilities to a firm's suppliers or customers, We use these to compute two propensity scores - one for exposure via forward and one for exposure via backward linkages.

Figure B2 shows the overlap of the network-based propensity scores. We apply cut-offs to the propensity score at 0.99 and 0.01 to avoid very extreme weights in the IPW procedure and limit our analysis to firms within this overlap region.

Figure B2: Overlap graphs for the two propensity scores

(a) exposure to foreign suppliers



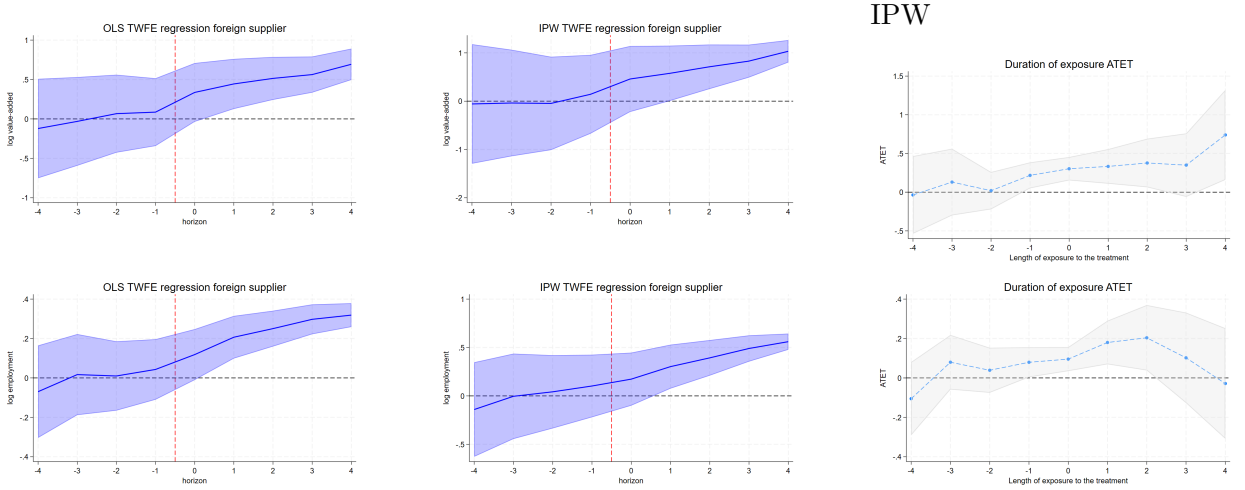
Note: The histogram depicts the calculated network-based propensity scores of exposure to a foreign-owned supplier for treated and control units. Vertical lines indicate the cut-off of extreme propensity scores used to focus on observations that lie within the region of variable treatment status.

Figure B3 show figures for standard OLS event-studies, weighted least squares event studies applying inverse probability weights for the ATT using the network-based propensity score to the control units, and Callaway and Sant'Anna event study plots applying the same propensity weighting strategy.

Finally, in Figure B4 we also conduct Synthetic Control estimations accounting for the link probability. To achieve this, we introduce the propensity to be exposed to a foreign-owned firm as a covariate to the entropy-regularised synthetic control estimator studied in Arkhangelsky and Hirshberg (2023).

Figure B3: Event studies after exposure to foreign supplier

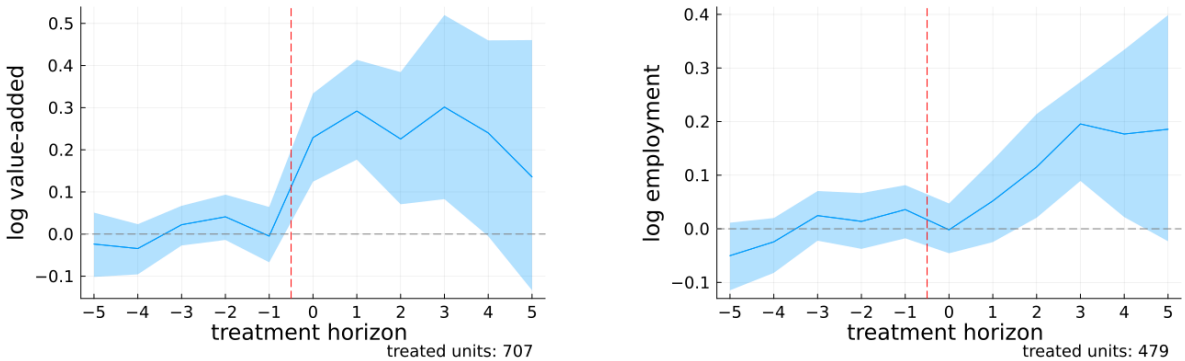
(a) OLS (b) IPW (c) Callaway & Sant'Anna IPW



Note: The event-study graphs report the results of TWFE and Callaway Sant'Anna event studied after exposure to a froeign supplier. Panel a) reports unweighted OLS. Panels b) and c) re-weight control units using the network-based propensity score.

Figure B4: Synthetic control event studies of forward linkage with propensity as covariate

(a) Value-added (b) Employment



Note: The event-study graphs report the results of Synthetic Control Difference-in-Differences estimates for the unbalanced panel without gaps as described in Appendix C but adopting the entroppy-regularised synthetic control estimator. The treatment is a domestic firm sourcing for the first time from a foreign-owned firm. The weights are optimized such that pre-treatment covariates balance with respect to pre-treatment outcomes and the network propensity score introduced above. The threshold used to define a substantial interaction is 10% of previous year's purchases. The shaded area reports 95% studentized bootstrap confidence intervals computed with 66 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

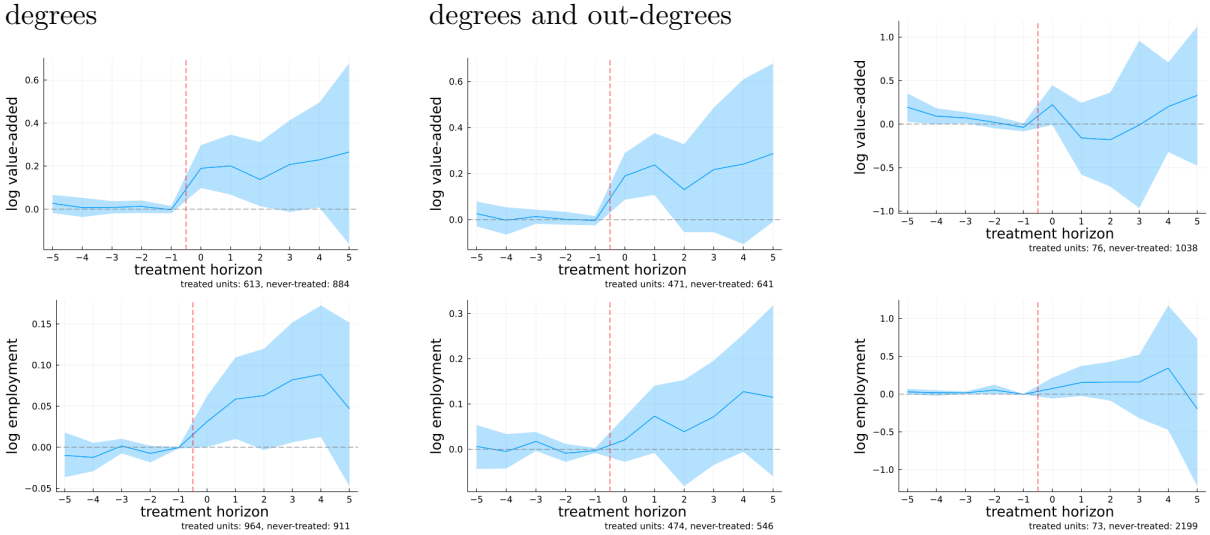
B.3 Alternative treatment and control groups

Figure B5: Forward and backward linkages with restricted control group

(a) Foreign supplier but no foreign buyer; with positive in-degrees

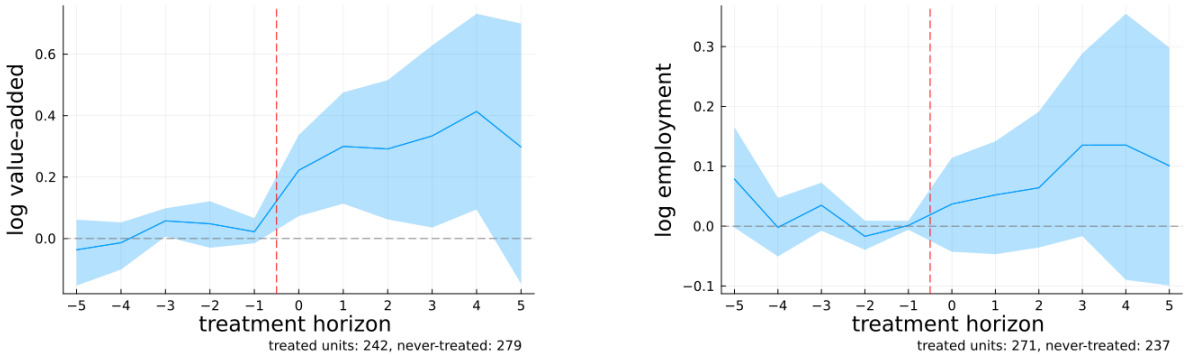
(b) Foreign supplier but no foreign buyer; with positive in-degrees and out-degrees

(c) Foreign buyer but no foreign supplier



Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4 but treated and control units are restricted as described in the respective panel heading.

Figure B6: Foreign supplier, treated and control groups are importers

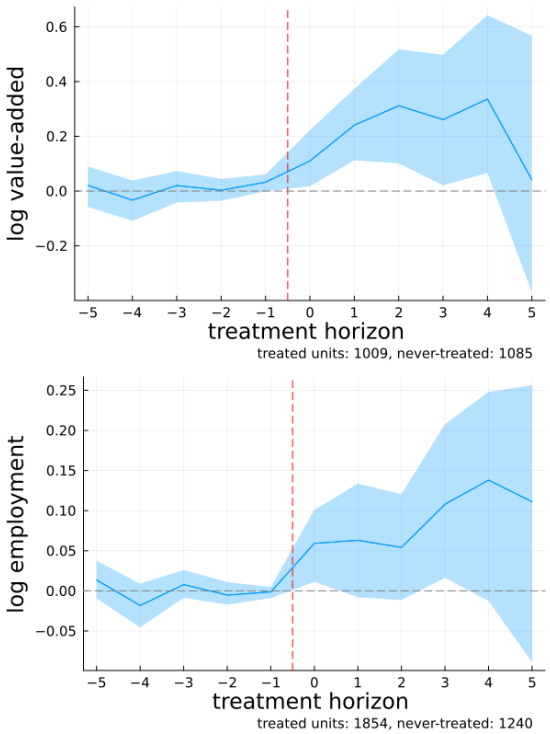


Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4 but both treated and control units are restricted to firms acting as direct importers.

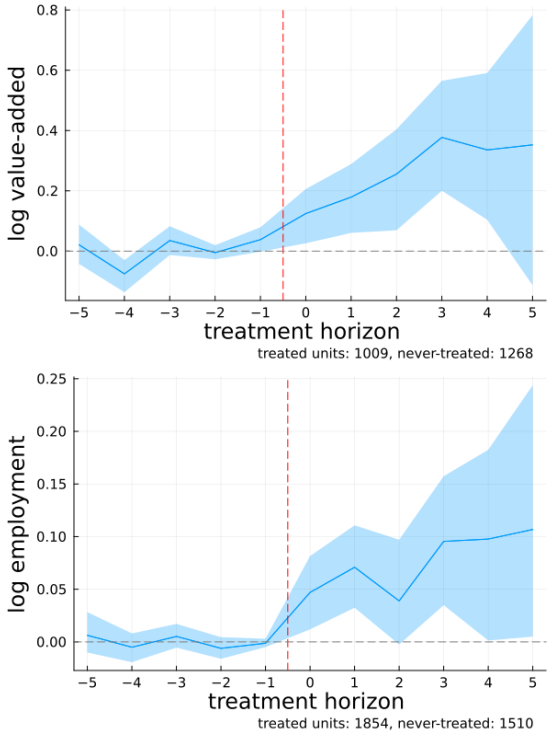
B.4 Foreign supplier or productive supplier premium

Figure B7: Synthetic Control Difference-in-Difference, foreign supplier

(a) Controls source from productive firms



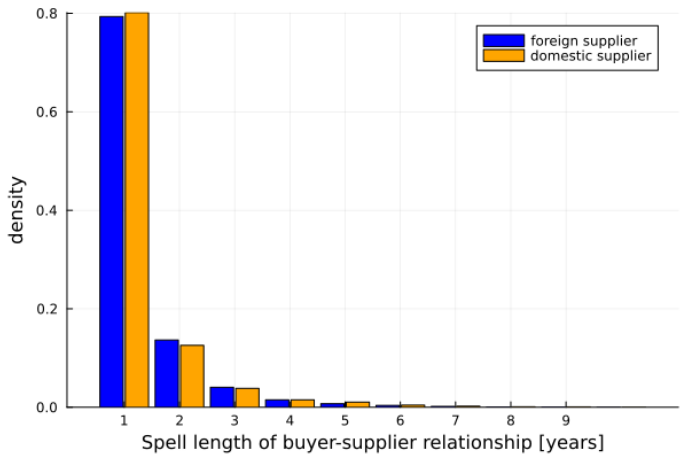
(b) Controls source from large firms



Note: The event-study graphs report the results of Synthetic Control Difference-in-Differences estimates for the unbalanced panel without gaps as described in Appendix C. In case of gaps in the panel, any spell containing a treatment event is retained and other spells are dropped from the analysis. For never-treated units, the longest consecutive spell is retained. The treatment is defined as a domestic firm starting to source from a foreign-owned supplier (forward linkage). The control units are further restricted to firms that in the same year as treatment occurs add at least one domestic supplier from the upper quartile of the size- or productivity distribution of firms. Both definitions of treatment and of controls follow the strategy described in section 3.1. The threshold used to define a substantial interaction is 10% of previous year's purchases. The sample consists of domestic firms where never-treated units with respect to foreign interaction contain a spell of at least 4 non-missing observations and treated units have at least 3 non-missing observations pre-treatment. The overall number of treated and never-treated units is reported below the graph. The effective number of control units is higher however since not-yet treated units are used in the pool of controls for eligible causal contrasts - although the restriction of the controls to having a domestic sourcing event restricts the size of the control group dynamically for every cohort of treated units. A synthetic control unit is computed for each treated unit and individual-level effects are then aggregated. The shaded area reports 95% studentized bootstrap confidence intervals computed with 90 bootstrap iterations that account for the collection of cohorts, estimation, and aggregation of cohort-level effects.

B.5 Persistence of relationship

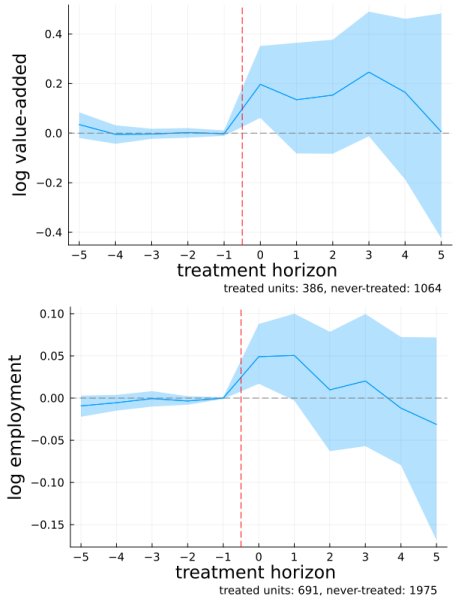
Figure B8: Distribution of spell-length of all buyer-supplier interactions, 2013-2022



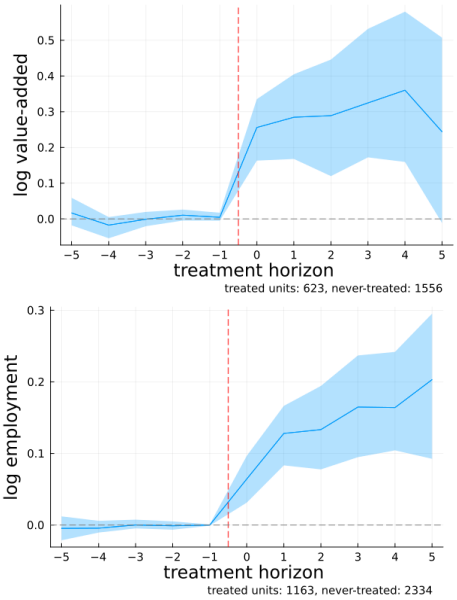
Note: The spell-length reflects the maximum number of consecutive years for which any two firms in the VAT annexes report a transaction. To ensure comparability of spell-lengths of interacting with domestic and foreign-owned suppliers, the two histograms are normalised within each group of suppliers. Overall, there are many more interactions with domestic than with foreign-owned firms.

Figure B9: Synthetic control event studies of one-off vs repeated interaction

(a) One-off interaction



(b) Repeated interaction

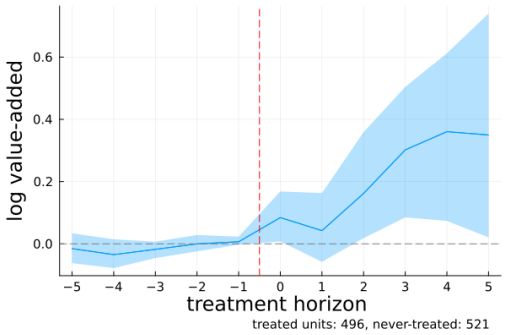


Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4. Treated units in panel a) are restricted to treated units that source from the foreign-owned firm in only a single period. Firms exposed to repeated sourcing events are excluded from the analysis. Panel b) restricts the treated units to those firms sourcing from a foreign-owned firm and maintaining this relationship for at least two subsequent years.

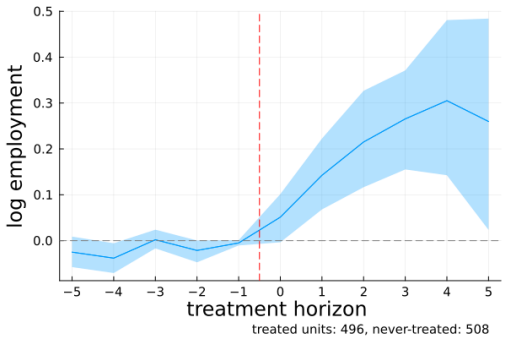
B.6 Homogeneous sample

Figure B10: Synthetic Control event studies, exposure to foreign supplier

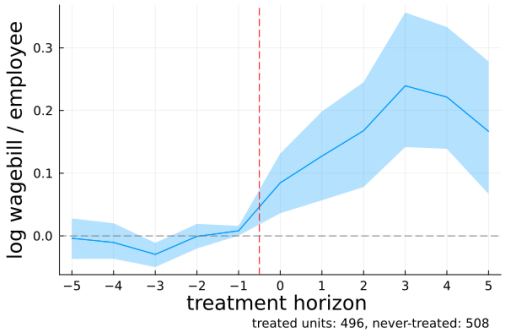
(a) Value-added



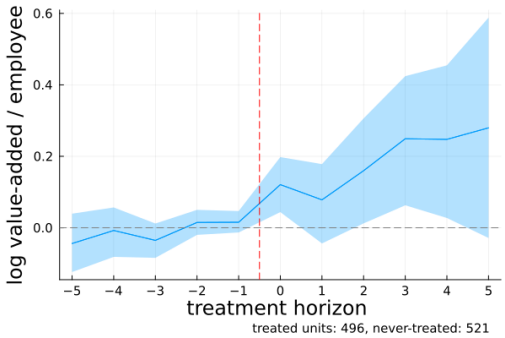
(b) Employment



(c) Wagebill per employee



(d) Value-added per employee



Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4. The treatment is exposure to a foreign-owned supplier according to the 10% threshold. The sample is restricted to the homogenous sample of firms for which all variables (value-added, employment, and wages) are available.

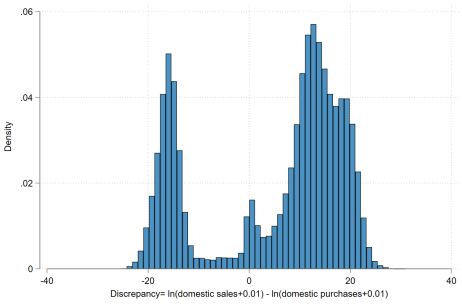
B.7 Misreporting

Figure B11 plots the distribution of discrepancies in sales reported by firms over time. Panel (a) shows discrepancies arising from either misreporting, that is, differences in bilateral reported values, or non-reporting, when one party does not report the transaction at all. Panel (b) isolates discrepancies driven purely by differences in transaction values reported by sellers and buyers. A large share of discrepancies is accounted for by non-reporting, where one side does not disclose transactions with its partner in a given year. We assess whether buying from foreign firms affects domestic firms' misreporting, capturing both discrepancies driven by differences in reported transaction values and discrepancies resulting from non-reporting of transactions by one of the parties.

Figure B12 presents results from a synthetic DD estimation showing no evidence that firms misreport sales relative to the purchases reported by their buyers around the time they begin sourcing from foreign firms. Figure B13 reports estimates after excluding bilateral relationships involving buyers that never report purchases, whose non-reporting may reflect tax exemptions. The results indicate that firms tend to report higher sales relative to purchases reported by their buyers in later years; however, the estimates remain statistically not different from zero. Combined with evidence that sourcing from foreign firms has an immediate effect on reported value added, these results suggest that atleast the short-term increase in firms' productivity is unlikely to be driven by changes in reporting behavior when firms begin buying from foreign suppliers.

Figure B11: Discrepancies in domestic sales

(a) Misreporting and non-reporting



(b) Misreporting

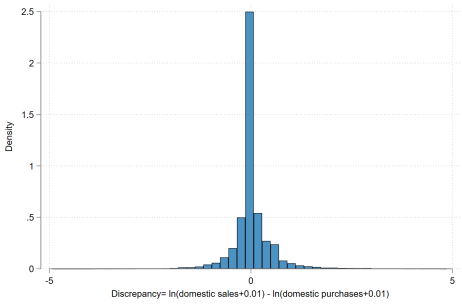
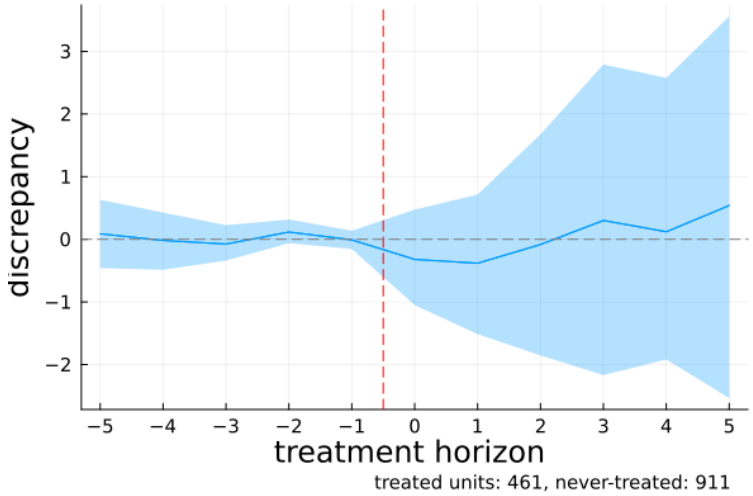
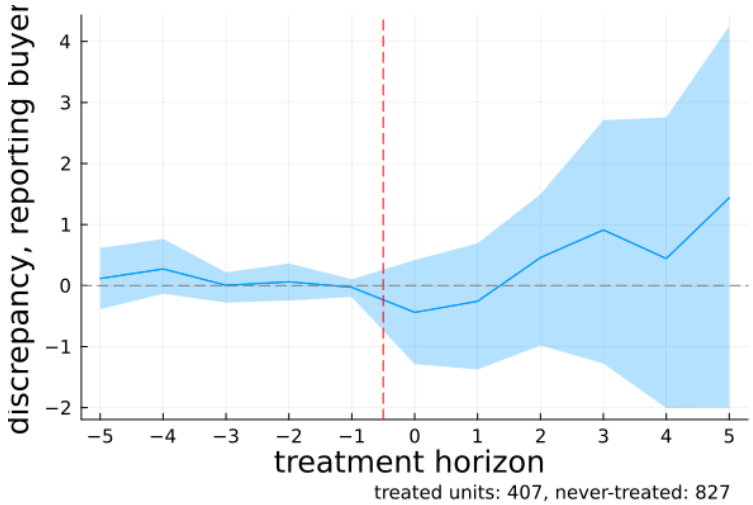


Figure B12: Linkages with foreign suppliers and misreporting



Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4. The outcome is the discrepancy measure described in Appendix section B.7 above. The weights are optimized such that pre-treatment pre-treatment balance is optimized for the misreporting measure reported as an outcome and log value-added.

Figure B13: Linkages with foreign suppliers and misreporting (excl. never reporting buyers)

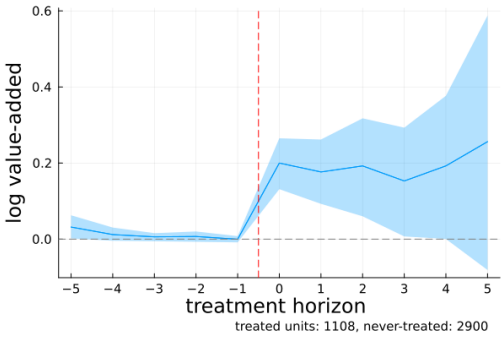


Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4. The outcome is the discrepancy measure described in Appendix section B.7 above. The weights are optimized such that pre-treatment pre-treatment balance is optimized for the misreporting measure reported as an outcome and log value-added. The sample is restricted to firms that report customers in the B2B data.

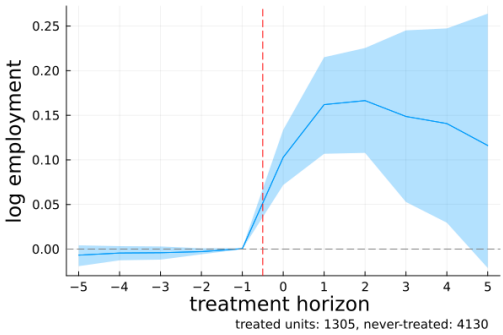
B.8 Alternative definition of FDI

Figure B14: Synthetic control event studies of forward linkages with registered FDI firms

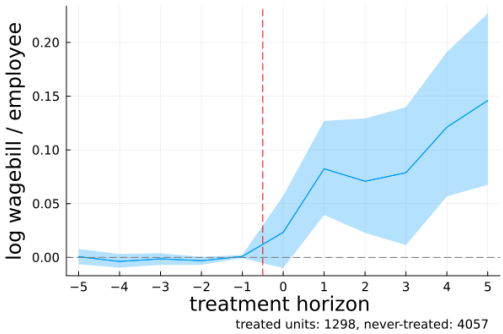
(a) Value-added



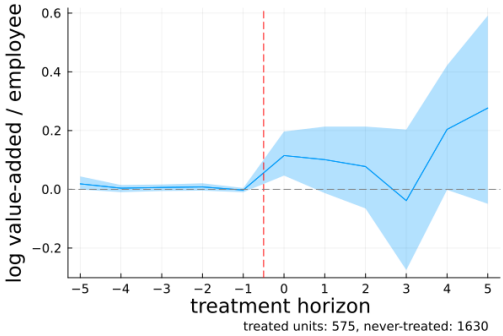
(b) Employment



(c) Wagebill per employee



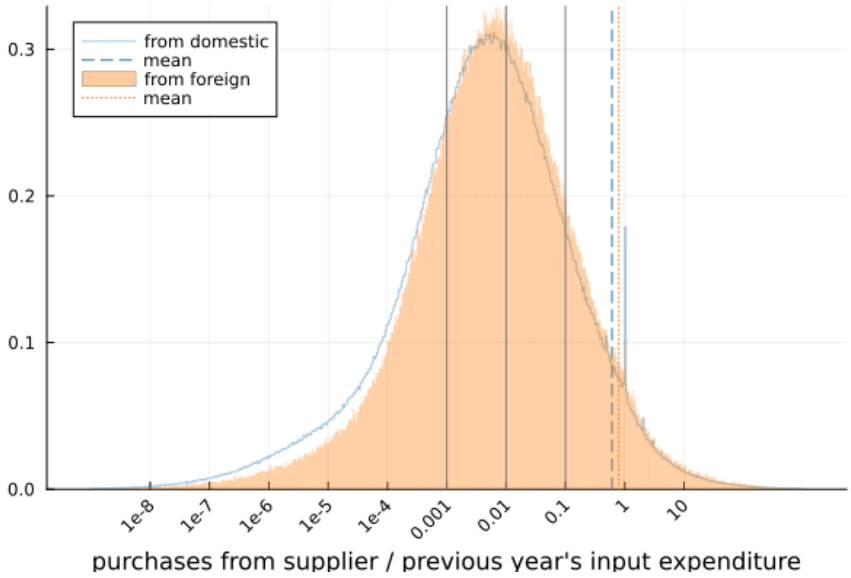
(d) Value-added per employee



Note: The event-study graphs report the results of Synthetic Control estimates for the unbalanced panel without gaps as described in Appendix C. The sampling procedure is the same as in the baseline Figure 4. Treatment is defined as a domestic firm sourcing from a foreign-owned firm that (voluntarily) registered their investment with the OneStop Center at the RDB in order to be able to access government incentives for investment promotion. This tends to capture larger and more productive foreign-owned firms.

B.9 Alternative exposure thresholds

Figure B15: Distribution of domestic firms' expenditure on intermediate inputs, 2022



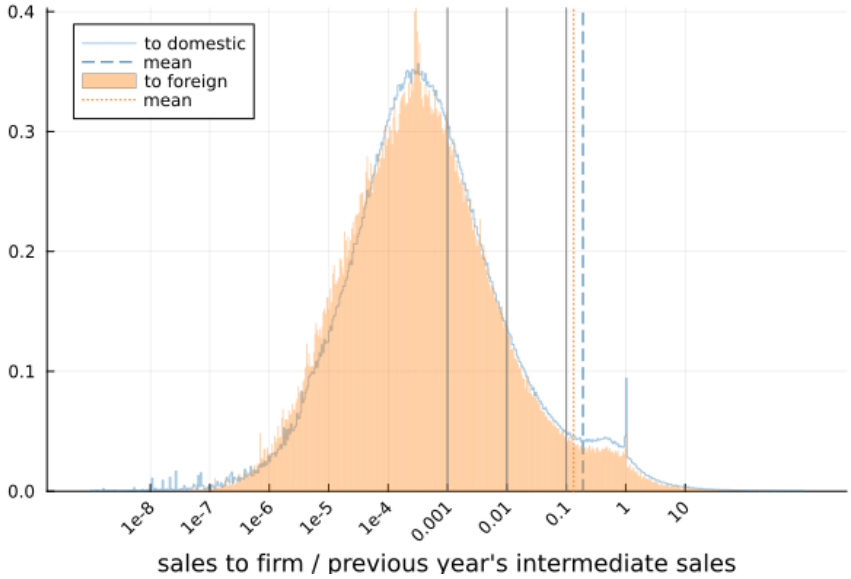
Note: The histograms plot the distribution of purchase shares of all dyadic (firm-to-firm) sales interactions involving a domestic buyer in 2022. The two histograms are for expenditure shares on inputs sourced from foreign-owned suppliers (the orange bars) and from domestic suppliers (the blue line) respectively. The denominator is the firm's overall expenditure in the previous year as used in the main identification strategy – therefore the individual purchase shares can exceed one. The x-axis follows a log-10 scale thus indicating that firms' purchase shares at the firm-to-firm interaction level are approximately log-normal distributed. The dashed and dotted lines report the mean of all purchase shares by the two sub-groups reflecting the long right tail of the log-normal distribution. Vertical lines reflect the 10%, 1%, and 0.1% cut-offs used for identification of meaningful interactions with foreign-owned firms in the robustness test respectively.

Table B1: Alternative thresholds: Foreign supplier

	log value-added					log employment				
	0.1%	**1%**	**5%**	**10%**	**20%**	**0.1%**	**1%**	**5%**	**10%**	**20%**
Horizon										
-5	-0.027	-0.041	0.009	0.024	0.03	-0.043	-0.034	-0.019	-0.014	-0.012
	(-0.134, 0.075)	(-0.137, 0.045)	(-0.054, 0.066)	(-0.014, 0.057)	(0.004, 0.068)	(-0.062, -0.028)	(-0.051, -0.024)	(-0.031, -0.013)	(-0.023, -0.006)	(-0.02, -0.007)
-4	-0.052	-0.041	-0.027	-0.013	-0.004	-0.027	-0.023	-0.015	-0.011	-0.009
	(-0.111, -0.008)	(-0.09, -0.001)	(-0.066, 0.001)	(-0.04, 0.005)	(-0.025, 0.018)	(-0.041, -0.012)	(-0.034, -0.016)	(-0.022, -0.01)	(-0.018, -0.007)	(-0.015, -0.002)
-3	-0.018	-0.01	-0.004	-0.002	0.003	-0.013	-0.01	-0.006	-0.003	-0.002
	(-0.047, 0.011)	(-0.032, 0.013)	(-0.018, 0.015)	(-0.014, 0.009)	(-0.007, 0.015)	(-0.019, -0.008)	(-0.016, -0.007)	(-0.01, -0.001)	(-0.007, -0.0)	(-0.006, 0.001)
-2	0.005	0.011	0.006	0.008	0.007	-0.011	-0.008	-0.005	-0.004	-0.003
	(-0.022, 0.034)	(-0.008, 0.035)	(-0.017, 0.03)	(-0.007, 0.023)	(-0.006, 0.021)	(-0.017, -0.005)	(-0.013, -0.004)	(-0.01, -0.002)	(-0.008, -0.001)	(-0.006, -0.0)
-1	0.029	0.024	0.006	0.003	0.001	0.002	0.002	0.001	0.001	0.001
	(0.008, 0.055)	(0.002, 0.048)	(-0.008, 0.024)	(-0.009, 0.015)	(-0.006, 0.007)	(0.001, 0.004)	(0.001, 0.003)	(0.001, 0.002)	(0.0, 0.001)	(0.0, 0.001)
0	0.152	0.197	0.202	0.223	0.232	0.123	0.132	0.121	0.102	0.109
	(0.057, 0.244)	(0.115, 0.288)	(0.111, 0.286)	(0.129, 0.311)	(0.152, 0.328)	(0.093, 0.156)	(0.103, 0.157)	(0.095, 0.149)	(0.072, 0.128)	(0.08, 0.136)
1	0.158	0.187	0.203	0.22	0.182	0.21	0.222	0.201	0.158	0.163
	(0.014, 0.306)	(0.026, 0.35)	(0.066, 0.324)	(0.112, 0.331)	(0.081, 0.293)	(0.163, 0.254)	(0.176, 0.259)	(0.158, 0.239)	(0.119, 0.199)	(0.126, 0.197)
2	0.273	0.31	0.281	0.245	0.168	0.245	0.25	0.225	0.165	0.192
	(0.063, 0.471)	(0.09, 0.492)	(0.137, 0.466)	(0.121, 0.366)	(0.04, 0.294)	(0.189, 0.302)	(0.186, 0.317)	(0.163, 0.286)	(0.099, 0.232)	(0.138, 0.251)
3	0.34	0.392	0.354	0.293	0.134	0.323	0.341	0.3	0.246	0.259
	(0.054, 0.606)	(0.128, 0.643)	(0.138, 0.56)	(0.115, 0.457)	(0.006, 0.265)	(0.244, 0.39)	(0.257, 0.427)	(0.23, 0.365)	(0.153, 0.335)	(0.191, 0.306)
4	0.595	0.624	0.456	0.315	0.079	0.376	0.386	0.318	0.255	0.257
	(0.341, 0.848)	(0.338, 0.964)	(0.211, 0.719)	(0.101, 0.532)	(-0.064, 0.244)	(0.29, 0.459)	(0.287, 0.479)	(0.236, 0.399)	(0.16, 0.351)	(0.188, 0.306)
5	0.533	0.634	0.412	0.207	0.102	0.427	0.44	0.369	0.286	0.296
	(0.212, 0.875)	(0.228, 1.072)	(0.088, 0.775)	(-0.033, 0.478)	(-0.12, 0.337)	(0.318, 0.524)	(0.339, 0.547)	(0.268, 0.435)	(0.172, 0.376)	(0.207, 0.377)

Note: The table reports Synthetic Difference-in-difference event-studies for the effect of forward linkages on domestic firms' value-added and employment for different specifications of the threshold. The specification follows the same strategy as reported in the baseline results in Figure 4 but using the reported threshold for definition of treatment as defined in section 3.1. 95% bootstrap confidence intervals are reported in parentheses.

Figure B16: Distribution of domestic firms' revenue from intermediate sales, 2022



Note: The histograms plot the distribution of sales shares of all dyadic (firm-to-firm) sales interactions involving a domestic seller in 2022. The two histograms are for sales shares on intermediate inputs sold to foreign-owned suppliers (the orange bars) and to domestic suppliers (the blue line) respectively. The denominator is the firm's overall revenue in the previous year as used in the main identification strategy – therefore the individual sales shares can exceed one. The x-axis follows a log-10 scale thus indicating that firms' sales shares at the firm-to-firm interaction level are approximately log-normal distributed in the left tail with a larger probability mass in the right tail exceeding the 10% cut-off used as the main specification in the paper. The dashed and dotted lines report the mean of all sales shares to the two sub-groups reflecting the long right tail of the log-normal distribution. Vertical lines reflect the 10%, 1%, and 0.1% cut-offs used for identification of meaningful interactions with foreign-owned firms in the robustness test respectively.

Table B2: Alternative thresholds: Foreign buyer

	log value-added					log employment				
	0.1%	**1%**	**5%**	**10%**	**20%**	**0.1%**	**1%**	**5%**	**10%**	**20%**
Horizon										
-5	-0.008	-0.007	0.006	0.01	0.032	-0.005	-0.007	0.002	0.003	0.001
	(-0.038, 0.022)	(-0.025, 0.006)	(-0.02, 0.037)	(-0.021, 0.042)	(-0.018, 0.084)	(-0.015, 0.003)	(-0.014, -0.0)	(-0.01, 0.013)	(-0.011, 0.019)	(-0.008, 0.008)
-4	0.003	0.0	0.003	0.001	0.006	-0.005	-0.003	0.001	0.002	-0.002
	(-0.014, 0.02)	(-0.014, 0.015)	(-0.009, 0.017)	(-0.016, 0.019)	(-0.013, 0.026)	(-0.01, 0.002)	(-0.007, 0.002)	(-0.006, 0.008)	(-0.008, 0.013)	(-0.008, 0.005)
-3	-0.001	0.002	0.011	0.009	0.006	-0.004	-0.002	0.001	0.001	0.002
	(-0.014, 0.008)	(-0.007, 0.013)	(-0.001, 0.021)	(0.0, 0.02)	(-0.005, 0.021)	(-0.01, 0.001)	(-0.005, -0.0)	(-0.002, 0.003)	(-0.002, 0.005)	(-0.002, 0.005)
-2	-0.001	0.002	-0.005	0.001	0.01	0.002	-0.002	-0.0	-0.001	-0.001
	(-0.008, 0.007)	(-0.007, 0.011)	(-0.019, 0.008)	(-0.007, 0.013)	(-0.007, 0.028)	(-0.002, 0.005)	(-0.008, 0.004)	(-0.002, 0.002)	(-0.004, 0.001)	(-0.004, 0.002)
-1	0.003	-0.0	-0.001	-0.002	-0.006	0.001	0.0	0.0	0.0	0.0
	(-0.0, 0.01)	(-0.004, 0.004)	(-0.009, 0.007)	(-0.008, 0.005)	(-0.016, 0.004)	(-0.0, 0.002)	(-0.0, 0.001)	(-0.0, 0.001)	(-0.0, 0.001)	(-0.0, 0.001)
0	0.072	0.111	0.148	0.223	0.328	0.095	0.098	0.1	0.099	0.149
	(-0.027, 0.176)	(0.023, 0.198)	(0.055, 0.239)	(0.121, 0.36)	(0.165, 0.496)	(0.061, 0.128)	(0.054, 0.131)	(0.063, 0.138)	(0.036, 0.164)	(0.08, 0.22)
1	0.069	0.03	-0.006	-0.09	-0.035	0.113	0.103	0.146	0.142	0.209
	(-0.068, 0.207)	(-0.114, 0.159)	(-0.146, 0.158)	(-0.287, 0.077)	(-0.264, 0.186)	(0.065, 0.168)	(0.049, 0.174)	(0.084, 0.208)	(0.042, 0.227)	(0.11, 0.309)
2	-0.017	0.033	-0.005	0.007	0.162	0.058	0.054	0.082	0.045	0.164
	(-0.191, 0.155)	(-0.162, 0.206)	(-0.172, 0.187)	(-0.165, 0.203)	(-0.046, 0.384)	(0.001, 0.131)	(-0.028, 0.14)	(-0.017, 0.174)	(-0.053, 0.154)	(0.025, 0.279)
3	-0.092	-0.01	0.008	-0.008	0.072	0.017	-0.009	0.055	0.095	0.182
	(-0.314, 0.082)	(-0.217, 0.151)	(-0.176, 0.185)	(-0.246, 0.222)	(-0.206, 0.358)	(-0.08, 0.109)	(-0.122, 0.1)	(-0.035, 0.142)	(-0.019, 0.212)	(0.065, 0.314)
4	-0.061	-0.039	-0.105	-0.12	-0.041	-0.036	-0.028	0.056	0.048	0.139
	(-0.33, 0.145)	(-0.229, 0.165)	(-0.32, 0.121)	(-0.372, 0.145)	(-0.293, 0.291)	(-0.138, 0.074)	(-0.146, 0.088)	(-0.081, 0.168)	(-0.127, 0.219)	(-0.001, 0.296)
5	-0.214	-0.122	-0.071	0.026	-0.08	-0.045	-0.062	0.049	0.093	0.242
	(-0.533, 0.12)	(-0.38, 0.202)	(-0.355, 0.236)	(-0.299, 0.377)	(-0.483, 0.309)	(-0.166, 0.075)	(-0.177, 0.102)	(-0.133, 0.221)	(-0.141, 0.337)	(0.005, 0.425)

Note: The table reports Synthetic Difference-in-difference event-studies for the effect of backward linkages on domestic firms' value-added and employment for different specifications of the threshold. The specification follows the same strategy as reported in the baseline results in Figure 5 but using the reported threshold for definition of treatment as defined in section 3.1. 95% bootstrap confidence intervals are reported in parentheses.

C Unbalanced Synthetic Control DiD estimator

In this appendix we outline how we compute the synthetic difference-in-difference estimates for the unbalanced panel. Denote outcomes as $Y_{i,t}$. For any cohort, suppose that we order outcomes such that index $i = 1, ..., N^{co}$ denotes control units. We define a cohort as all units treated at time z, observed at treatment horizon h for which at least p pre-treatment outcomes are observed. That is, a cohort is a sub-panel for which observations are non-missing from period $z - p$ up to period $z + h$. For each cohort (z, h, p) of treated units, we find the cohort of valid controls, that is firms with non-missing observations from $z - p$ to $z + h$ that have not been exposed to treatment at $z + h$. This control group comprises both never-treated and not-yet-treated units, although in principle we could focus on either group. We then conduct the following analysis on this sample.

First, we compute unit-weights for the synthetic control group following the constrained and normalised minimisation problem of differences between the mean observed pre-treatment outcome between treated and controls.

$$\widehat{\omega}^0_{z,h,p}, \widehat{\omega}_{z,h,p} = \text{argmin}_{\omega^0, \omega^{sdid}} \sum_{t=z-p}^{z-1} \left(\omega_0 + \sum_{i=1}^{N^{co}_{z,h,p}} \omega_i Y_{i,t} - \sum_{i=N^{co}_{z,h,p}+1}^{N^{co}_{z,h,p}+N^{tr}_{z,h,p}} \frac{1}{N^{tr}_{z,h,p}} Y_{i,t} \right)^2 + \zeta^2 p ||\omega||_2^2$$

subject to the constraint that the set of ω_i lies on the boundary of the simplex, i.e. $\sum_{i=1}^{N^{co}_{z,h,p}} \omega_i = 1$. ζ is a normalisation constant where we utilize the parametrisation defined in Arkhangelsky et al. (2021) and $||\omega||_2$ is the L2-norm of unit-weights.

Second, we compute weights for the pre-treatment periods that for control units best predict outcomes in the post-treatment period.

$$\widehat{\lambda}^0_{z,h,p}, \widehat{\lambda}_{z,h,p} = \text{argmin}_{\lambda^0, \lambda^{sdid}} \sum_{i=1}^{N^{co}_{z,h,p}} \left(\lambda^0 + \sum_{t=z-p}^{z-1} \lambda_t Y_{i,t} - \frac{1}{h+1} \sum_{t=z}^{z+h} Y_{i,t} \right)^2 + \zeta^2_{time} ||\lambda||_2^2$$

subject to the constraint $\sum_{t=z}^{z+h} \lambda_t^{scdid} = 1$. These correspond exactly to the specification in Arkhangelsky et al. (2021) if the observed cohort were the only cohort analysed. We then estimate cohort-specific average treatment effects on the treated $\tau^h_{z,t,p}$ where $t \leq h$ is the horizon of observation and h is the maximum horizon observed in cohort (z, h, p) as

$$\begin{aligned} \widehat{\tau}^h_{z,t,p} = & \left(\sum_{i=N^{co}_{z,h,p}+1}^{N^{co}_{z,h,p}+N^{tr}_{z,h,p}} \frac{1}{N^{tr}_{z,h,p}} Y_{i,t} - \sum_{i=1}^{N^{tr}_{z,h,p}} \widehat{\omega}_i^{scdid} Y_{i,t} \right) \\ & - \sum_{l=h-p}^{h-1} \lambda_l \left(\sum_{i=N^{co}_{z,h,p}+1}^{N^{co}_{z,h,p}+N^{tr}_{z,h,p}} \frac{1}{N^{tr}_{z,h,p}} Y_{i,l} - \sum_{i=1}^{N^{tr}_{z,h,p}} \widehat{\omega}_i^{scdid} Y_{i,l} \right) \end{aligned}$$

This yields a cohort-horizon-specific effect at each point for the cohorts. For every cohort,

we only retain $\tau^h_{t,h,p}$, i.e. the post-treatment effect at the horizon h for which the cohort (z, h, p) was selected. This ensures that no treated unit is double-counted in any of the horizon-specific post-treatment estimates. We then aggregate horizon-specific ATTs as

$$\widehat{\overline{\tau}}_h = \sum_z \sum_p \frac{N^{tr}_{z,h,p}}{\sum_z \sum_p N^{tr}_{z,h,p}} \widehat{\tau}^h_{z,h,p}$$

For pre-treatment periods, we aggregate horizon-specific effects but retaining all estimates generated. The pre-treatment estimates are not an indication of parallel trends but rather serve as an indication whether the computation of the synthetic control group successfully manages to match pre-treatment outcomes. Any deviations from zero imply that the estimator is not reliable. By contrast, pre-treatment estimates close to zero are not sufficient to infer that the identifying assumptions of the estimator hold.[22]

[22]This can be seen as analogous to testing for the absence of pre-trends in a standard difference-in-differences estimator which is necessary but not sufficient for the estimator's assumptions to hold.