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Abstract*

Intra-firm trade, from parents to affiliates, has been combined with standard models of multinational production (MP) to deliver gravity-style predictions for foreign affiliates' sales. Nonetheless, the evidence shows that intra-firm trade is concentrated among a small set of large multinational firms. Using firm-level data from 35 countries, we document that only firms belonging to multinational corporations (MNCs) in the upper tail of the firm's size distribution are significantly affected by the distance to their parents. We present a simple framework featuring MNCs' selection into intra-firm trade and derive the analytical gravity equations that are consistent with the empirical findings.

JEL classifications: F12, F23
Keywords: Intra-firm trade, Multinational production

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1. Introduction

The proximity-concentration trade-off constitutes the basis of one of the most important theories of multinational production. Under this theory, a firm decides between i) concentrating production in its domestic market and serving foreign consumers through exports that are subject to transportation costs and ii) setting up an additional plant abroad in close proximity to its foreign clients. In stark contrast with the prediction of the workhorse monopolistic competition model of trade and foreign direct investment, several new empirical papers document that total foreign affiliates' sales are subject to gravity-style forces akin to those observed for aggregate exports (Yeaple, 2009; Keller and Yeaple, 2013; Irarrázabal et al., 2013). That is, rather than overcoming the transportation costs associated with exports, multinational sales are decreasing with respect to remoteness and other geographical variables.

A natural explanation for the observed patterns of bilateral foreign affiliate sales is the existence of trade in intermediate inputs across countries within the boundaries of the firm. The usage of intermediate inputs produced by the parent introduces a source of complementarity between trade and multinational production, given that foreign affiliates have to import intermediate inputs from their home market to produce overseas. Intra-firm trade is indeed an important component of multinational activities. In the case of the United States, exports of manufactured goods from U.S. parents to their cross-border network of affiliates account for 20 percent of total U.S. exports, and intra-firm imports by foreign-controlled U.S. affiliates from their foreign parent groups account for 20-25 percent of total U.S. imports.

Based on these facts, several models of horizontal multinational production and intra-firm trade have assumed in their framework that all affiliates import from their parents. Nonetheless, a striking feature of intra-firm trade data is its pronounced heterogeneity across firms. Using detailed data for U.S. multinationals and their network of foreign affiliates from the Bureau of Economic Analysis (BEA), Ramondo et al. (2014) have documented that intra-firm trade is concentrated among a small number of large affiliates, representing only a very small share of their inputs and total sales. They documented that in 2004 the median manufacturing affiliate received none of its inputs from its parent firm[1] and sold 91 percent of its production to unrelated parties, mostly located in the host country.

[1] Of course, this does not rule out the possibility that an affiliate is importing intermediate inputs from another affiliate who is part of the international production chain. Unfortunately, such flows are not recorded in any of the available

The theory of multinational production based on vertical integration is also challenged by the gravity observed in the activity of multinational companies (i.e., the more distant the host country from headquarters, the lower the sales and employment of the foreign affiliates). In contrast with models of horizontal multinational production and intra-firm trade in which firms may or may not engage in intra-firm trade, in models of vertical multinational production, intra-firm trade is a necessary condition for the existence of foreign affiliates, whose main role is to provide intermediate inputs to their parents and to other affiliates within the corporation. Therefore, the vertical integration theory of multinational activity could not rationalize the observed absence of intra-firm flows among firms within the same corporate group selling the majority of their output to unrelated parties in the host market.

These findings pose new challenges to the theory. First, as we highlighted before, existing models assume that all affiliates import from their parents, and they are therefore silent about the selection and skewness observed on intra-firm flows. Second, if intra-firm trade is what causes affiliate sales to decline with trade frictions, then gravity forces will affect only those firms in the upper tail of the firm size distribution but not smaller firms.[2] Using the ORBIS dataset, we present evidence consistent with a significant resistance to geographical barriers for firms at the upper tail of the firm size distribution. Although significantly less strong and statistically imprecise, we also find evidence that standard gravity variables (i.e., distance, common border, common language, and regional trade agreements) play a weak role in diminishing the observed foreign affiliate sales for smaller firms which often do not trade with their parents and sell the vast majority of their output to unrelated parties in the host market. These results of the impact of gravity on multinational activity are robust to different econometric specifications.

In order to rationalize these findings, we present a simple multi-country model of heterogeneous firms in which parent firms decide whether or not to supply foreign affiliates with intermediate inputs and, if so, they optimally decide the fraction of intermediate inputs that should be imported from the parent company. Results from the proposed theoretical framework match the distribution of multinational sales as well as the intra-firm trade patterns observed in the data: the least productive firms do not import at all from their parents, whereas the most productive ones

datasets. Nevertheless, the fact that the vast majority of affiliates sell their output to unrelated parties alleviates part of these concerns. We discuss these issues in more detail in a later section.

[2] Of course, the fact that intra-firm trade is concentrated among the largest multinational corporations, could be enough to generate FDI gravity in the aggregate data.

engage in intra-firm trade. In the model, the selection is explained by the irreversible investment that a multinational corporation has to make to establish an adequate platform to carry on cross-border transactions within the boundaries of the firm on a regular basis.[3] We derive the analytical bilateral gravity equations for i) export sales, ii) foreign affiliate sales for those firms importing inputs from parents, and iii) foreign affiliate sales of those firms outsourcing inputs from unaffiliated parties. We show that gravity forces vary across the three groups, which is consistent with our empirical findings.

This paper contributes to previous efforts to rationalize intra-firm trade patterns. Irarrázabal et al. (2013) propose a Helpman et al. (2004) model (henceforth HMY) of horizontal multinational production with intra-firm trade from parents to affiliates. In their model, all firms engage in intra-firm trade and imports of intermediate inputs from their parents. Similarly, Ramondo and Rodríguez-Clare (2013) and Keller and Yeaple (2013) develop a general equilibrium model of trade and multinational production in which foreign affiliates use an international input bundle in production, where some share is imported from the parent firm. This paper differs from these approaches by endogenizing the existence of intra-firm trade as well as the degree to which it occurs.

Following Keller and Yeaple (2013), we assume that when a firm produces overseas, it either i) establishes communication with the headquarters to receive instructions for producing each intermediate input (direct knowledge transfer) or ii) transfers knowledge across borders by exporting intermediate inputs embodying the technology (indirect knowledge transfer). When the firm produces its own intermediate inputs, it incurs the cost of transferring knowledge across countries (which varies across firms depending on knowledge intensity). If the firm instead buys intermediate inputs from its parent, it incurs the associated transportation costs.

Our paper improves upon the previous theoretical frameworks in several dimensions. First, since knowledge intensity is more heterogeneous across firms within an industry than it is across industries, we choose to make knowledge intensity firm-specific rather than sector-specific, as in Keller and Yeaple (2013). Second, our model is the first to introduce firm selection into intra-firm trade. In our model, the effects of gravity forces on affiliates' sales increase incrementally with firm size and then jump up (in absolute terms) for larger firms due to the presence of intra-firm

[3] The high cost associated with these important coordination efforts is a fact well explored in the international management literature (Seuring and Goldbach, 2002).

trade. To the best of our knowledge, our paper is the first to test for bilateral gravity forces in foreign affiliate sales along the firm size distribution. Our findings confirm the increasing effect of distance from parent on foreign affiliate sales along the firm size distribution, but more importantly, we provide evidence of a jump of the effect for firms in the 90th percentile of the distribution.

Our paper is also related to the strand of literature that attempts to distinguish horizontal and vertical multinational production by tracking the patterns of intra-firm trade. Antras and Helpman (2004) developed a theoretical model of trade with heterogenous firms and incomplete contracts to study firm boundaries and outsourcing decisions. They show that the parent firm chooses to outsource intermediate inputs from its affiliates (intra-firm trade) or from unrelated parties (arms-length trade) to maximize profits given its level of productivity and the importance of relationship-specific investments needed between the parent and the affiliate. Our paper differs from Antras and Helpman (2004) in two ways: i) it attempts to model trade flow from parent to affiliate (instead of flows of intermediate inputs from affiliates to parents) while taking the boundaries of the firm as given, and ii) it tries to explain intra-firm trade under the framework of horizontal FDI, rather than vertical FDI as in Antras and Helpman (2004).

Other papers, like Carr et al. (2001), rely on models in which both vertical and horizontal firms can arise endogenously due to the simultaneous existence of trade costs and different factor intensities across activities, without counting on observed intra-firm trade flows (Markusen et al., 1996; Markusen, 1997). The theory explains the volume of production of foreign affiliates as a function of the characteristics of the host and source country, finding that outward investment from a source country to affiliates in a host country is increasing in the sum of their economic sizes, their similarity in size, the relative skilled labor abundance of the parent nation, and the interaction between size and relative endowment differences.

Our work relates to the literature that aims to understand the determinants of the existence and magnitude of intra-firm flows. In order to account for the two-way intra-firm trade and the multiple border-crossings of intermediate goods observed in the data, Egger and Pfaffermayr (2005) specify bilateral intra-firm imports and exports equations at the bilateral-sector level as a function of market size, unit labor costs and aggregate affiliate characteristics. Bernard et al. (2010) examine the product and country determinants of intra-firm trade and find that factors associated with engaging in related-party trade differ from those associated with the intensity of intra-firm trade once a link is established. In particular, they find that higher-quality country governance is associated with a higher probability of related-party trade taking place, yet higher-quality country governance leads to the largest reductions in intra-firm trade in low contractibility products. Unlike these papers, we rely on firm-level data, rather than on aggregate country-sector level data, on parents and affiliates' sales and R&D expenditures to understand the relationship between MP gravity and firm size.

Our paper is also related to the literature that uses firm-level data. Corcos et al. (2013) exploits data on imported manufactured goods by French firms in 1999 and finds that the choice of intra-firm sourcing is more likely in more productive, capital- and skill-intensive firms, and that imports from countries with well-functioning judicial institutions are more likely to be intra-firm, results that provide empirical support to the property rights theory (Antras, 2003; Antras and Helpman, 2004). Additionally, exploiting a unique sample of foreign affiliates in Sub-Saharan Africa, Blanas and Seric (2018) document that foreign affiliates engaging in intra-firm trade are relatively few (a finding in line with Ramondo et al., 2014) and that the majority of these also engage in trade at arm's length, accounting for an important fraction of their total trade. Unlike these papers, we test the strength of the gravity of multinational production at different parts of the firm size distribution in order to infer the role of intra-firm trade and provide a theoretical framework that rationalizes these empirical observations.

The reminder of the paper is organized as follows. Section 2 discusses the main source of data used in our analysis as well as the main characteristics of multinational sales at the firm level. Section 3 presents the three main stylized fact that support our contribution to the literature. Section 4 presents the theoretical framework and derives the analytical implications for intra-firm flows and multinational sales. Section 5 concludes. Proofs, detailed analytical derivations and further empirical results can be found in the Online Appendix.

2. Data

2.1 Multinational Production Data

In this section, we explain in detail the source and characteristics of the dataset used in the analysis. The primary source of information is ORBIS, which gathers firm-level information across a wide range of countries. In particular, it contains relevant information about the ownership structure of the firm, with a detailed list of direct and indirect subsidiaries and stockholders, the company's degree of independence, its ultimate owner and other companies in the same family.[4]

The richness and usefulness of ORBIS lies in the large scope and depth of the ownership linkages across affiliates that it offers. But despite its wide coverage, there are important challenges in using ORBIS firm-level data in order to analyze multinational corporations. In particular, the financial ownership linkages in ORBIS often do not correspond to the notion of management control and multinational corporation embedded in most trade models. By not having a proper identification of the ownership structure of multinational firms, we face the risk of misrepresenting corporate groups, increasing the misalignment between the objects in our models and the moments in the data. Alviarez and Handly (2015) provide a full characterization of ORBIS dataset in order to close this gap, and to construct a suitable dataset for the study of multinationals, improving upon the Global Ultimate Owner (GUO) and the Immediate Shareholder (ISH) often used to link firms across borders.[5]

Unfortunately ORBIS does not have information about the transaction between parents and affiliate firms, as the BEA or to some extent the Census Bureau data does; it instead offers more information about the foreign affiliates' operations, including financial statements, as well as a comprehensive set of indicators of economic activity. Regarding the sample, we consider all multinational corporations with financial information for the period (2004-2013). The analysis focuses on multinational corporations whose primary activity is manufacturing industries. Four categories of information are used for each firm: i) industry information, including the 4-digit NAICS code of the primary industry in which the establishments operate; ii) location information; iii) non-consolidated financial information, including operating revenue, employment, assets, investment, wages, material cost; and iv) degree of ownership and detailed information about the global ultimate owner, including a comprehensive set of financial information on parent firms that

[4] Alfaro and Chen (2012) have assessed the extent and coverage of this data set using more aggregated information for alternative sources.

[5] We also consider a company to be an ultimate owner (UO) if it has no identified shareholders or if its shareholders' percentages are not known. It is worthwhile to mention that we consider only Global rather than Domestic ultimate owners. The Domestic UO is the highest company in the path between a foreign affiliate and its Global UO but that is located in the same country as the affiliate firm. Thus, an affiliate will be considered domestic, rather than foreign, when the GUO and the DUO are both in the same country. The definition of Global Ultimate Owner, with a minimum of 50 percent ownership adopted in this paper, is also the one followed by international agencies and by the U.S. Bureau of Economic Analysis.

includes industry of operation, revenue, employment, assets, research and development expenditures, and number of patents, among other features.

In order to construct a useful sample, the data were subjected to an extensive cleaning-up process in which we eliminate firms whose operating revenue is below one million dollars and with less than 15 employees. Furthermore, to alleviate the problem from potential outliers, we eliminate firms below the 0.1th percentile and above the 99.9th percentile in the distribution of sales. The final sample comprises 8,572 foreign affiliates and 2,210 parents, covering 261 manufacturing industries for the period 2004-2013.

2.2 Distance from Headquarters

To calculate the distance from the affiliate's location to its headquarters, as well as the weight distance from each affiliate to other affiliates that belong to the same corporate group and that are located in third countries, we use specific information on the address of each company to determine its exact location (longitude and latitude) and with this information determine the exact distance between each affiliate within the corporate group. Figures D1 and D2 in the Online Appendix illustrate the spatial sales distribution of Spanish and French foreign affiliates located in Italy, and Italian and German firms located in France, respectively, in the Chemical and in the Transportation and Equipment sectors. As can be observed, foreign affiliates from different countries can substantially differ in their location within a country, and even coming from the same country but in different sectors. Therefore, it is possible to underestimate or overestimate the distance from parents to affiliates if the same distance from capital to capital is assigned to all corporations, in all sectors, operating in a given country pair.

2.3 Other Data

In some of our empirical specifications we construct and use ad valorem time-varying bilateral trade costs for the United States (see Online Appendix for further details). Other bilateral variables (common language, common boarder, colonial history, etc.) and control variables such as GDP and measures of institutional quality are extracted from the CEPII Gravity Data and World Bank Indicators.

3. Stylized Facts

In this section, we introduce some key regularities about the foreign sales and the location patterns of multinational firms. First, we show evidence of the granularity of multinational activity from the parent as well as the affiliate perspective. It is important to note that multinationals are a relatively rare type of firm; despite the disproportional contribution of multinationals to total output and trade, they represent less than 1 percent of all companies. Moreover, the vast majority of parents only operate in one foreign market regardless of the manufacture industry, and for any given market-sector pair the market share of foreign production is concentrated in a very small set of affiliates. Second, we present some initial empirical evidence on the differential effects of distance on MP depending on firm size. Overall, this section provides the grounds of our motivation and provides support for the building blocks of the model proposed in Section 4.

3.1 The Distribution of Foreign Affiliate Sales Is Fat-Tailed for Each Country and Sector Pair

A well-documented fact is that firm sales follow a Zipf Law distribution (Gabaix, 2009; di Giovanni and Levchenko, 2012). In addition, Ramondo et al. (2014) show that intra-firm trade is concentrated among a small number of large affiliates. In particular, firms below the mean of the size distribution do not trade with their parent firms at all. In this subsection, we show that the distribution of sales of U.S. foreign affiliates—as well as the sales of foreign affiliates in the United States—is very fat tailed not only overall, within an industry, or within a country, but also for a given country-sector pair. Table 1 shows that the largest 1 percent of firms accounts for more than 50 percent of total sales in various countries. Figure D3 in the Online Appendix plotting firm log rank against log size (measured by employment) confirms the Zipf Law distribution of the firm size.

3.2 Research and Development Intensity Is Highly Heterogeneous across Multinational Firms within a Narrowly Defined Industry

As discussed in the introduction, direct knowledge transfer is a key element in MP. The cost of direct knowledge transfer between parent and affiliates depends on the knowledge (research) intensity and the complexity of products, as demonstrated by Keller and Yeaple (2013). Therefore, research intensity impacts whether a firm engage in intra-firm trade and the share of inputs imported from parents. In addition, the elasticity of foreign affiliates' sales with respect to distance from parent will depend on the firm research intensity to some extent. Borga and Zeile (2004) find that for foreign manufacturing affiliates the propensity to source intermediate goods from their U.S. parents is increasing in their parent R&D and capital intensity. This suggests that the propensity of affiliates to source intermediate inputs from their parents is related to the level of intangible assets embodied in the inputs traded within the firm.

The expenditure in research and development is remarkably higher among the most productive U.S. parent firms. In fact, more than 80 percent of the R&D expenditures in a given industry is in the hands of a small number of very large firms. Figure 2 shows the density of parents' R&D expenditure share for four selected 3-digit level NACE sector classification: i) manufacturing of parts and accessories for motor vehicles—NACE 293 (top-left panel); ii) manufacture of other special-purpose machinery—NACE 289 (top-right panel); iii) manufacture of basic pharmaceutical products—NACE 211 (bottom-left panel); and iv) manufacture of air and spacecraft and related machinery—NACE 303 (bottom-right panel). The share of R&D is calculated as the share of the research and development expenditures of the firm relative to the total R&D expenditures of all U.S. parent firms operating in the same 3-digit sectoral classification. It is clear that the concentration of R&D expenditures in a few large parents is not being driven by sector-specific characteristics. The results are qualitatively similar even when considering only those firms belonging to a given sector.

3.3 Gravity and Firm Size

Using different datasets, at varies levels of disaggregation and using alternative specifications, previous studies have found that foreign affiliate sales decrease with distance from their parent. Horizontal models of foreign direct investment, in which multinational activity serves as an alternative to trade, have rationalized this fact by including trade in intermediates inputs from parent to affiliates, which as arms-length trade is also subject to gravity forces. Strikingly, using firm-level BEA data on intra-firm trade, Ramondo et al. (2014) documented that only a few large firms in large corporations conduct intra-firm trade transactions.

In this subsection we show that, consistent with the observed patterns of intra-firm trade, firms below the median are significantly less affected by distance from headquarters, but in contrast, firms in the upper tail of the firm size distribution are strongly affected by gravity variables. We divide the analysis by different measures of firm size, and we also compare our results with the literature. We adopt three alternative ways of classifying foreign firms by their size. First, we construct groups of affiliates by the size of the corporate group they belong to, by assigning each corporation to a given quartile according to the size of their global sales relative to other MNCs in the same source country-sector pair.[6] Second, we classify affiliates by their size relative to other foreign affiliates in the same host country sector-pair, but regardless of the size of the corporation they belong to. Third, we use the variation of firm size within a given parent or corporate group to compare the effect of gravity on affiliates of different sizes.

To establish a benchmark — and to be able to compare with previous literature — Table 2 presents the effect of physical distance and tariff on the natural log of affiliate sales by pooling all firms together without discriminating across different sizes. Table 2 shows that affiliate' sales are negatively affected by their distance to the parent, after controlling for the size of the parent (measured by their sales) and controlling for different sets of fixed effects in the specification. The left panel of Table 2 (columns 1, 2 and 3) controls for sector, host country and source country characteristics by including sector, location and origin fixed effects. In the right panel (column 4 to 6), sector-location fixed effects are included in addition to origin fixed effects to control for any characteristics that are particular to a sector-host country combination. Notice that controlling by the weight distance from the affiliate to other affiliates belonging to the same corporation but located in third countries (column 2 and 5) increases the effect of distance from the affiliate to the parent in the home country.[7] In columns 3 and 6, higher tariffs between the host and source country in the sector of operation of the foreign affiliate negatively affect the size of the affiliate's sales.

These results at the level of the firm are consistent with evidence found by previous studies using different datasets, levels of aggregation and alternative specifications. In particular, Ramondo et al. (2014) found a negative effect of distance on affiliate sales and number of affiliates, aggregated at the country-affiliates sector-parent level for U.S. multinationals. In addition, using BEA data at the firm level, Keller and Yeaple (2013) found that the size of U.S. foreign affiliates significantly decreases with trade cost, and that this effect is more prominent for affiliates whose

[6] Results are robust to a quartile classification based on the size of global sales in the primary sector of the parent regardless of the country where the headquarter is located. We prefer a ranking source that is country-parent sector specific because, even when the market is common across corporations (i.e., the entire world), the size of home and nearby market have important effects on the corporation's global sales.

[7] The coefficient of distance to affiliates in third countries is positive and statistically significant, suggesting that the more remote from other affiliates the firm is, the larger its size. This is consistent with affiliates that not only sell to domestic markets, but also sell to other nearby countries.

parents operate in knowledge-intensive sectors. Nonetheless, the direct effect of trade cost on affiliate size becomes insignificant when sector and location fixed effects are included.[8] Irarrázabal et al. (2013), using data on Norwegian firms, found a negative and significant effect of distance on affiliate sales when data are aggregated at the location sector level, but the significance decreases when firm-level data are used and firm fixed effects at the corporate group level are introduced.

Table 3 shows results similar to those found by previous research when restricted only to U.S. foreign affiliates, and, instead of looking at the effect of distance and tariff, we follow Keller and Yeaple (2013) in constructing U.S. trade cost as the sum of freight and tariff.[9] The first two columns in Table 3 include parent fixed effects and the second column also includes the interaction between R&D intensity at the sectoral level and trade cost, with a negative and significant coefficient at the 5 percent level. That is, affiliates operating in more knowledge-intensive sectors are more affected by gravity forces. Controlling instead for sector and country fixed effects and the size of the corporate group, columns 3 and 4 eliminate the direct statistical significance of distance on sales. These results are analogous to the ones found by Keller and Yeaple (2013).[10]

Given that trade among affiliates within a corporation is restricted to the largest corporations and that only the largest one percent account for more than half of a country's production, we proceed to explore whether the effect of gravity is different across different segments of the firm's size distribution. Table 4 uses all the foreign affiliates in our sample and assign each affiliate to the quartile that corresponds to its parent. As we mentioned above, each corporation is assigned to a given quartile according to the size of their global sales relative to other MNCs in the same source country-sector pair. To test whether there is any differential effect across firms of different sizes, we include quartile dummies interacted with our variable of distance to parent. As expected, affiliates belonging to larger corporate groups are larger on average, but

[8] Both trade cost and the interaction of trade cost and knowledge intensity are statistically significant when parent fixed effects are included. Nonetheless, the direct effect of trade cost on affiliate size is reduced when country and sector controls are included, and it disappears when parent fixed effects are replaced by location and sector fixed effects.

[9] Freight costs are usually calculated from trade values including cost, insurance, freight (c.i.f) to values that do not include them (free on board, or f.o.b values). Unfortunately, this cannot be calculated for all countries using the trade values reporter for the importer and the exporter for each country pair-sector triplet. At four digits of sectoral disaggregation half of the observations have fob values above the c.i.f values, generating negative freight cost. For the United States we use CENSUS data processed by Shoot in order to compute the weighted freight costs. See Online Appendix for details.

[10] In Online Appendix Table D4 we report the results for all foreign affiliates and not only the United States.

more importantly the interaction term between each quartile and distance is negative and statistically significant for all quartiles—and particularly stronger for affiliates belonging to corporations in the upper quartile. In fact, given that the direct effect of distance on affiliate size is positive, it is clear that the total effect is negative and significant only for affiliates in the third and fourth quartiles, and it is particularly strong for the latter. Notice that this result is robust to alternative specifications including different sets of fixed effects as well as the interaction of R&D intensity and distance as well as the unit direct requirement of the industry of the affiliate from the industry of the parent.

Next, we classify affiliates by their size relative to other foreign affiliates in the same host country sector-pair but regardless of the size of the corporation they belong to. To this end we use a quantile regression approach for the percentiles 10, 25, 50, 85 and 90, and the results are presented in Table 5. For comparison, the first column of Table 5 shows the results for OLS that serve as benchmark. The OLS coefficient that captures the average effect of distance on affiliate sales is negative and significant. Nonetheless, the effect of distance between the foreign affiliate and its parents located in the source country varies over percentiles. In fact, only the size of affiliates above the median is significantly affected by distance from its parents after adding a rich set of controls as well as location, source country and sector fixed effects. Interestingly, the average effect of the interaction between R&D intensity and distance to parent is negative and significant, but these effects are strong for lower percentiles of the firm size distribution, while they virtually disappear for higher percentiles. The direct requirements of the industry where the affiliate operates from inputs from the industry of the parent is significant for large foreign affiliates. A service dummy has been included, which take the unit value when in the same country where the affiliate is located there is also an affiliate from the same corporate group whose primary activity is management services.[11]

Figure 3 shows the quantile point estimates (solid line) for the distance coefficients as well as the confidence intervals at the 95 percent level (gray area). The dashed lines correspond to the OLS coefficient, and the vertical dots represent its corresponding confidence intervals. Notice that

[11] Tables D1 and D2 show the number of multinational corporations and the corresponding share of revenue for MNCs whose affiliates all operate in manufacturing. As can be observed, MNCs acting exclusively in manufacturing are almost an exception for corporations operating in more than five countries. Similarly, MNCs with operations in manufacturing as primary activity but with some affiliates in management services and wholesale represent a larger share of revenue among MNCs with a presence in more than five countries.

for low and high percentiles the point estimates of the quantile regression lie outside the OLS confidence interval and that the confidence interval of the OLS and the one corresponding to the quantile regression differ considerably for the extreme quantiles, showing greater overlap for middle quantiles.

To make these results comparable to previous work, we run a similar regression, but only focusing on manufacturing U.S. foreign affiliates. A similar pattern emerges in which most of the statistical significance of OLS estimates is driven by the larger effect of distance on affiliate sales for relatively large firms. As before, the unit input requirements are positive and statistically significant for large foreign affiliates, and distance affects sales size more for those affiliates in sectors R&D-intensive. Notice that for the sample of U.S. firms, tariffs negatively affect affiliate size. This is in line with large foreign affiliates accounting for most intra-firm transactions, as documented in Ramondo et al. (2014); full results are reported in Online Appendix Table D5. Figure 4 shows the coefficient on distance along the quantile domain. As can be observed, relatively large U.S. foreign affiliates are statistically more affected by gravity, while relatively small U.S. affiliates are bigger when located in remote countries.[12]

Finally, we use the variation of firm size within a given parent or corporate group to compare the effect of gravity on affiliates of different sizes. Table 6 shows five specifications, all of which include parent fixed effects. After adding sector fixed effects and country level controls, such as GDP and a proxy for institutional quality, we find that within a corporation, more distant affiliates are more negatively affected by gravity forces. Nonetheless, this effect disappears when the interaction of R&D intensity at the sectoral level and distance from headquarters is included in the regression specification.

In summary, the evidence shows that on average multinational sales are significant affected by gravity forces. Nonetheless, those results mask a great deal of heterogeneity over the quantiles of the firm size distribution. Only firms above the median, with particularly stronger effects on the last quartile of the distribution, are affected by distance and tariffs. Therefore, these results support the idea of intra-firm trade as the source of the observed gravity of multinational production activity. The model presented in the next section attempts to address the observed selection in

[12] Figure D6, in the Online Appendix, shows that tariff only exerts a negative and significant effect in the upper tail of the firm size distribution.

intra-firm trade and its implications on foreign affiliates' sales in relation to distance from parents along the firm size distribution.

4. The Model

Our model is based on Helpman et al. (2004). Firms are heterogeneous in terms of their productivities. Goods are horizontally differentiated, with each variety produced by a firm that acts as a monopolist. A firm can enter the foreign market via exporting or by opening a foreign affiliate in the destination market (FDI). As is well known, in choosing between either mode of entry, a firm faces a proximity-concentration trade-off: establishing a foreign affiliate is associated with lower variable trade costs but a higher fixed cost of conducting multinational production. The model predicts a definitive hierarchy of firms: the least productive firms do not produce, low-productivity firms only sell to the domestic market, medium-productivity firms export, and the most productive firms become multinational corporations. Furthermore, as in Irarrázabal et al. (2013) and Keller and Yeaple (2013), we introduce parent-to-affiliate intra-firm trade to generate FDI gravity akin to the standard trade gravity.

The model contributes to the literature in many ways. First, to be consistent with the stylized facts (i.e., intra-firm trade is concentrated among the very most productive multinational corporations, with the majority of FDI firms report zero intra-firm), we introduce fixed cost of intra-firm trade. Second, consistent with the empirical fact that the share of intermediate inputs to total input costs is also increasing with firm size, we tie firm productivity to firm knowledge intensity (R&D) to associate intra-firm trade with firm size. Finally, we show that FDI gravity-style forces are present for all foreign affiliates, increasing with firm size and significantly higher for the largest affiliates (i.e., affiliates that engage in intra-firm trade with parents.)

4.1 Consumer Demand

The world economy consists of N countries (indexed by i, n). Each country is populated by L_n utility-maximizer consumers, with each consumer inelastically supplying one unit of labor (the only factor of production). A representative consumer in country n derives her utility from the consumption of a homogenous good Q_0 and a continuum of differentiated goods that belong to the differentiated sector Q_n. Consumers' preferences between the homogenous good and the differentiated goods sector are represented by the Cobb-Douglas utility function with an income share μ spent on the differentiated goods

$$U_n = Q_0^{1-\mu} Q_0^{\mu}, \mu \ \in \ (0,1) \tag{1}$$

Preferences on the differentiated good are CES with elasticity of substitution are $\sigma > 1$. The consumption of each variety ω in the of all available varieties in country is n, Ω_n (endogenously determined); $q^d(\omega)$, enters the CES aggregation symmetrically:

$$Q_n = \left[\int_{\omega \in \Omega_n} q^d(\omega)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}} \tag{2}$$

As is well known, the demand for each variety in country n is given by: $q^d(\omega) = A_n p_n(\omega)^{-\sigma}$. Here, $p_n(\omega)$ denotes the price of variety ω in country n. The index of market size in country n, $A_n = \frac{\mu X_n}{P_n^{1-\sigma}}$, is exogenous from the point of view of consumers and individual producers, with P_n denoting the aggregate price level in the differentiated goods sector in country n and X_n representing the total expenditures in country n.

4.2 Production and Market Structure

The market for the homogenous good is perfectly competitive, and the production technology of the homogenous product is linear in labor: w_n units of labor are required to produce one unit of the homogenous good in country n. The homogenous good is freely traded in the world economy. So, as long as $1-\mu$, L_n, and the variable trade costs are large enough, the production of the homogenous good Q_0 in country $n \ \in \ \{1, 2, \dots N\}$ is strictly positive. The price of the homogenous good is normalized to one; in effect, the wage in country n is pinned down by the numeraire and is equal to w_n.[13]

Each country n is endowed with exogenously given potential number of firms (producers) J_n. Each firm produces a unique variety using a variety-specific composite intermediate input. Productivity $\varphi \ \in \ R_{++}$ is a firm-specific that is drawn from a known cumulative distribution $G(\varphi)$ with probability density distribution $g(\varphi)$. Since φ is firm-specific, and each firm produces a

[13] The incomplete specialization assumption has been used by many researchers for tractability and simplification purposes (for example, see Chaney, 2008). Proceeding without the outside sector will not alter the results presented in the paper, however.

unique variety, we index goods with φ instead of ω. A firm with productivity draw φ requires $\frac{1}{\varphi}$ units of the firm-specific composite intermediate input M_{φ} to produce one unit of variety $\omega(\varphi)$. The composite intermediate input is produced under a CES aggregation of a continuum of intermediate inputs with elasticity of substitution $\eta \geq 1$:[14]

$$M_{\varphi} = \left(\int_{0}^{\infty} \beta(z|\varphi)^{\frac{1}{\eta}} m(z)^{\frac{\eta-1}{\eta}} dz \right)^{\frac{\eta}{\eta-1}} \tag{3}$$

Several points warrant attention here. First, $m(z)$ is the quantity of an intermediate input of knowledge intensity z, with higher φ indicating higher knowledge intensity. Second, $\beta(z|\varphi)$ is the cost share of intermediate input z to the total cost of intermediate input bundle specific to φ-firm, and $\infty\ \beta(z|\varphi)dz = 1$ for any φ. Third, $\beta(z|\varphi)$ is log-supermodular in z and φ. That is, while all firms employ the same CES aggregation and use the same continuum of intermediate inputs, the share of each intermediate input z to the total cost of intermediate composite is firm-specific. To be precise, $\beta(z|\varphi)$ is log-supermodular in z and φ if for $z' > z''$ and $\varphi^1 > \varphi^2$, $\beta(z'|\varphi^1)\ \beta(z''|\varphi^2) > \beta(z'|\varphi^2)\ \beta(z''|\varphi^2)$. In words, firm φ is more knowledge-intensive because it requires relatively more knowledge-intensive intermediate inputs relative to the low productivity firm φ^2.[15] Finally, the production technology of producing intermediate inputs is common across all firms: one unit of labor is needed to produce one unit of z.

4.3 Mode of Entry

A domestic firm gains access to the domestic market in country n after incurring a fixed cost of production f_{nn} units of labor. Country $i \neq n$ exporters to country n are subject to both fixed export cost f_{ni}[16] units of country i labor, and iceberg-type variable trade costs, $\tau_{ni} - 1 > 0$. Country i firms can also serve country n via FDI: pay a fixed cost of FDI, f_{ni}^{fdi} units of country i labor and start serving n via its affiliates there. In doing so, a firm avoids the transportation costs associated with shipping the final good but conveys an additional fixed cost of opening an affiliate in country

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[14] It can be shown that the limit of the CES aggregation as η approaches one is Cobb-Douglas.

[15] The intermediate composite aggregation and the notion of log-supermodularity were outsourced from Keller and Yeaple (2013). In contrast to Keller and Yeaple (2013), knowledge-intensity is defined on the firm level, not the industry level; a propriety that enables us to generate firm-level prediction regarding intra-firm trade. For a formal treatment of the log-supermodular assumption and its usage in the international trade context, see Costinot (2009).

[16] First subscript refers to the destination market and the second one to the origin country.

n.[17] Conditional on establishing a foreign affiliate in country n, a parent firm in country i has the option to let its affiliate to produce all intermediate inputs composite M (standard HMY setting), or chooses to ship intermediate inputs to its affiliate (intra-firm trade) where the share of inputs off-shored and the volume of the intra-firm trade are endogenous. If a parent in country i decides to engage in zero intra-firm trade with its affiliate (i.e., let the affiliate produce all the intermediate inputs and the final good), and since M_φ is firm-specific, an affiliate needs $t_{ni}(z) > 1$ units of labor to produce one unit of intermediate input z, reflecting that affiliates are less efficient than their parents. If the firm engages in intra-firm trade, a parent firm pays a fixed cost of f_{ni}^{int} units of country i labor and also pays standard iceberg-type trade costs τ_{ni} to ship the intermediate inputs to its affiliates. As before, those intermediate goods produced by the affiliate itself are subject to productivity losses, which are intermediate input-specific t_{ni}(z)> 1.[18]

The production of intermediate input with knowledge intensity z is firm-knowledge-specific. Moving knowledge over geographic space is costly. Transferring the knowledge required to produce intermediate input z to an affiliate entail, for example, communication cost, and misinterpretation. Put differently, knowledge is not perfectly codified, and therefore any knowledge transfer between a parent and its affiliate is subject to errors. Intuitively, the higher the knowledge intensity of the intermediate input z, the higher the cost of transferring knowledge from a parent to the affiliate.

Knowledge transfer takes two forms. The first is *disembodied knowledge transfer*: parent firms directly transfer the necessary knowledge of producing input z to their affiliates who use the transmitted knowledge to produce that particular intermediate input. If this is the case, as mentioned above, knowledge transfer costs are denoted by $t_{ni}(z)$. To capture the idea that the cost of moving knowledge over space is increasing with knowledge intensity z, we assume that $t_{ni}(0) = 0$, $\lim_{z\to\infty} t_{ni}(z) > \tau_{ni}$ and $t'_{ni}(z) > 0$.[19] The second form is *embodied knowledge transfer*: simply, a parent produces intermediate input z and ships it to the affiliate in country n.

[17] Notice that, in the model, the decision to open an affiliate in country n is endogenous. Therefore, parent firms might choose to perform FDI in multiple countries, in which case the multinational will have more than one affiliate, one in each country.

[18] $t_{ni}(z)$ is a function of trade frictions. Nonetheless, trade costs τ_{ni} rise faster with distance and other trade frictions than does $t_{ni}(z)$. Formally, $0 < \frac{\partial t_{ni}}{\partial \tau_{ni}} < 1$.

[19] Notice that the cost of knowledge transfer is not firm-specific; however, the aggregate cost of disembodied knowledge transfer for a given share of the intermediate inputs varies across firms because of the log-supermodulity assumption.

Finally, the production technology of the final good is invariant to the location of the producer (parent vs. affiliate): regardless of who produces the final good (parent or affiliate), $\frac{1}{\varphi}$ units of M_φ are needed to produce one unit of the final good. The decisions whether to export, to open an affiliate, and to outsource intermediate inputs impact the production of final good only through its impact on the production of the composite of intermediate input M_φ.

4.4 Partial Equilibrium

First, we characterize the geography of input sourcing. The decision whether to outsource the production of intermediate input z involves comparing the cost of embodied knowledge transfer $w_i\tau_{ni}$ and disembodied knowledge transfer $w_n t_{ni}(z)$. The cost of obtaining input z of a foreign affiliate is $c(z) = min\{w_n t_{ni}(z), w_i\tau_{ni}\}$. Given our assumption on the function $t_{ni}(z)$, there exists an intermediate input with knowledge intensity $\tilde{z}$ such that: for any $z < \tilde{z}$, $t_{ni}(z) < \varpi\tau_{ni}$, and for $z > \tilde{z}$, $t_{ni}(z) > \varpi\tau_{ni}$. Then, we define $\tilde{z}(\tau_{ni}\varpi) = t_{ni}^{-1}(\tau_{ni}, \varpi)$, where $\varpi \equiv \frac{w_i}{w_n}$. Conditional on serving market n by FDI, we characterize the cost of the composite intermediate input to an affiliate with productivity draw φ,

$$C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi\tau_{ni}) \\ = \begin{cases} w_n\bar{t}_{ni} & if\ \mathrm{I}(\varphi) = 0, \\ \left(\int_0^{\tilde{z}(\tau_{ni},\varpi)} \beta(z|\varphi)(t_{ni}(z)w_n)^{1-\eta}dz + (\tau_{ni}w_i)^{1-\eta}\int_{\tilde{z}(\tau_{ni},\varpi)}^{\infty} \beta(z|\varphi)dz\right)^{\frac{1}{1-\eta}} & if\ \mathrm{I}(\varphi) = 1, \end{cases} \qquad (4)$$

where $\bar{t}_{ni} \equiv \left(\int_0^\infty \beta(z|\varphi)\, t_{ni}(z)^{1-\eta}dz\right)^{\frac{1}{1-\eta}}$. The indicator function $\mathcal{I}(\varphi)$ equals one if an affiliate outsources some of the intermediate inputs from its parent and zero otherwise. As we show below, the indicator function depends on firm's productivity draw φ.[20]

[20] Notice that in in the data foreign affiliates could buy intermediate inputs from their parents and also from domestic suppliers. We do not include this last possibility in our model in order to keep the model as parsimonious as possible. However, allowing affiliates to buy inputs from domestic firms will not change the qualitative predictions of our model or the derived gravity equations. The key issue here is that production technology of some key inputs is firm-specific and hence must be produced within the firm boundaries (either by parent or affiliate). To see this in more detail, let us extend the model to include the possibilities of buying other inputs from domestic firms by assuming that the final good production requires (M, the intermediates inputs that must be produced within the firm boundaries) and (N, inputs that can bought from anywhere). The new production function becomes a Cobb-Douglas in terms of M and N: $Y = \varphi M^\beta N^{1-\beta}$ instead of $Y = \varphi M$. This will leave equation (4), which specifies the share of M to be produced by parents or by affiliate, unchanged. Hence, conditional on choosing to serve country n by FDI, the firm decision to

Given the isoelastic demand facing each working firm in country n, profits for an affiliate in country n and a parent in country i can be written as,[21]

$$\pi_{ni}^{aff} = \varphi^{\sigma-1} B_n C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi)^{1-\sigma} - w_i\left(f_{ni}^{fdi} + \mathcal{I}(\varphi) f_{ni}^{int}\right), \tag{5}$$

An affiliate chooses to outsource intermediate inputs from parent if and only if the increase in its profits due to the decrease in the marginal cost of composite intermediate input is large enough to cover the fixed cost of intra-firm trade:

$$\varphi^{\sigma-1} B_n = \left[\Delta C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi)\right] \geq w_i f_{ni}^{int}, \tag{6}$$

where $\Delta C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi) \equiv C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi) = 1, \varphi)^{1-\sigma} - C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi) = 0, \varphi)^{1-\sigma}$ denotes the gains in variable profits as a result of the decline in the marginal cost of composite intermediate input once an affiliate starts intra-firm trade with its parent. In the Appendix, we show that the left-hand side of Equation (6) is continuous and strictly increasing in φ. As a result, there exists a productivity cutoff φ_{ni}^{int} such that all affiliates with productivity above it choose to import a share of its intermediate inputs from their parents whereas, conditional on FDI, firms with productivity below it do not import from parents. The productivity cutoff φ_{ni}^{int} is simply pinned down from equation (6):

$$\left(\varphi_{ni}^{int}\right)^{\sigma-1} B_n \left[C_{ni}^M\left(\tau_{ni}, \mathcal{I}(\varphi) = 0, \varphi_{ni}^{fdi}, \varpi\right)^{1-\sigma} - (w_i \tau_{ni})^{1-\sigma}\right] = w_i\left(f_{ni}^{int} - f_{ni}\right) \tag{7}$$

The FDI cutoff $\varphi_{ni}^{fdi} < \varphi_{ni}^{int}$ is found in the usual way by equating export profits $< \pi_{ni}(\varphi)$ with FDI profits without intra-firm π_{ni}^{fdi}

$$\left(\varphi_{ni}^{fdi}\right)^{\sigma-1} B_n \left[C_{ni}^M\left(\tau_{ni}, \mathcal{I}(\varphi) = 0, \varphi_{ni}^{fdi}, \varpi\right)^{1-\sigma} - (w_i \tau_{ni})^{1-\sigma}\right] = w_i\left(f_{ni}^{fdi} - f_{ni}\right) \tag{8}$$

Exporting cutoff to country n is given by:

$$\varphi_{ni}^{\sigma-1} B_n (w_i \tau_{ni})^{1-\sigma} - w_i f_{ni} = 0 \tag{9}$$

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engage on intra-firm and the fraction of inputs to be produced by the affiliate will be identical to the one derived in our original model.

[21] $B_n \equiv \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} A_n$. Notice that the marginal cost of producing the final good is given by $\frac{C_{ni}^M(\varphi,.)}{\varphi}$, which we require to be strictly decreasing in φ. This can be done by imposing a specific functional form on $C_{ni}^M(\varphi)$ such that the marginal cost of the final good is decreasing in φ or, equivalently, we assume that the firm's draw φ is transformed to actual firm productivity via a strictly increasing function $f(\varphi)$ such that the marginal cost of the final good is decreasing in φ.

To complete the characterization of varieties produced and consumed in country n, the zero-profit cutoff (ZPC) is as usual,

$$\varphi_{nn}^{\sigma-1} B_n {w_n}^{1-\sigma} - w_n f_{nn} = 0 \tag{10}$$

The usual parameters restrictions (i.e., HMY) are imposed to retain the firm hierarchy observed in the data (see Online Appendix). The sales of a country i foreign affiliate in country n, $r_{ni}^{aff}(\varphi)$ are given by

$$r_{ni}^{aff}(\varphi) = \sigma\varphi^{\sigma-1} B_n \left[C_{ni}^{M}(\tau_{ni}, \mathcal{J}(\varphi), \varphi, \varpi)\right]^{1-\sigma} \tag{11}$$

Proposition 1: *Country i foreign affiliate sales (conditional on opening an affiliate) in country n, $r_{ni}^{aff}(\varphi)$ are decreasing in trade costs τ_{ni}. Let $\varepsilon_{ni}^{r}(\varphi, \tau_{ni}) < 0$ be the elasticity of affiliate sales with respect to trade costs, then the absolute value of $\varepsilon_{ni}^{r}(\varphi, \tau_{ni})$ is increasing in φ. In words, the sales of more productive and knowledge intensive firms (affiliates) are more sensitive to trade costs. That is, **FDI Gravity** is more pronounced for more productive and knowledge-intensive parents-affiliates.*

The proof of Proposition 1 is relegated to the Online Appendix. The proposition links gravity forces between parent and affiliates to firm productivity (or knowledge intensity, as in Keller and Yeaple, 2013).

4.5 General Equilibrium and Gravity Equations

Next, we proceed to derive the aggregate bilateral gravity equations for exporters, affiliates who import and affiliates who import from parents. To this end, we provide functional forms of the log-supermodular function $\beta(z|\varphi)$, the cost of disembodied knowledge transfer, and the distribution of productivity draw, and then solve for the general equilibrium. Before proceeding further, we set $\eta = 1$, and therefore M_φ is a Cobb-Douglas composite intermediate input: $M_\varphi = \mathcal{C}.exp\{\int_0^\infty \beta(z|\varphi)\ln m(z)dz\}$.[22] The correspondent cost function of the intermediate input composite is: $\mathcal{C} = exp\{\int_0^\infty \beta(z|\varphi)\ln m_z dz\}$. Let $\phi(\varphi)$ denote φ -firm's knowledge intensity where $\phi(\varphi)$ is weakly increasing in φ. In order to simplify the analysis, we assume that $\phi(\varphi)$ takes two values low and high: $\phi(\varphi) \in \{\phi^l, \phi^h\}$. We adopted a very simple reduced form to

[22] $\mathcal{C} \equiv \int_0^\infty \beta(z|\varphi)\ln m(z)dz$ is constant.

connect the well-documented relationship between firm's size (productivity) and knowledge intensity; specifically, for any $\varphi(\phi) > \varphi_{ni}^{int}$, $\phi = \phi^h$ and $\phi = \phi^l$ otherwise. This greatly simplifies the analysis without altering our results regarding the correlation between intra-firm trade and firm's knowledge-intensity. We are still able to use this simple functional form to compare intra-firm trade across firms with different knowledge intensity. Accordingly, we change the notation slightly: we use $\beta(z|\phi)$ instead of $\beta(z|\varphi)$. The cost share function $\beta(z|\phi)$ is log-supermodular in z and ϕ; therefore, we let $\beta(z|\phi)$ be an exponential with parameter $\frac{1}{\phi}$.[23]

We additionally assume that the costs of disembodied technology transfer also vary with destination-original pair characteristics. Broadly, the factors that are widely used in estimating trade costs between countries are also expected to affect the costs of disembodied technology transfer but with a lower order of magnitude: $t_{ni}(z) = g_{ni}t(z)$. Hence, $\bar{t}_{ni} = g_{niexp}\left\{\int_0^\infty \beta(z|\phi)\ln t(z)dz\right\}$.[24] To operationalize the model we let $g_{ni} = \tau_{ni}^{\alpha}$, where $\alpha \in (0,1)$. Following Keller and Yeaple (2013), we set the knowledge transfer function $t(z) = \exp\{z\}$. With the functional forms at hand, the marginal cost of obtaining the composite intermediate input for an affiliate with knowledge intensity $\phi \in \{\phi^l, \phi^h\}$ is

$$C_{ni}^{M}(\tau_{ni}, \mathcal{I}, \phi) = \begin{cases} \bar{t}_{ni} = \tau_{ni}^{\alpha}\exp\{\phi\} & \text{if} \quad \mathcal{I} = 0 \\ \exp\left\{\phi\left(1 - \tau_{ni}^{\frac{\alpha-1}{\phi}}\right) + \alpha \ln \tau_{ni}\right\} & \text{if} \quad \mathcal{I} = 1 \end{cases} \tag{12}$$

providing that $\tau_{ni} > g_{ni}\exp\{\phi^l\}$.[25]

The relevant cutoffs for country-pair (n, i) are given as follows[26]

$$\text{Zero profit cutoff ZPC: } \varphi_{nn}^{\sigma-1} = \frac{f_{nn}}{B_n}$$

$$\text{Export cutoff : } \varphi_{ni}^{\sigma-1} = \frac{f_{ni}}{B_n}\tau_{ni}{}^{\sigma-1}$$

$$\text{FDI cutoff : } \left(\varphi_{nn}^{fdi}\right)^{\sigma-1} = \frac{f_{ni}^{fdi} - f_{ni}}{B_n C_{1ni}}$$

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[23] $B(z|\phi) = \frac{1}{\phi}\exp\left\{\frac{-z}{\phi}\right\}$. It is straightforward to check that $\log\beta(z|\phi)$ is supermodular and $\int_0^\infty \beta(z|\phi)dz = 1$.

[24] $1 < g_{ni} < \tau_{ni}$. Akin to τ_{ni}, g_{ni}denotes the costs of disembodied knowledge transfer as a function of distance, common border and language, the time zone of n, i, and colonial origins.

[25] This assumption is needed in order for the FDI cutoff to be well defined. ϕ^l is very small such that $\exp(\phi^1) \approx 1$.

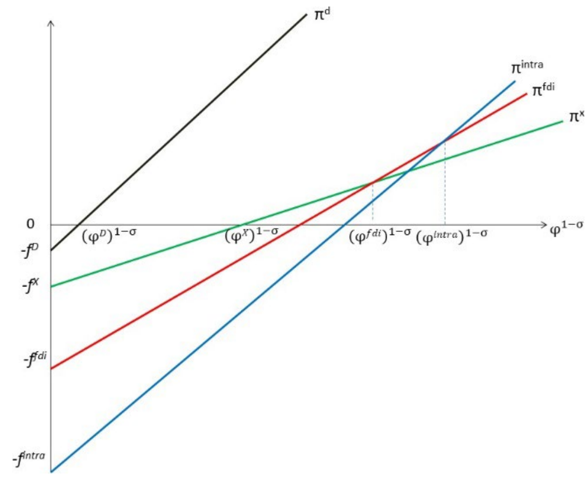
[26] $C_{1ni} \equiv \tau_{ni}^{\alpha(1-\sigma)}\exp^{\frac{\alpha-1}{\phi}}\{\phi(1-\sigma)\} - \tau_{ni}^{1-\sigma} > 0$.

$C_{2ni} \equiv \exp\left\{\phi\left(1 - \tau_{ni}^{\frac{\alpha}{\phi}}\right) + \alpha\ln\tau_{ni}\right\}^{1-\sigma} - \tau_{ni}^{\alpha(1-\sigma)}\exp\{\phi(1-\sigma)\} > 0$.

$$\text{intra-firm cutoff: } \left(\varphi_{nn}^{fdi}\right)^{\sigma-1} = \frac{f_{ni}^{int}}{B_n C_{2ni}}$$

Given the usual parameters restrictions (see Online Appendix), the logic of the standard HMY model is strongly presented in our framework, as shown in Figure 1.

Figure 1. Profit from Domestic Sales, Exports, FDI and Intra-Firm Trade



Notes: This figure shows the different productivity cutoff for different firms, where $(\varphi^{D})^{1-\sigma}$represents the cutoff for domestic producers, $(\varphi^{X})^{1-\sigma}$ represents the cutoff for exporters, $(\varphi^{fdi})^{1-\sigma}$ represents the cutoff for firms engaging in multinational production, and $(\varphi^{intra})^{1-\sigma}$ represents the cutoff for foreign affiliates that also engage in intra-firm trade

At the heart of it is the proximity-concentration trade-off in which proximity is represented by the slope of each profit's line, while concentration is represented by y-axis intersection. However, there are two main differences with previous models: i) in HMY the line representing the profits for affiliates who import intermediate inputs, π^{int}, is absent; and ii) in HMY the line denoted by π^{fdi} is parallel to the domestic profits line, whereas in Irarrázabal et al. (2013), the line representing the profits for affiliates who do not import from parents, π^{fdi}, is absent since the model assumes that all affiliates import from parents.[27]

[27] There are two factors that contribute to optimally having π^{intra} always below the intersection between π^{fdi} and π^{X}. First, the fixed cost paid by exporters or by firms that only do FDI, is considerably lower compared with the fixed cost paid by an affiliate that imports intermediate inputs from its parent. Second, and more importantly, the slope of the π^{intra} is much steeper than the other two since affiliates that engage in intra-firm trade will incur increasing iceberg costs. Then, for levels of productivity for which profits from exports and from FDI are the same, profits from intra-firm trade are positive but lower than the other two. For sufficiently higher levels of productivity, however, firms will optimally prefer to conduct intra-firm trade instead of producing all their intermediate inputs in house

To close the model, we assume that firm's productivity is distributed Pareto with shape parameter κ,[28]

$$G(\phi) = 1 - \phi^{\kappa}, \text{ for } \phi > 1, \text{ and } \kappa > \sigma - 1$$

The aggregate price index in country n is given by

$$P_n^{-\kappa} = \frac{\kappa}{\kappa - (\sigma - 1)} \left(\frac{\sigma}{\sigma - 1}\right)^{-\kappa} \left(\frac{\mu X_n}{\sigma}\right)^{\frac{\kappa - (\sigma-1)}{\sigma - 1}} \Xi_n \tag{13}$$

Indeed, total expenditures in country n, X_n, is an endogenous variable.[29] Since the mass of firms is exogenously given, the aggregate profits of country n firms, including affiliates' profits, are strictly positive. Accordingly, total income/expenditure in country n is the sum of labor income and aggregate profits of all country n firms: $X_n = w_n L_n + \Pi_n$. As in Chaney (2008), we assume that each consumer in country n holds w_n shares in a completely diversified mutual global fund with s dividends per share in terms of the numeraire. Additionally, as in Eaton and Kortum (2002) and Chaney (2008), J_i is proportional to the size of labor force in country n; $J_n = w_n L_n$. Therefore, $X_n = w_n L_n(1 + s)$, and $J_n = \frac{X_n}{1+s}$. In the Appendix, we show that s is a function of the model's exogenous parameters: $s = \frac{\sigma - 1}{\sigma(\kappa - 1) + 1}$.

We substitute for X_n in equation (13) to find the aggregate equilibrium price level in country n in terms of the model's exogenous parameters. Once P_n is obtained, we can retrieve all the relevant cutoffs, trade flows, foreign affiliates' sales, and economic welfare.

[28] The assumption that $\kappa > \sigma - 1$ ensures the the distribution of firm's size has a finite mean. In general, $G(\varphi) = 1 - \left(\frac{\varphi_{min}}{\varphi}\right)^{\kappa}$, and $\kappa > 2$. We work with $\varphi_{min} = 1$.

[29] $\Xi_n \equiv \sum_{i=1}^{N} J_i \left(\tau_{ni}^{-\kappa} f_{ni}^{\frac{\sigma-1-\kappa}{\sigma-1}} + \mathcal{I}_{i\neq n} \left\{\left(f_{ni}^{fdi} - f_{ni}\right)^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{1ni}^{\frac{\kappa}{\sigma-1}} + \left(f_{ni}^{int}\right)^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{2ni}^{\frac{\kappa}{\sigma-1}}\right\}\right)$. The indicator function $\mathcal{I}_{i\neq n} = 1$ if $i \neq n$ and zero otherwise.

4.6 Aggregate Sales: Gravity Equations

The model delivers three gravity equations: i) aggregate export sales from country i to country n: X_{ni}; ii) country i foreign affiliates' sales in country n, with no intra-firm between parents and affiliates: X_{ni}^{fdi}; and iii) Country i foreign affiliates' sales in country n, for affiliates that import from parents; X_{ni}^{int}.[30]

$$X_{ni} = \frac{\mu X_n X_i \tau_{ni}^{-\kappa} \delta_{ni}}{\Xi_n} \tag{14}$$

$$X_{ni}^{fdi} = \frac{\mu X_n X_i \{\tau_{ni}^{\alpha} \exp(\phi)\}^{-\kappa} \lambda_{ni}}{\Xi_n} \tag{15}$$

$$X_{ni}^{int} = \frac{\mu X_n X_i \exp\left\{\phi\left(1 - \tau_{ni}^{\frac{\alpha-1}{\phi}}\right) + \alpha(\ln \tau_{ni})\right\}^{-\kappa} \vartheta_{ni}}{\Xi_n} \tag{16}$$

Ξ_n is a reminiscent of the multilateral resistance term in Eaton and Kortum (2002). It is a measure of country n attractiveness (remoteness) taking into account all trading countries. The bilateral terms δ_{ni}, λ_{ni}, and ϑ_{ni} depend only on country i and country n parameters.[31] Relative to the standard gravity equation (e.g., Melitz-Chaney style model with no FDI), the impact of variable trade costs on country i exporters to country n is more involved. Without FDI sales, country i aggregate exports to country n can be decomposed into the intensive and the extensive margins, with the average exporter's sales being invariant to variable trade costs and the mass of exporting firms negatively associated with trade costs. In the presence of FDI sales, variable trade costs impact both the mass of exporters and average export sales per firm. In Chaney (2008), for instance, δ_{ni} is a function of fixed costs of export f_{ni}, and does not depend on τ_{ni}. Here, λ_{ni} is a

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[30] With a slight abuse of notation, we redefine $\Xi_n \equiv \sum L_i(1+\mathrm{s})\left(\tau_{ni}^{-\kappa} f_{ni}^{\frac{\sigma-1-\kappa}{\sigma-1}} + \mathcal{J}_{i\neq n}\left\{\left(f_{ni}^{fdi} - f_{ni}\right)^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{1ni}^{\frac{\kappa}{\sigma-1}} + \left(f_{ni}^{int}\right)^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{2ni}^{\frac{\kappa}{\sigma-1}}\right\}\right)_{i=1}^{N}$

[31] $\delta_{ni} \equiv f_{ni}^{\frac{\sigma-1-\kappa}{\sigma-1}} - \left[\frac{f_{ni}^{fdi} - f_{ni}}{\tau_{ni}^{(1-\sigma)(\alpha-1)} \exp(\phi(1-\sigma)) - 1}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}}$, $\lambda_{ni} \equiv \left[\frac{f_{ni}^{fdi} - f_{ni}}{1 - \tau_{ni}^{(1-\sigma)(1-\alpha)} \exp(\phi(\sigma-1))}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}} - \left[\frac{f_{ni}^{int}}{\left(\tau_{ni}^{\alpha}\exp(\phi)\right)^{\sigma-1} C_{2ni}}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}}$, and $\vartheta_{ni} \equiv \left[\frac{f_{ni}^{int}}{\left(\exp\left(\left(\phi\left(1-\tau_{ni}^{\frac{\alpha-1}{\phi}}\right) + \alpha \ln \tau_{ni}\right)\right)\right)^{\sigma-1} C_{2ni}}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}}$. Our assumptions about firms' hierarchy and the necessary parameter restrictions to maintain it are sufficient for both δ_{ni} and ϑ_{ni} to be positive. On the other hand, λ_{ni} is positive if $f_{ni}^{int} > \left(f_{ni}^{fdi} - f_{ni}\right)\frac{C_{2ni}}{C_{1ni}}$.

function of τ_{ni}, and therefore the response of X_{ni} to changes in τ_{ni} depends on changes in δ_{ni} and $\tau - \kappa$. Formally, let $\xi_{X,\tau}$ be the elasticity of aggregate exports sales between countries i and n with respect to variable trade costs τ_{ni}, and $\xi_{\delta,\tau}$ τ is the elasticity of δ with respect to τ, then[32]

$$\xi_{X,\tau} = -\kappa - \left|\xi_{\delta,\tau}\right| < 0 \tag{17}$$

Likewise, the elasticity of aggregate foreign affiliate sales for affiliates that do not import from their parents with respect to variable trade costs, and the elasticity of aggregate foreign affiliates' sales for affiliates that import from their parents are, respectively, given by[33]

$$\xi_{X^{fdi},\tau} = -\alpha k + \xi_{\lambda,\tau}, \tag{18}$$

$$\xi_{X^{int},\tau} = -\left[\tau_{ni}^{\frac{(\alpha-1)}{\phi}}(1-\alpha) + \alpha\right]\kappa + \xi_{\vartheta,\tau} < 0 \tag{19}$$

Aggregate affiliates' sales (for importer affiliates) decrease as trade costs increase. The elasticity in equation (19) is negative for any $\alpha \in (0,1)$ as the term in the bracket is positive and $\xi_{\vartheta,\tau} < 0$. The finding that foreign aggregate affiliates' sales are negatively correlated with trade costs for importer affiliates is not surprising and consistent with the models that introduce intra-firm trade between affiliates and parents such as Irarrázabal et al. (2013) and Keller and Yeaple (2013). The gravity for aggregate sales of non-importer affiliates requires more attention in our setting. The intra-firm trade mechanism that puts gravity forces in play is not present in the case of small affiliates who never import from parents. Nonetheless, to a lesser extent and under some reasonable parameters' restrictions, the aggregate sales of non-importer affiliates are still suffering from gravity forces (see the Appendix for formal derivations and the conditions for DI gravity to hold). In our context, affiliates need the knowledge-specific to produce the final good, which they can obtain through importing intermediate inputs from parents—embodying knowledge—or through direct knowledge transfer, which is not observed in the data. Since trade frictions impact the cost of knowledge transfer, affiliates' marginal cost and sales are negatively affected by the distance from headquarter and other common trade frictions.

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[32] $\xi_{\delta,\tau} = -\frac{\kappa-(\sigma-1)}{\sigma-1}\left[\frac{f_{ni}^{fdi}-f_{ni}}{\tau^{\sigma-1}C_{1ni}}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}-1}\left[\frac{(1-\sigma)(\alpha-1)\tau^{(1-\sigma)(\alpha-1)-1}\exp(\phi(1-\sigma))}{(\tau^{\sigma}-1C_{1ni})^2}\right]\frac{\tau}{\delta} < 0.$

[33] $\xi_{\delta,\tau} = \left(\kappa-(\sigma-1)\right)\left[\tau^{\alpha(1-\sigma)}\frac{\exp(\phi(1-\sigma))}{C_{2ni}}\left((a-1)\right)\tau^{\frac{\alpha-1}{\phi}}\right] < 0$. Deriving the sign of $\xi_{\lambda,\tau}$involves a tremendous algebra and is not trivial. In general, $\xi_{\lambda,\tau}$ is negative if α is not very close to zero.

4.7 Discussion: Linking the Model to the Empirics

Because we are using firm level data, not aggregate sales, the interpretation of our findings in the previous section is subtle. For instance, Table 2 states that the average sales per existing affiliate declines with transportation costs. Table 5 shows that average sales per affiliates decline with transportation costs only for firms with the largest affiliates, at the 85th percentile of the firm size distribution. To rationalize these findings within our theoretical framework, we decompose the effect of changing variable trade costs into intensive margin (average sales per firm) and the extensive margin (average sales of new entrants) effects as in Chaney (2008). By differentiating the expression for aggregate exports from country i to country n $X_{ni} = J_i \int_{\varphi_{ni}}^{\varphi_{ni}^{fdi}} r_{ni}(\varphi) dG(\varphi)$, the following expression for the elasticity of X_{ni} with respect to τ_{ni} is obtained,[34]

$$\xi_{X,\tau} = \overbrace{(1-\sigma)}^{Intensive\ margin} + \overbrace{\frac{\kappa-(\sigma-1)}{\varphi_{ni}^{\sigma-1-\kappa} - (\varphi_{ni}^{fdi})^{\sigma-1-\kappa}} \left[\xi_{\varphi^{fdi},\tau} \left(\varphi_{ni}^{fdi}\right)^{\sigma-1-\kappa} - \varphi_{ni}^{\sigma-1-\kappa}\right]}^{Extensive\ margin} \tag{20}$$

where, $\xi_{\varphi^{fdi},\tau}$ denotes the elasticity of FDI cutoff with respect to variable trade costs. For a sufficiently large α, $\xi_{\varphi^{fdi},\tau}$ is positive; yet it is still small enough such that the extensive margin continues to be negative. In fact, $\xi_{\varphi^{fdi},\tau} < 1$ for any value of $\alpha \in (0,1)$.[35] Consistent with our finding that the number of foreign affiliates in the lower tail of firm's size distribution decreases as the distance from headquarter increases, we proceed with positive elasticity of FDI cutoff with respect to trade costs, $0 < \xi_{\varphi^{fdi},\tau} < 1$ (see Online Appendix, Figures D4 and D5). Interestingly, even if the FDI cutoff is increasing in τ, as in HMY, the ratio of the number of multinational firms to the number of exporters increases as trade costs increase. Clearly, if the FDI cutoff is ∞, the model collapses to Chaney's model and $\xi_{X,\tau} = -\kappa$.

The same analysis for the aggregate sales of affiliates who do not import from parents, X_{ni}^{fdi} is executed,

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[34] We use the Leibniz integral rule to differentiate the aggregate exports expression.

[35] Specifically, $\xi_{\varphi^{fdi},\tau} = \frac{\alpha exp(\phi(1-\sigma)) - \tau_{ni}^{(1-\sigma)(1-\alpha)}}{exp(\phi(1-\sigma)) - \tau_{ni}^{(1-\sigma)(1-\alpha)}} < 1$. If $\xi_{\varphi^{fdi},\tau}$ is negative, then both the sales of existing exporters and the sales of new exporters decrease with trade costs.

$$\xi_{X^{fdi},\tau} = \overbrace{\alpha(1-\sigma)}^{Intensive\ margin} + \overbrace{\frac{-(\kappa-(\sigma-1))}{\left(\varphi_{ni}^{int}\right)^{\sigma-1-\kappa} - \left(\varphi_{ni}^{fdi}\right)^{\sigma-1-\kappa}}\left[\xi_{\varphi^{int},\tau}\left(\varphi_{ni}^{int}\right)^{\sigma-1-\kappa} - \xi_{\varphi^{fdi},\tau}\left(\varphi_{ni}^{fdi}\right)^{\sigma-1-\kappa}\right]}^{Extensive\ margin} \quad (21)$$

The elasticity of the intra-firm cutoff with respect to variable trade costs is denoted by $\xi_{\varphi^{fdi},\tau}$.[36] It is clear that the average sales per non-importer affiliate (intensive margin) is invariant to distance from headquarter or other bilateral trade frictions. This speaks directly to our empirical findings in the previous section: average sales per existing affiliate seem not to be associated with distance to headquarter, controlling for countries, time, and firm fixed effects. Nonetheless, the impact of trade costs on the extensive margin and hence aggregate affiliates sales, is still negative.[37]

The impact of variable trade costs on the intensive and the extensive margins for affiliates who import from their parents is as follows

$$\xi_{X,\tau} = \overbrace{(1-\sigma)\left[(1-\alpha)\tau_{ni}^{\frac{\alpha-1}{\phi}} + \alpha\right]}^{Intensive\ margin} + \overbrace{\kappa-(\sigma-1)\,\xi_{\varphi^{int},\tau}}^{Extensive\ margin} \quad (22)$$

Both sales per existing importer affiliates and the sales of new importer affiliates decline as trade costs increase. The impact of trade costs on the intensive margin is unambiguously negative. That is, conditional on importing inputs from parents, average sales per affiliate declines with distance from parent headquarter.

5. Conclusion

This paper starts by documenting an empirical regularity that cannot be fully taken into account by existing theoretical frameworks: foreign affiliates' sales are decreasing in trade costs even for those affiliates who do not engage in intra-firm transactions. In order to close this gap, we propose a new theoretical framework to rationalize this finding together with another stylized fact: the majority of firms do not engage in intra-firm transactions and, even among those that do, intra-firm trade is highly concentrated in a small set of large multinational firms. Internalizing these

[36] $\xi_{\varphi^{fdi},\tau} = \frac{1}{1-\sigma}\frac{\partial \ln C_{2ni}}{\partial \ln\tau} > 0$.

[37] In the Appendix we show that this is true if the fixed costs of intra-firm trade are sufficiently high.

regularities into a unified model improves our understanding of the nature and structure of multinational firms and the complex network connections between parents and affiliates. In addition, it provides a guide to further develop a quantitative framework that allows us to measure the welfare gains associated with reduction in trade barriers in a granular economy, where not only exports and multinational activity are subject to selection and are concentrated in a few big firms, but also intra-firm transactions across borders.

This paper is part of a larger research agenda which attempts to quantify the potentially large gains from trade as well as the gains from multinational production that take place in an economy where trade liberalization will not only impact physical trade but also transfer of knowledge across countries. This could affect employment in the host and the home country, and consequently could have sizable implications in the skilled composition of workers in both economies. Moreover, the interaction between trade costs and knowledge transfer across firms might be a useful tool to advance the theory of the boundaries of multinational firms.

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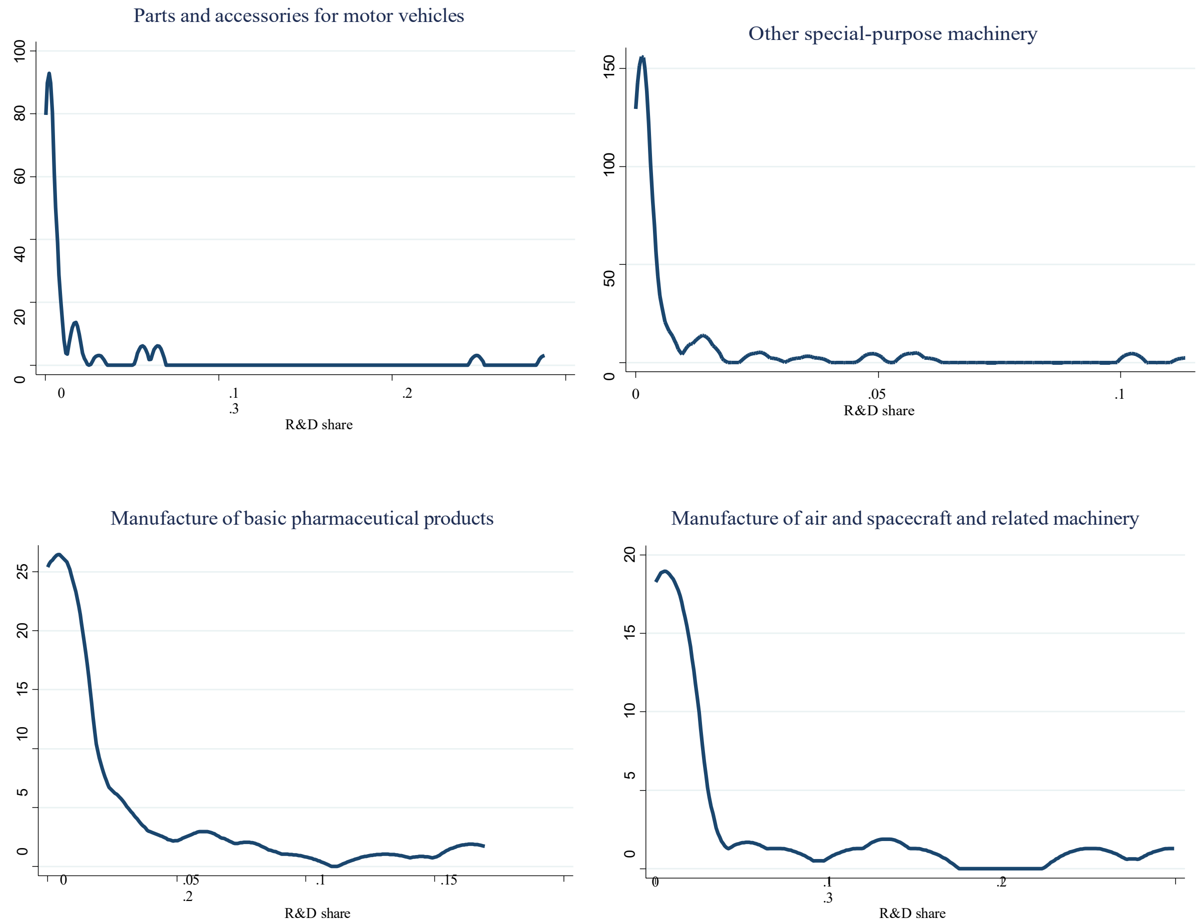
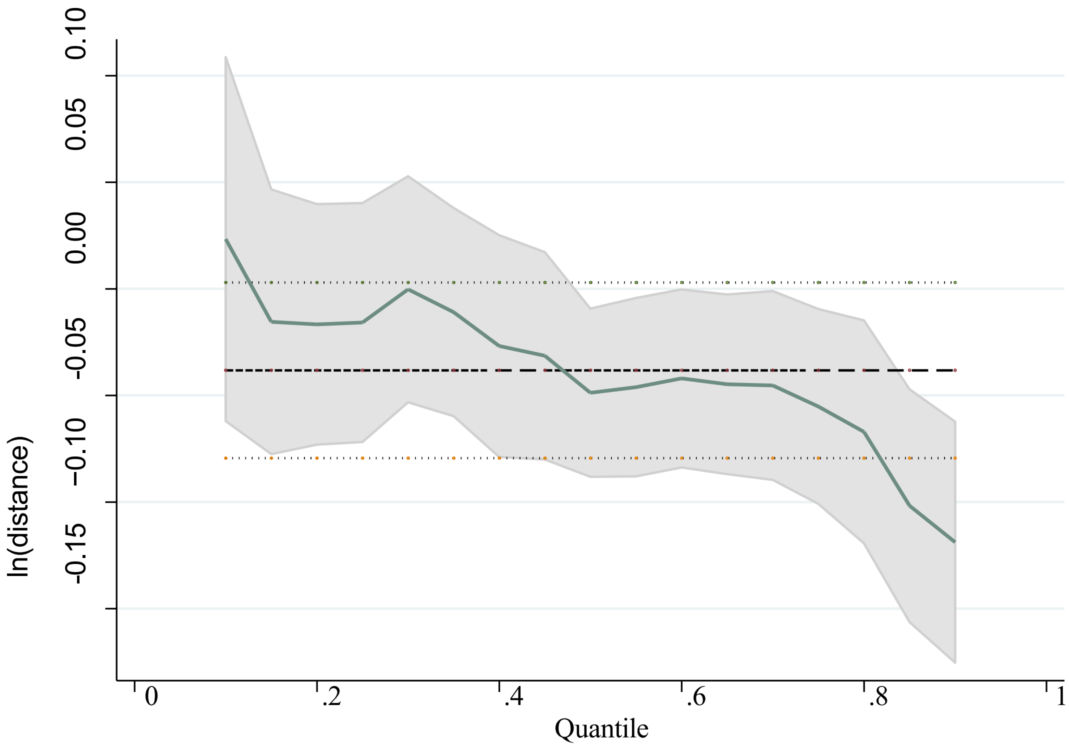
Tables and Figures

Figure 2. Density of Firms' R&D Shares for Selected Industries



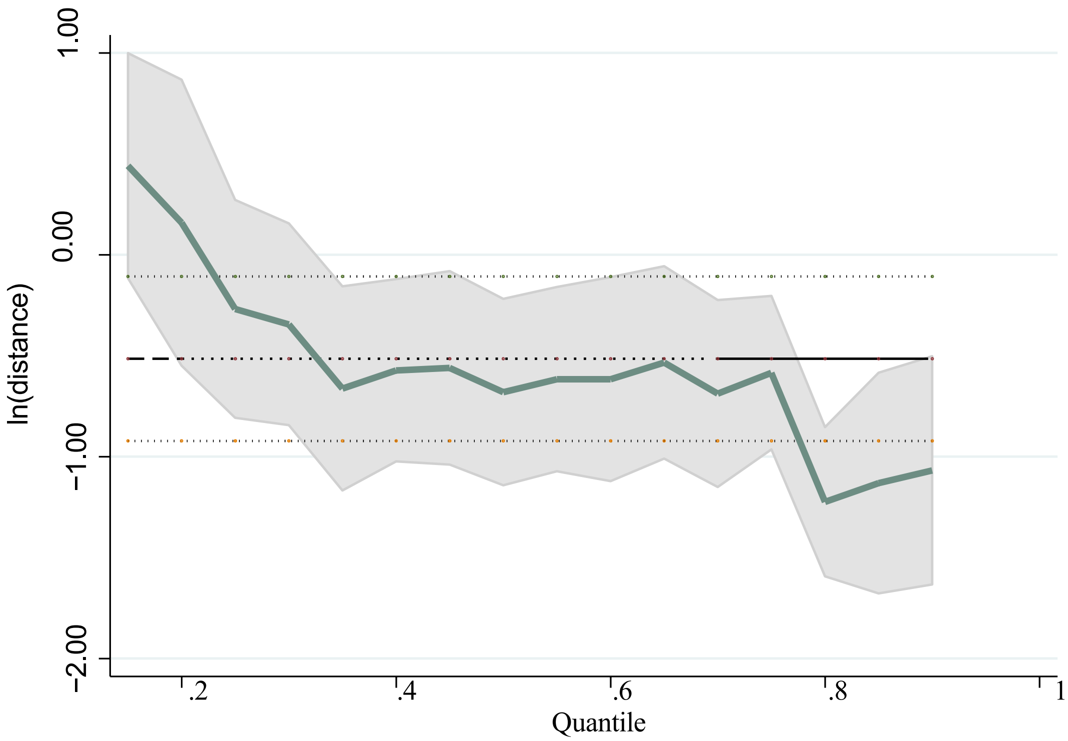
Notes: This figure shows the density of the parent's share of R&D expenditure share for four selected three-digit level of NACE sector classification: i) manufacturing of parts and accessories for motor vehicles—NACE 293 (top-left panel); ii) manufacture of other special-purpose machinery—NACE 289 (top-right panel); iii) manufacture of basic pharmaceutical products—NACE 211 (bottom-left panel), and iv) manufacture of air and spacecraft and related machinery—NACE 303 (bottom-right panel). The share of R&D is calculated as the fraction of the total Research and Development expenditure of the firm relative to the total R&D expenditure of all U.S parent firms operating the same 3-digit sectoral classification.

Figure 3. Effect of Distance across Foreign Affiliate Sales' Quantiles



Notes: This figure illustrates how the effects of distance between the foreign affiliate and its parent located in the source country vary over quantiles, and how the magnitude of the effects at various quantiles differ considerably from the OLS coefficient, even in terms of the confidence intervals around the coefficient. Confidence intervals at the 95% are defined by the gray area.

Figure 4. Effect of Distance across U.S. Affiliate Sales' Quantiles



Notes: This figure illustrates how the effects of distance between the U.S. foreign affiliate and its parent in the United States vary over quantiles, and how the magnitude of the effects at various quantiles differ from the OLS coefficient, even in terms of the confidence intervals around the coefficient. Confidence intervals at the 95% are defined by the gray area.

Table 1. Firm Size Distribution

	Firm's size distribution (measured by sales)					
Country	80pct	90pct	93pct	95pct	97pct	99pct
Austria	8.2	14	17.6	21.5	27.9	42.3
Belgium	4.5	9.3	12.9	16.6	22.7	36.6
Germany	7.0	12.0	14.1	16.7	21.1	32.1
Denmark	3.1	8.3	12.6	17.6	25.7	42.6
Spain	10.1	16.7	20.3	23.7	28.8	40.1
Finland	6.2	10.7	13.3	15.9	20.3	31.4
France	8.0	13.1	16.0	18.9	23.6	34.4
United Kingdom	2.0	5.5	7.6	9.8	13.4	22.6
Greece	13.0	21.3	25.7	29.8	36.1	49.1

Notes: This table shows the firm's size distribution measured by their sales for selected countries. Each row in each country represents the fraction of total revenue accounted for firms below each percentile. Therefore, column 1 shows the percentage of total sales accounted by 80 percent of firms in each country. Similarly, the last columns reflect the percentage of total sales accounted by 99 percent of the firms in the economy. Notice that this table considers all firms in the economy: local firms, foreign affiliates as well as home country multinationals.

Table 2. Gravity Equation of Multinational Production (firm-level pooled regression)

Dep. Variable	Foreign Affiliate Sales					
	(1)	(2)	(3)	(4)	(5)	(6)
ln dist	– 0.043**	–0.086***	–0.090***	– 0.034*	–0.075***	–0.067***
	(0.020)	(0.021)	(0.021)	(0.020)	(0.021)	(0.022)
ln dist aff		0.121***	0.118***		0.120***	0.117***
		(0.018)	(0.016)		(0.018)	(0.019)
ln tariff			–0.108**			–0.706***
			(0.050)			(0.244)
ln parent sales	0.366***	0.355***	0.360***	0.366***	0.355***	0.359***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Origin FE	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	No	No	No
Sector FE	Yes	Yes	Yes	No	No	No
Sector-Location	No	No	No	Yes	Yes	Yes
R-squared	0.367	0.366	0.369	0.394	0.395	0.395
N.Obs. (firms)	21,553	21,553	20,498	21,553	21,553	20,498

Notes: Dependent variable: natural log of foreign affiliates sales. Independent variables include the natural log of parent's sales, the natural log of the distance between the parent and the host market (ln *dist*); the natural log of distance between the foreign affiliates and other affiliates belonging to the same corporation located in third countries (ln dist aff); the natural log of tariff, a dummy of common border (*border*), common language (*language*) and whether or not the host market and the source country had a colonial relationship (*colony*). Robust standard errors in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Table 3. Gravity of U.S. Foreign Affiliates (firm-level pooled regression)

Dep. Variable	U.S. Foreign Affiliates			
Sales	(1)	(2)	(3)	(4)
ln trade cost	–7.514***	–4.660**	–1.243	0.487
	(1.571)	(2.131)	(1.438)	(1.914)
ln parent sales			0.275***	0.282***
			(0.013)	(0.013)
RD_{int} × ln trade cost		–1.071**	–0.954***	–0.958***
		(0.541)	(0.208)	(0.203)
ln GDP	0.281***	0.280***	0.243***	
	(0.027)	(0.027)	(0.026)	
Location FE	No	No	Yes	Yes
Sector FE	No	No	Yes	Yes
Parent FE	Yes	Yes	No	No
R-squared	0.07	0.08	0.182	0.213
N.Obs. (firms)	3,754	3,754	3,754	3,754

Notes: Dependent variable: natural log of foreign affiliates sales. Independent variables include the natural log of trade cost defined as the sum of tariff and freight cost ($\text{trade cost} = 1 + \text{tariff}_{us,n}^{j} + \text{freight}_{us,n}^{j}$); in the interaction between research and development (R&D) intensity and trade cost. Robust standard errors in parentheses; and the natural log of location's GDP. Significance is denoted: * p < 0.10 ** p < 0.05 *** p < 0.01.

Table 4. Gravity of Foreign Affiliate Sales (Quartile Dummies)

Dep. Variable	Foreign Affiliates Sales			
	(1)	(2)	(3)	(4)
ln dist	0.139***	0.151***	0.175***	0.175***
	(0.036)	(0.036)	(0.037)	(0.037)
ln dist aff	0.050**	0.044***	0.044***	0.044***
	(0.019)	(0.019)	(0.019)	(0.019)
ln tariff	0.102**	0.099**	–0.733***	–0.733***
	(0.490)	(0.490)	(0.240)	(0.240)
ln parent sales	0.254***	0.232***	0.232***	0.232***
	(0.007)	(0.007)	(0.008)	(0.007)
$RD_{int} \times dist$	–0.004***	–0.010***	–0.008***	–0.008***
	(0.001)	(0.003)	(0.003)	(0.002)
rap		–0.084		–0.045
		(0.015)		(0.015)
Service dummy		0.478***		0.472***
		(0.32)		(0.32)
*quartile*2	1.165***	1.238***	1.323***	1.323***
	(0.301)	(0.299)	(0.302)	(0.302)
*quartile*3	1.871***	1.876***	1.973***	1.974***
	(0.231)	(0.231)	(0.231)	(0.231)
*quartile*4	2.819***	2.818***	2.778***	2.778***
	(0.229)	(0.230)	(0.230)	(0.230)
*quartile*2 × *dist*	–0.124***	–0.133***	–0.144***	–0.144***
	(0.044)	(0.044)	(0.044)	(0.044)
*quartile*3 × *dist*	–0.183***	–0.184***	–0.196***	–0.196***
	(0.033)	(0.034)	(0.034)	(0.034)
*quartile*4 × *dist*	–0.260***	–0.256***	–0.257***	–0.257***
	(0.033)	(0.033)	(0.033)	(0.033)
Other controls	Yes	Yes	Yes	Yes
Origin FE	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	No
Sector FE	Yes	Yes	Yes	No
Sector-Location	No	No	No	Yes
R-squared	0.381	0.391	0.397	0.381
N.Observations	20,498	20,498	20,498	20,498

Notes: Independent variables include the natural log of parent's sales, the natural log of the distance between the parent and the host market; the natural log of distance between the foreign affiliates and other affiliates belonging to the same corporation located in third countries; the natural log of tariff; the interaction between (R&D) intensity and distance; a dummy of common border, common language and whether or not the host market and the source country had a colonial relationship. Robust standard errors in parentheses.

Table 5. Gravity Equation of Foreign Affiliate Sales: (Quantile Regression)

Dep. Variable	Foreign Affiliates Sales					
	OLS	Q(10)	Q(25)	Q(50)	Q(85)	Q(90)
ln dist	– 0.038**	0.023	–0.016	– 0.049*	–0.102***	–0.119***
	(0.019)	(0.049)	(0.028)	(0.025)	(0.028)	(0.033)
ln dist aff	0.114***	0.122**	0.105***	0.126***	0.123***	0.115***
	(0.019)	(0.048)	(0.029)	(0.024)	(0.019)	(0.027)
ln tariff	0.088*	0.187	0.194***	0.059	0.014	0.044
	(0.048)	(0.169)	(0.070)	(0.056)	(0.064)	(0.063)
ln parent sales	0.260***	0.204***	0.239***	0.271***	0.320***	0.335***
	(0.005)	(0.005)	(0.007)	(0.006)	(0.007)	(0.008)
$RD_{int} \times dist$	–0.009***	–0.018***	–0.014***	–0.008***	–0.002	–0.004
	(0.003)	(0.006)	(0.003)	(0.003)	(0.003)	(0.004)
r_{ap}	0.221*	0.123**	–0.011	0.208	0.305***	0.444***
	(0.126)	(0.051)	(0.048)	(0.312)	(0.119)	(0.039)
Services dummy	0.406***	0.392**	0.413***	0.449***	0.413***	0.386***
	(0.032)	(0.089)	(0.048)	(0.040)	(0.041)	(0.046)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Origin FE	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.343	0.407	0.424	0.426	0.424	0.421
N.Observations	20,498	20,498	20,498	20,498	20,498	20,498

Notes: Dependent variable: natural log of foreign affiliates sales. The first column shows the results from ordinary least square regression. The other columns present the results of a quantile regression at different quantiles: 10th, 25th, 50th and 90th percentiles of the firm size distribution. Independent variables include the natural log of parent's sales, the natural log of the distance between the parent and the host market (ln *dist*); the natural log of distance between the foreign affiliates and other affiliates belonging to the same corporation located in third countries (ln dist aff); the natural log of tariff; the interaction between research and development (R&D) intensity and distance. Other controls include, a dummy of common border (*border*), common language (*language*) and whether or not the host market and the source country had a colonial relationship (*colony*). Robust standard errors in parentheses.
Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Table 6. Gravity Equation of MP: Parent Fixed Effects

Dep. Variable	Foreign Affiliates Sales				
	(1)	(2)	(3)	(4)	(5)
ln dist	–6.24***	–0.134***	–0.106***	–0.106***	0.255
	(1.160)	(0.022)	(0.022)	(0.022)	(0.177)
ln dist aff		0.134***	0.188***	0.188***	0.203*
		(0.022)	(0.055)	(0.055)	(0.123)
ln tariff			0.148***	0.148***	0.011
			(0.042)	(0.042)	(0.106)
$RD_{int} \times dist$					–1.304*** (0.486)
r_{ap}				0.023	–0.188
				(0.151)	(0.745)
ln GDP			0.241***	0.241***	0.337***
			(0.013)	(0.013)	(0.032)
rule of law			0.009***	0.009***	0.010***
			(0.001)	(0.001)	(0.002)
Location FE	No	No	No	No	No
Sector FE	No	No	Yes	Yes	Yes
Parent FE	Yes	Yes	Yes	Yes	Yes
R-squared	0.06	0.05	0.156	0.213	0.213
N.Observations	21,553	21,553	20,444	3,754	3,754

Notes: Dependent variable: natural log of foreign affiliates sales. Independent variables include the natural log of parent's sales, the natural log of the distance between the parent and the host market (ln *dist*); the natural log of distance between the foreign affiliates and other affiliates belonging to the same corporation located in third countries (ln dist aff); the natural log of tariff; the interaction between research and development (R&D) intensity and distance. Other controls include the natural log of location's country GDP and the Rule of Law institutional ranking from the World Bank. Robust standard errors in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Online Appendix

Appendix A: Proofs

In order to show that within all firms that decide to enter country n by establishing a foreign affiliate, only a subset of those firms (the most productive) choose to ship intermediate inputs to its affiliates we derive the elasticity of firm marginal costs with respect of trade costs and introduce two useful lemmas. The elasticity of $C_{ni}^{M}(\tau_{ni}, \mathcal{I}(\varphi) = 1, \varphi, \varpi)$ with respect to trade costs τ_{ni}, $\varepsilon^{MC}(\tau_{ni}, \varphi, \varpi)$ is given by

$$\varepsilon^{MC}(\tau_{ni}, \varphi, \varpi) = \frac{(w_i\tau_{ni})^{1-\eta} \int_{\Sigma\ (\tau_{ni},\omega)}^{\infty} \beta(z \mid \varphi)dz}{\int_0^{L(\tau_{mi},\varpi)} \beta(z \mid \varphi)(t(z)w_n)^{1-\eta}dz + (\tau_{ni}w_i)^{1-\eta} \int_{z(\tau_{ni},\varpi)}^{\infty} \beta(z \mid \varphi)dz}. \quad \text{(A.1)}$$

Lemma A.1 *The elasticity of marginal cost of composite intermediate input with respect to trade costs* τ_{ni} *is increasing in firm's productivity* φ*. For* $\varphi^1 > \varphi^2, \varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^1) > \varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^2) > 0$.

Lemma A.2 *let* $\theta(\tau_{ni}, \varphi, \varpi)$ *be the share of imported inputs* $M(\tau_{ni}, \varphi, \varpi)$ *in total composite intermediate input costs* $TC(\tau_{ni}, \varphi, \varpi)$*. Then,* $\theta(\tau_{ni}, \varphi, \varpi) = \frac{M(\tau_{ni},\varphi,\varpi)}{T(\tau_{ni},\varphi,\varpi)} = \varepsilon^{MC}(\tau_{ni}, \varphi, \varpi)$*is i) increasing in* φ*, ii) the import cost share is declining in trade costs for all firms, iii) the rate of decline in the import cost share is slower in the more knowledge-intensive firms and iv) the rate of decline in the import cost is slower in the more knowledge-intensive firms.*

Proof: Lemma A.1. The proof is based on Keller and Yeaple (2013). By contradiction method, assume that $\varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^1) < \varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^2)$. Then,

$$\int_{\Sigma}^{\infty} \beta(z \mid \varphi^1)dz \int_0^{2} \beta(z \mid \varphi^2)t(z)^{1-\eta}dz < \int_{\tilde{z}}^{\infty} \beta(z \mid \varphi^2)dz \int_0^{2} \beta(z \mid \varphi^1)t(z)^{1-\eta}dz \quad \text{(A.2)}$$

Without loss of generality we set $\varpi = 1$. By definition, if $\beta(z \mid \varphi)$ is log-supermodular in z and α, then for $z' > z''$,

$$\beta(z' \mid \varphi^1)\beta(z'' \mid \varphi^2)t(z)^{1-\eta} > \beta(z' \mid \varphi^2)\beta(z'' \mid \varphi^1)t(z)^{1-\eta}. \quad \text{(A.3)}$$

Integrate with respect to z'' over $[0, z')$ and with respect to z' over $[z', \infty)$, and replace z' with $\tilde{z}$ we get

$$\int_2^{\infty} \beta(z \mid \varphi^1)dz \int_0^{\varepsilon} \beta(z \mid \varphi^2)t(z)^{1-\eta}dz > \int_2^{\infty} \beta(z \mid \varphi^2)dx \int_0^{2} \beta(z \mid \varphi^1)t(z)^{1-\eta}dz \quad \text{(A.4)}$$

Contradiction ■

Proof: Lemma A.2. Part i) follows immediately Lemma A.1. For part two, the elasticity of $\theta(\tau_{nii}, \varphi)$ with respect to τ_{ni} is given by (w.l.o. $\frac{\partial t(z)}{\partial \tau} = 1$)

$$\xi_{\theta,\tau} = -(\eta-1)\big(1-\theta(\tau,\varphi)\big) - \frac{\partial \tilde{z}(\tau)}{\partial \tau}\frac{\beta(z \mid \varphi)\tau}{\int_{\tilde{z}(\tau)}^{\infty} b(z \mid \varphi)dz} < 0 \qquad \text{(A.5)}$$

The third part is implied by the monotone likelihood ratio property: $\frac{\beta(z|\varphi^i)}{\int_{\tilde{z}}^{\infty}\beta(z|\varphi^1)dx} < \frac{\beta(z|\varphi^2)}{\int_{\tilde{z}}^{\infty}\beta(z|\varphi^2)dz}$, and $\theta(\tau,\varphi^1) > \theta(\tau,\varphi^2)$. ■

The two lemmas above highlight the role of firm's knowledge intensity (productivity), trade impediments and the interaction between the two in shaping intra-firm trade on the firm level. More knowledge-intensive firms are so because they require more knowledge-intensive intermediate inputs. A more knowledge-intensive affiliate imports higher share of its intermediate inputs from its parent, and consequently an increase in trade costs raises the marginal cost of composite intermediate inputs of more knowledge-intensive affiliates proportionally more than less knowledge-intensive firms. Changes in trade costs impact firms' decision regarding embodied and disembodied knowledge transfer, yet the degree of substitution between them is significantly less for more knowledge intensive firms. An increase in trade costs, for example, leads to less decrease in the share of imported inputs to aggregate composite intermediate input costs for high knowledge-intensive affiliate since the more knowledge-intensive affiliate's ability to substitute embodied with disembodied knowledge transfer is constrained by the large demand for the highly knowledge-intensive inputs.

Proposition A.1 *There exists a productivity cutoff φ_{ni}^{int} such that*

$$\mathcal{I}(\varphi) = \begin{cases} 1 & if\ \varphi \geq \varphi_{ni}^{int} \\ 0 & otherwise \end{cases}$$

That is, only the most productive foreign affiliates in country n engage in intra-firm trade with their parents (import intermediate inputs from their parents).

Proof: And affiliate chooses to import from its parent if,

$$\varphi^{\sigma-1}B_n\big[\Delta C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi),\varphi,\varpi)\big] \geq w_i f_{ni}^{int} \qquad \text{(A.6)}$$

The first term is the left-hand side of the equation above $\varphi^{\sigma-1}$ is increasing in φ. The second term $\Delta C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi),\varphi,\varpi) \equiv \Delta C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi)=1,\varphi)^{1-\sigma} - C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi)=0,\varphi)^{1-\sigma}$ is also increasing in φ. Notice that $C(\mathcal{I}=0,\varphi^1) > C(\mathcal{I}=0,\varphi^2)$,[38] whereas $C(\tau=1,\mathcal{I}=1,\varphi^1) = C(\tau=1,\mathcal{I}=1,\varphi^2)$. By Lemma A.1, $\varepsilon^{MC}(.,\varphi^1) > \varepsilon^{MC}(.,\varphi^2)$, then moving from no intra-firm trade to importing any share of intermediate inputs from parents yields larger saving in the cost of producing the intermediate composite input for the higher knowledge-intensive firm (more productive). ■

[38] Notice that $C(\mathcal{I}=0,\varphi) = \bar{t} = \int_{\tilde{z}}^{\infty}\beta(z \mid \varphi)t(z)^{1-\eta}dz$, which is indeed increasing φ under the assumptions about $\beta(z \mid \varphi)$ and $t(z)$.

Proposition 1: *Country i foreign affiliate sales (conditional on opening an affiliate) in country n, $r_{ni}^{aff}(\varphi)$ are decreasing in trade costs τ_{ni}. Let $\varepsilon_{ni}^{r}(\varphi,\tau_{ni}) < 0$ be the elasticity of affiliate sales with respect to trade costs, then the absolute value of $\varepsilon_{ni}^{r}(\varphi,\tau_{ni})$ is increasing in φ. In words, the sales of more knowledge-intensive firms (affiliates) are more sensitive to trade costs. That is,* ***FDI Gravity*** *is more pronounce for more knowledge- intensive parents-affiliates.*

Proof: Notice that

$$\varepsilon_{ni}^{r}(\varphi,\tau_{ni},\mathcal{I}) = (1-\sigma)\varepsilon_{ni}^{MC}(\varphi,\tau_{ni},\mathcal{I}) \tag{A.7}$$

The proof then follows immediately from the properties of $\varepsilon_{ni}^{MC}(\varphi,\tau_{ni},\mathcal{I})$. Moreover, when $\mathcal{I}=0$, as explained in the text $\bar{t}$ is increasing with τ_{ni}. Thus the proof is complete. ■

Appendix B: Detail Derivations

Derivation of the marginal cost of intermediate input composite: equation (12) With $w_i = 1$ for $i \in \{1,2,\dots,N\}$, domestic producers composite intermediate input cost is given by $C_{nn}^{M} = 1$, while

$$C_{ni}^{M}(\tau_{\mathrm{ni}},\varphi,\mathcal{I}) = \begin{cases} \bar{t} & \text{if} \quad I = 0, \\ \exp\left\{\int_{0}^{\varepsilon} \beta(z \mid \varphi) \ln t(z)\, dz + \int_{\bar{z}}^{\infty} \beta(z \mid \varphi) \ln \tau_{ni} dz\right\} & \text{if} \quad \mathcal{I} = 1 \end{cases}$$

Applying the definition of $\bar{t}$ and the functional forms of $t(z)$ and $\beta(z \mid \varphi)$, we get

$$C_{\mathrm{ni}}^{M}(\tau,\phi,\mathcal{I}) = \begin{cases} \tau^{\alpha} \exp\left\{\int_{0}^{\infty} \frac{1}{\phi} \exp\left(-\frac{z}{\phi}\right) z dz\right\} & \text{if } \mathcal{I} = 0 \\ \exp\left\{\int_{0}^{\tilde{z}} \frac{1}{\phi} \exp\left(-\frac{z}{\phi}\right)(\alpha \ln \tau + z) dz + \ln \tau \int_{\tilde{z}}^{\infty} \frac{1}{\phi} \exp\left(-\frac{z}{\phi}\right) dz\right\} & \text{if } \mathcal{I} = 1 \end{cases} \tag{B.1}$$

Integrating by parts and substituting out $\tilde{z} = (1-\alpha)\ln \tau_{\mathrm{ni}}$, the required results are obtained. Foreign affiliate's sales are given by equation (11). Given the functional forms provided in this section, we have:

$$r_{ni}^{fdi} = \sigma\varphi^{\sigma-1} B_n (\tau_{ni}^{\alpha} \exp(\phi))^{1-\sigma}, \tag{B.2}$$

and

$$r_{ni}^{int} = \sigma\varphi^{\sigma-1} B_n \left(\exp\left\{\phi\left(1 - \tau_{ni}^{\frac{a-1}{\phi}}\right) + \alpha \ln \tau_{ni}\right\}\right)^{1-\sigma}. \tag{B.3}$$

Accordingly, the elasticity of foreign affiliate's sales with respect to trade costs is given by

$$\varepsilon^{r}_{\text{ni}}(\phi,\tau_{ni},\mathcal{J}) = \begin{cases} (1-\sigma)\alpha < 0 \quad \text{if } \mathcal{J}=0, \\ (1-\sigma)\left((1-\alpha)\tau_{ni}^{\frac{\alpha-1}{\phi}} + \alpha\right) \text{ if } \mathcal{J}=1 \end{cases} \tag{B.4}$$

It is straightforward to verify that the sales of affiliates who import from their parents respond relatively more than the sales of affiliates who do not import from their parents. Furthermore, for affiliates who import from their parents, their sales are more responsive to change in trade costs the higher the knowledge intensity: $\frac{\partial \varepsilon^{r}_{ni},(\phi,\tau_{ni})}{\partial \phi} < 0$.

Parameter Restrictions and Firms Hierarchy: Consistent with the literature we impose the following restrictions on the model's parameters to sustain firms' hierarchy in the HMY.

- Exporters are more productive than non-exporters: $\varphi_{ii} < \varphi_{ni,}$ if, under symmetric countries, $f_{ni} > \tau_{in}^{1-\sigma} f_{ii}$.
- Exporters are less productive than multinational firms: $\varphi_{ni} < \varphi_{ni}^{fdi}$; if $f_{ni}^{fdi} > (\tau_{ni}\varpi)^{\sigma-1}\bar{t}^{\,1-\sigma} f_{ni}$, and $\bar{t} < \omega\tau_{\text{ni}}$.
- Multinational firms with nonzero intra-firm are more productive than multinational firms with zero intra-firm: $\varphi_{ni}^{\text{int}} > \varphi_{ni}^{fdi}$; if $f_{ni}^{int} > 0$.[39]

Aggregate price index: The aggregate price index in country n is given by

$$P_n^{1-\sigma} = \int_{\varphi nn}^{\infty} p_{nn}(\varphi)^{1-\sigma} dG(\varphi) + \sum_{i\neq n}^{N} J_i \int_{\varphi ni}^{\infty} p_{ni}(\varphi)^{1-\sigma} dG(\varphi), \tag{B.5}$$

$$p_{ni}(\varphi) = \begin{cases} \frac{\sigma}{\sigma-1}\frac{\tau_{ni}}{\varphi} & \text{if } \varphi_{ni} < \varphi < \varphi_{ni}^{fdi} \\ \frac{\sigma}{\sigma-1}\frac{{\tau_{ni}}^{\alpha}\exp(\phi)}{\varphi} & \text{if } \varphi_{ni}^{fdi} < \varphi < \varphi_{ni}^{int} \\ \frac{\sigma}{\sigma-1}\frac{\exp\left(\phi\left(1-\tau_{ni}^{\frac{\alpha-1}{\phi}}\right)+\alpha ln\tau_{ni}\right)}{\varphi} & \text{if } \varphi_{ni}^{int} < \varphi \end{cases}$$

Evaluating the integration and using the Pareto distribution assumption, we get the formula for price index in the text.

[39] In fact, f_{ni}^{int} has to be greater than $f_{ni}^{fdi} - f_{ni}$

Dividends per share s: In the text we claim that $s = \frac{\sigma-1}{\sigma(k-1)+1}$. Let Π_n be the aggregate profits of all firms in country n, including foreign affiliates' profits,

$$\Pi_n = \sum_{i=1}^{N} J_n \left\{ \int_{\varphi_{in}}^{\varphi_{in}^{fdi}} \pi_{in}(\varphi) dG(\varphi) + \int_{\varphi_{in}^{fdi}}^{\varphi_{in}^{int}} \pi_{in}^{fdi}(\varphi) dG(\varphi) + \int_{\varphi_{in}^{int}}^{\infty} \pi_{in}^{int}(\varphi) dG(\varphi) \right\}, \tag{B.6}$$

and $\varphi\varphi_{i=1}^{fit} = \varphi_{nn}^{\text{int}} = \infty$. The domestic/export profits, non-importer foreign affiliates' profits and importer affiliates' profits are denoted by $\pi_{\text{in}}(\varphi), \pi_{in}^{fdi}(\varphi)$, and $\pi_{in}^{\text{int}}(\varphi)$, respectively. Using the functional forms of the profits, the Pareto distribution, the cutoffs' equations and integrating, we get

$$\Pi_n = \frac{\sigma-1}{\sigma\kappa} \sum_{i=1}^{N} R_{\text{in}} + R_{\text{in}}^{fdi} + R_{in}^{int} \tag{B.7}$$

$R_{\text{in}}, R_{in}^{fdi}$ and R_{in}^{int} denote the values of the aggregate sales of exporting to country i, the aggregate sales of foreign affiliates that do not import, and the importer aggregate affiliate sales, respectively. Indeed, $R_{in}^{\text{di}\,i} = R_{nn}^{\text{int}} = 0$. Let Π denote the world aggregate profits: $\Pi = \sum_{n\in N} \Pi_n$, then

$$\Pi = \frac{\sigma-1}{\sigma\kappa} \sum_{n\in N} \sum_{i\in N} R_{in} + R_{in}^{fdi} + R_{in}^{int} \tag{B.8}$$

$$= \frac{\sigma-1}{\sigma\kappa} Y \tag{B.9}$$

Here, Y is the world total sales/expenditures. World's total profits Π is also given by the dividends per share times the total number of shares. Thus, $\Pi = \sum_{n\in N} sL_n = \frac{\sigma-1}{\sigma\kappa} Y = \frac{\sigma-1}{\sigma\kappa} \sum_{n\in N} L_n (1+s)$, where the last equality follows from balanced trade and the fact that $X_n = L_n + \Pi_n = L_n + 8L_n$. Then,

$$s = \frac{\Pi}{\sum_{n\in N} L_n} = \frac{\sigma-1}{\sigma\kappa}(1+s)$$

$$\rightarrow s = \frac{\sigma-1}{\sigma(\kappa-1)+1}$$

Derivation of Gravity Equations

Aggregate exports from country i to country n is given by[40]

$$X_{ni} = J_i \int_{\varphi_{mi}}^{\varphi_{mi}^{fdi}} \sigma\varphi^{\sigma-1}\left(\frac{\mu X_n}{P_n^{1-\sigma}}\right)\tau_{ni}^{1-\sigma}dG(\varphi) \tag{B.10}$$

Evaluating the integration, using the formula for the aggregate price level, and substituting out the cutoffs and $J_i = \frac{X_i}{1+s}$, we obtain the gravity equation derived in the text. Similarly, non-importer affiliates' aggregate sales and importer affiliates' aggregate sales can by expressed by

$$X_{ni}^{fdi} = J_i \int_{\varphi_{ni}^{fdi}}^{\varphi_{ni}^{int}} \sigma\varphi^{\sigma-1}(X_n/P_n^{1-\sigma})[\tau_{ni}^{\alpha}exp(\phi)]^{1-\sigma}dG(\varphi) \tag{B.11}$$

$$X_{ni}^{int} = J_i \int_{\varphi_{ni}^{int}}^{\infty} \sigma\varphi^{\sigma-1}(X_n/P_n^{1-\sigma})\left(exp\phi\left(1-\tau_{ni}^{\frac{\alpha-1}{\phi}}\right)+\alpha\ln\right)^{1-\sigma} dG(\varphi) \tag{B.12}$$

Using the same steps as before, we get the gravity equations for non-importer affiliates' sales and importer affiliates' sales.

FDI Gravity: Affiliates who do not import from parents

In the text we claimed that the sales of non-importer decrease in trade frictions; equation (18). In order to prove this formally we use our analysis of the intensive/extensive margin. Remember that we can disentangle the impact of trade costs on affiliates' sales into the intensive and the extensive margins;

The extensive margin is negative if and only if, $\xi_{\rho\rho di,\tau}\left(\varphi^{fdi}\right)^{\sigma-1-\kappa} > \xi_{\rho^{\text{int}},\tau}\left(\varphi^{\text{int}}\right)^{\sigma-1-\kappa}$. For this cutoff to be well defined, we require $f_{ni}^{int} > \left(f_{ni}^{fdi} - f_{ni}\right)\frac{C_{2mi}}{C_{1n}}$. If f_{ni}^{int} is way larger than the last term, then the last term of the previous inequality becomes very small and approaches zero as $f_{ni}^{int} \to \infty$. Therefore, there exists $f_{ni}^{\text{int}} < \infty$ such that the extensive margin is negative. If this condition does not hold, all what we need to have FDI-gravity is $-\frac{\xi_{\varphi^{int},\tau}(\varphi_{ni}^{int})^{\sigma-1-\kappa} - \xi_{\varphi^{fdi},\tau}(\varphi_{ni}^{fdi})^{\sigma-1-\kappa}}{(\varphi_{ni}^{fdi})^{\sigma-1-\kappa} - (\varphi_{ni}^{int})^{\sigma-1-\kappa}} < \alpha(\sigma-1)\kappa - (\sigma-1)$, which is easily satisfied for reasonable parameter values. If either of these two conditions is satisfied, FDI sales must be negatively correlated with trade frictions.

[40] Notice that we do not include the intra-firm export in the total exports. It is easy to show that total intra-firm exports is a constant share of the importer total affiliates' sales.

Appendix C: Data Documentation

Trade cost data: For the United States we construct an ad valorem measure of trade cost, defined as:

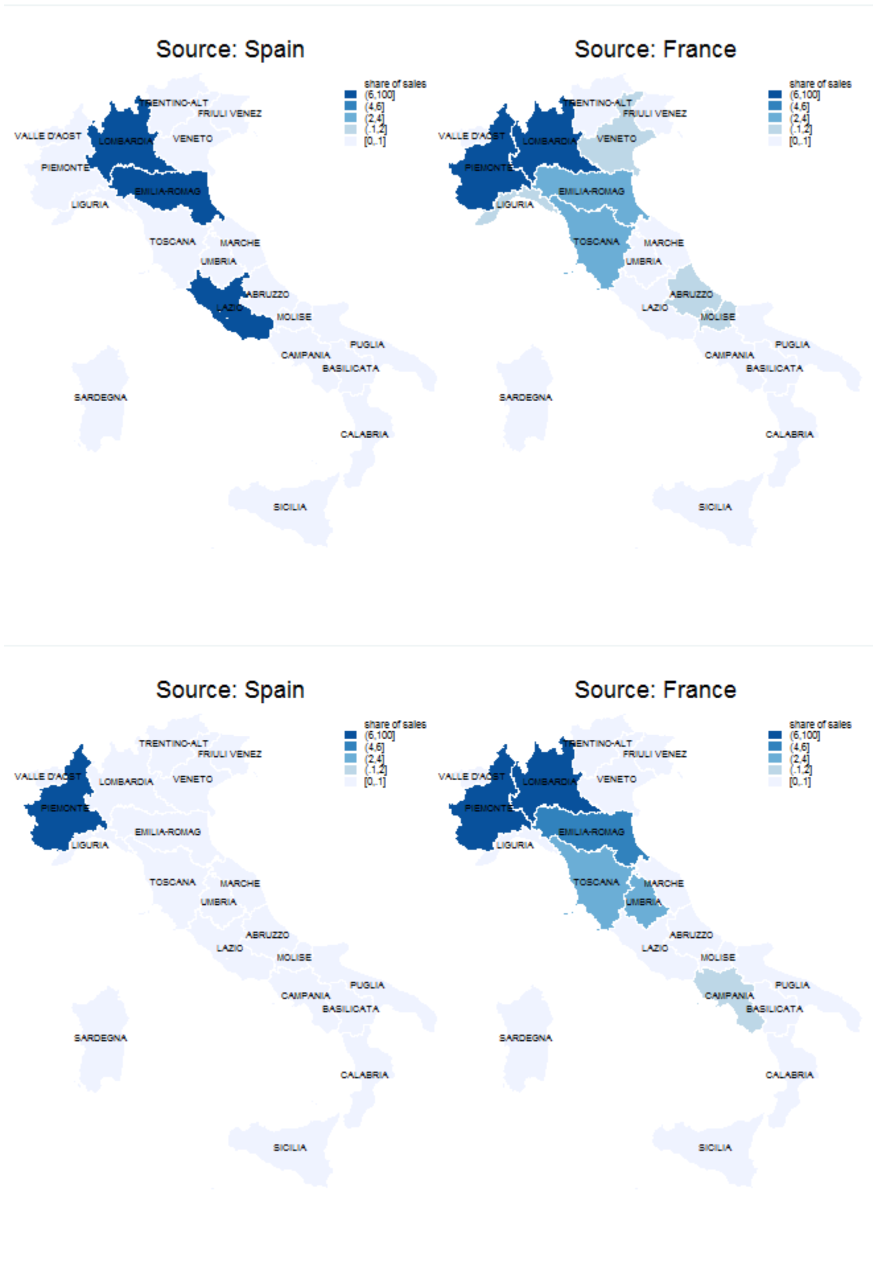
$$\tau_{us,n}^{j} = 1 + \text{freight}_{us,n}^{j} + \text{tariff}_{us,n}^{j} \quad \text{(B.5)}$$

where $\text{freight}_{us,n}^{j}$ is an ad valorem measure of freight costs, and $\text{tariff}_{us,n}^{j}$ is an ad valorem measure of tariff, both at the country-sector level. Freight cost is constructed as the ratio of freight and insurance charges to the custom value of imports. The data are taken from Feenstra, Romalis and Schott (2002) provided at the 10-digit level, which already provide concordance for NAICS classification. The tariff data from the United Nations' Trade Analysis and Information System (TRAINS) consist of two parts: most favored nation (MFN) tariff and the preferential tariff. Then we construct a tariff variable for each country pair-industry triplet that equals the preferential trade tariff if an agreement exists and equals the most favored nation tariff otherwise. For country pair-industry for which information of preferential agreement were not in TRAINS we proceeded to replace by zero tariff all industries for which a given country-pair have regional trade agreements. The industry classifications of both of the tariff information are reported in four different revisions of Harmonized System (HS): HS 1988/1992 or H0, HS 1996 or H1, HS 2002 or H2, HS 2007 or H3. On the other hand, each observation of most favored nation tariff or preferential tariff data is reported only in one revision of HS code. In order to compare the trading pattern with domestic production patterns across industries and country pairs, we further match the different versions of HS classifications with the North American Industry Classification System (NAICS).

Figure D3 shows the distribution of the market share of each affiliate in the selected countries. As can be observed, most firms represent a very small share in each market, and only a small share of firms have remarkably large market share. Figures D4 and D5 evaluate the share of French and Italian multinationals in foreign markets. In particular, the figures at the top left of Figures D4 and D5 report the number of Italian (French) affiliates, divided by Italian (French) market share, selling in a particular destination (on the vertical axis) vs. the size of the destination market (on the horizontal axis). Italian (French) market share is measured as total exports to a destination relative to the destination absorption, while market size is absorption measured in billions of U.S. dollars. All quantities are expressed in logs and plotted on a log scale. The figure at the top right reports average sales in Italian (French) (on the vertical axis) vs. destination market popularity (on the horizontal axis). Market popularity is measured as the rank in terms of the number of Italian-based firms conducting MP to the destination. All quantities are expressed in logs and plotted on a log scale. The figure at the bottom panel reports the number of firms engaging in MP in the kth most popular destination (on the horizontal axis) vs. the number of firms engaging in MP in *k* or more countries (on the vertical axis). All quantities are expressed in logs and plotted on a log scale.

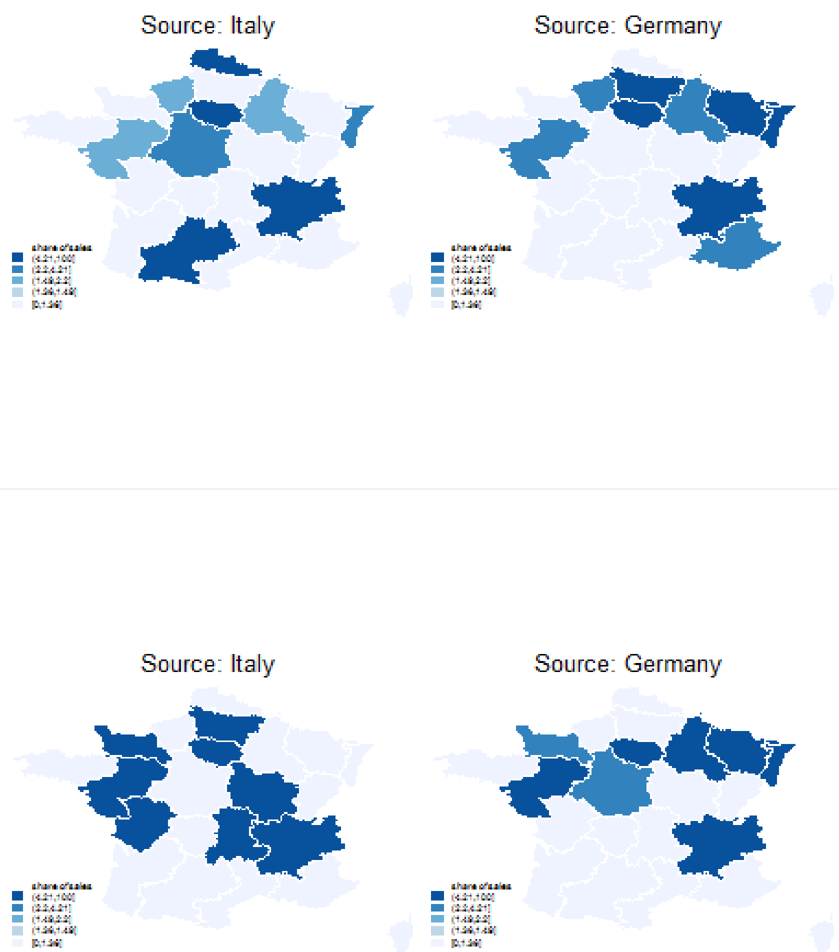
Appendix D: Additional Figures and Tables

Figure D1. Italy. Top Panel: Chemicals. Bottom Panel: Transport Equipment



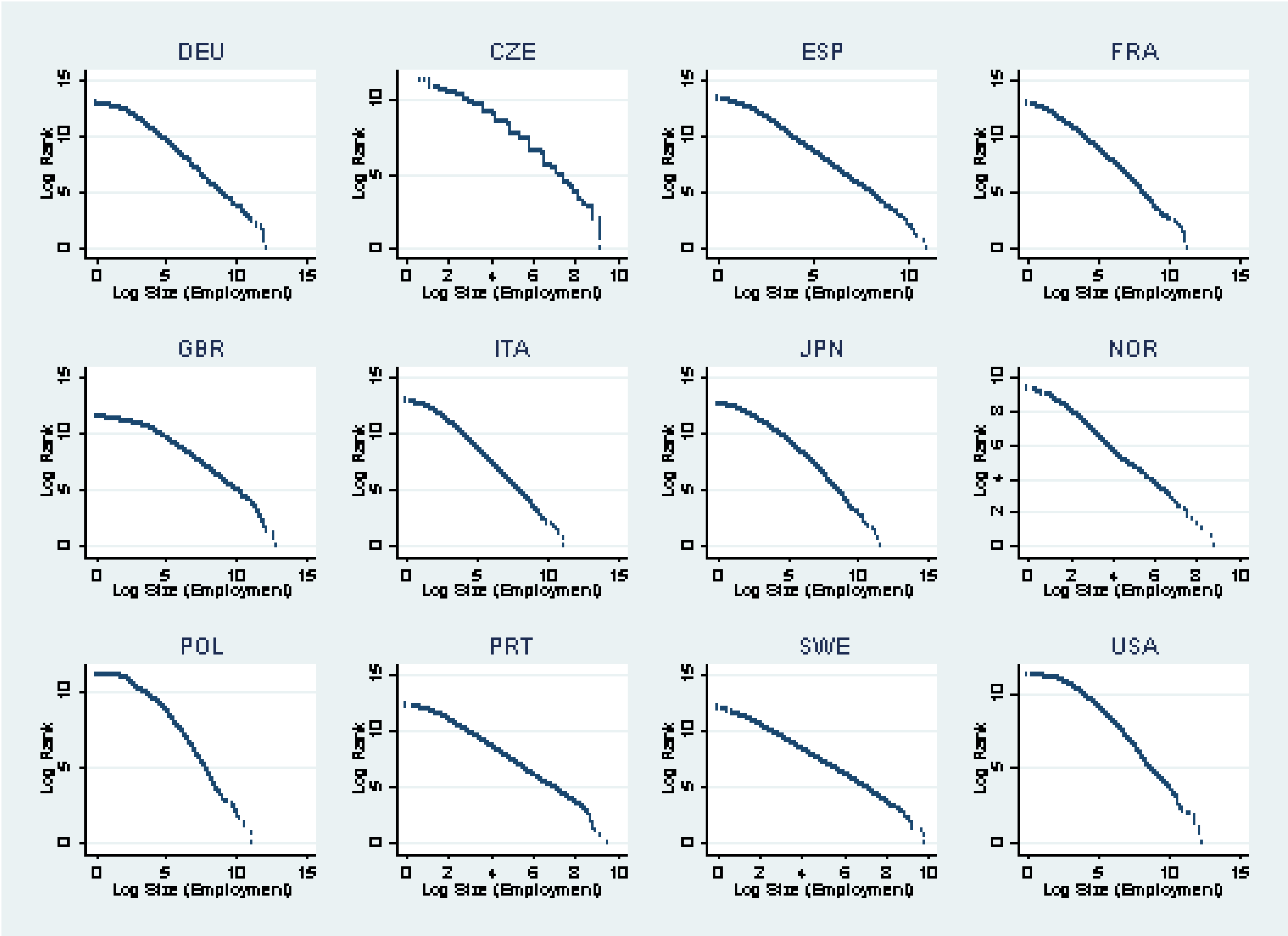
Note: This figure illustrates the spatial sales distribution of Spain and French foreign affiliates located in Italy in the Chemical sector (top panel) and in the Transportation Equipment sector (bottom panel). The darker the area, the higher the share of sales of foreign affiliates concentrated in a given province.

Figure D2. France: Top Panel: Chemicals.
Bottom Panel: Transport Equipment



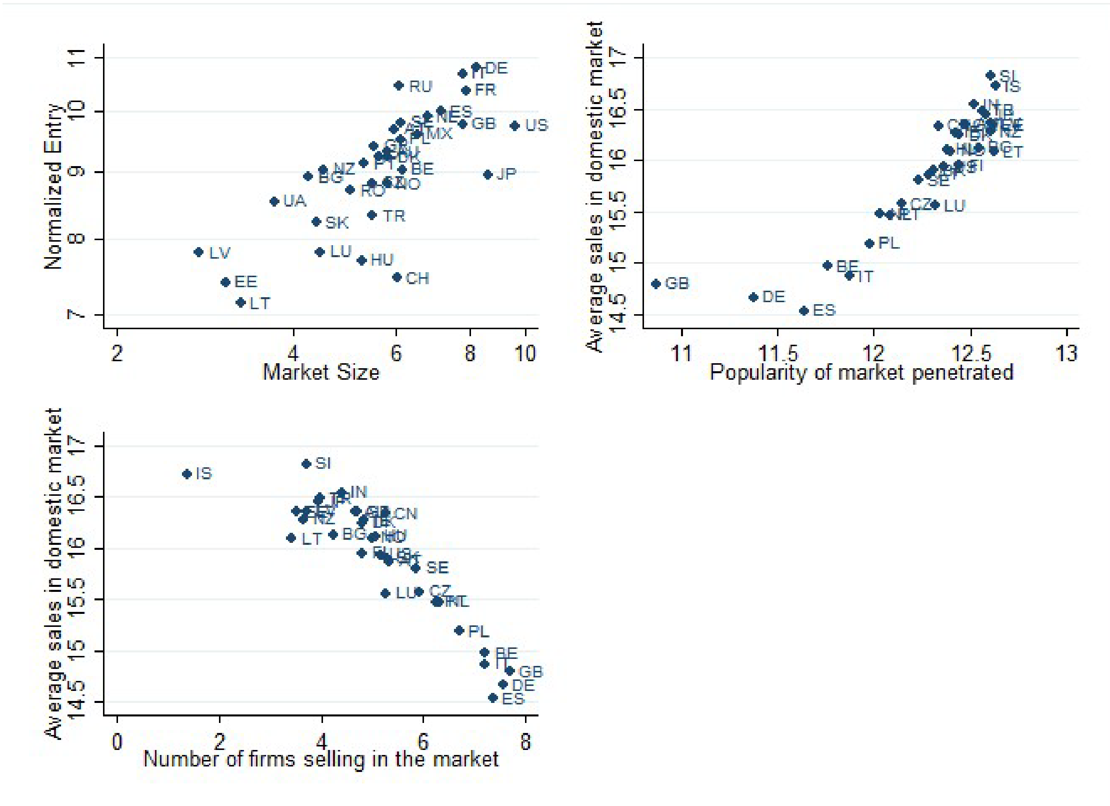
Note: This figure illustrates the spatial saless distribution of Italian and German foreign affiliates located in France in the Chemical (top panel) and in the Transportation Equipment (bottom panel) sector. The darker the area, the higher the share of sales of foreign affiliates concentrated in a given province.

Figure D3. Log Rank vs. Log Size Measured by Employment



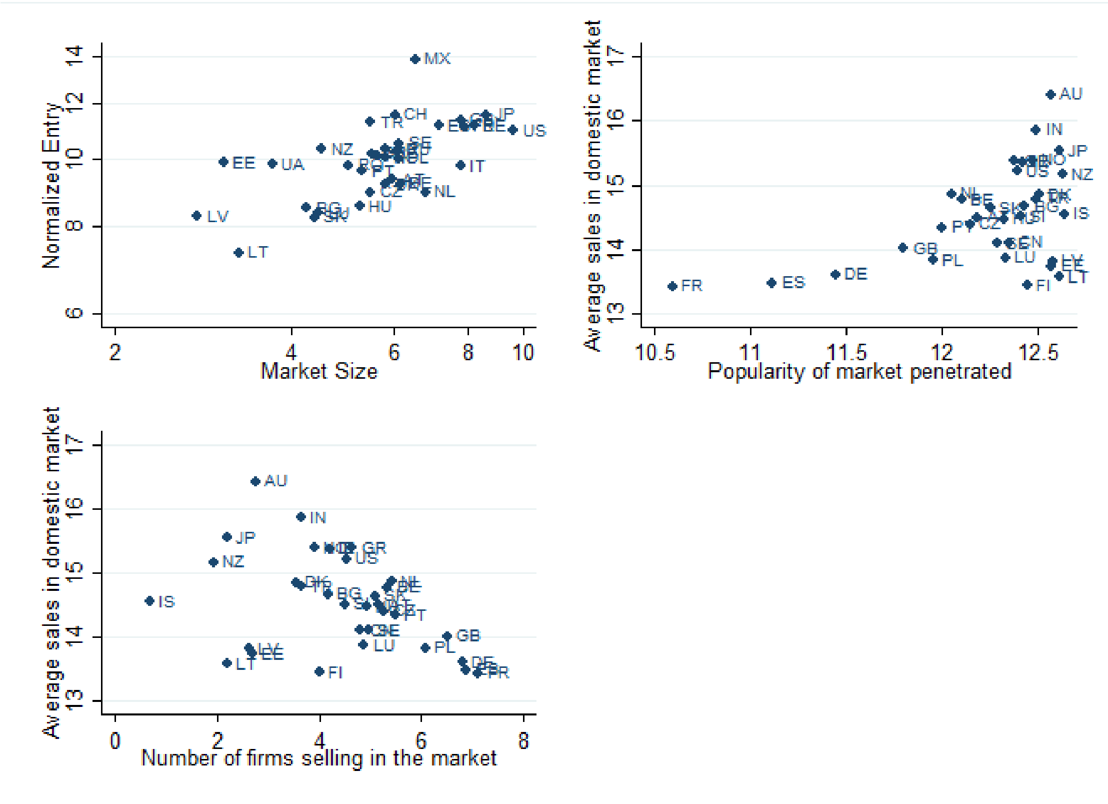
Notes: Each figure represents the plot of log(rank) against log(size) measured in terms of employment for selected countries. All firms with information on number of employees are considered in this analysis.

Figure D4. The Anatomy of MNCs: France



Notes: The figure at the top left reports the number of French affiliates, divided by French market share, selling in a particular destination (on the vertical axis) vs. the size of the destination market (on the horizontal axis). French market share is measured as total exports to a destination relative to the destination absorption while market size is absorption measured in billions of U.S. dollars. All quantities are expressed in logs and plotted on a log scale. The figure at the top right reports average sales in French (on the vertical axis) vs. destination market popularity (on the horizontal axis). Market popularity is measured as the rank in terms of the number of French-based firms conducting MP to the destination. All quantities are expressed in logs and plotted on a log scale. The figure at the bottom panel reports the number of firms engaging in MP in the kth most popular destination (on the horizontal axis) vs. the number of firms engaging in MP in k or more countries (on the vertical axis). All quantities are expressed in logs and plotted on a log scale.

Figure D5. The Anatomy of MNCs: Italy



Notes: The figure at the top left reports the number of Italian affiliates, divided by Italian market share, selling in a particular destination (on the vertical axis) vs. the size of the destination market (on the horizontal axis). Italian market share is measured as total exports to a destination relative to the destination absorption while market size is absorption measured in billions of U.S. dollars. All quantities are expressed in logs and plotted on a log scale. The figure at the top right reports average sales in Italian (on the vertical axis) vs. destination market popularity (on the horizontal axis). Market popularity is measured as the rank in terms of the number of Italian-based firms conducting MP to the destination. All quantities are expressed in logs and plotted on a log scale. The figure at the bottom panel reports the number of firms engaging in MP in the kth most popular destination (on the horizontal axis) vs. the number of firms engaging in MP in k or more countries (on the vertical axis). All quantities are expressed in logs and plotted on a log scale.

Table D1. Sectoral Distribution within a Corporate Group

Country	No. of MNCs	Manuf. Only (share)	No. of MNCs	Manuf. Only (share)
	(< 5 countries)		(>= 5 countries)	
Austria	1,071	0.20	182	0.05
Belgium	1,132	0.17	168	0.07
Germany	3,394	0.25	701	0.06
Denmark	879	0.15	169	0.02
Spain	1,727	0.15	145	0.03
Finland	650	0.22	115	0.05
France	1,498	0.20	381	0.05
U.K.	1,616	0.16	365	0.09
Greece	127	0.16	17	0.00
Italy	2,454	0.30	320	0.03
Japan	798	0.34	376	0.06
Norway	709	0.16	87	0.11
Poland	248	0.15	33	0.00
Portugal	452	0.12	22	0.00

Notes: This table shows the distribution of manufacturing versus non-manufacturing within the corporate group. The first and third columns show the number of MNCs in each source country operating in less than five and five or more countries, respectively. The second and fourth columns show the share of MNCs whose affiliates operate in manufacturing only.

Table D2. Sectoral Distribution within a Corporate Group

Country	No. of MNCs	Manuf. and Wholesale/Services	No. of MNCs	Manuf. and Wholesale/Services
	(< 5 countries)		(>= 5 countries)	
Austria	1,071	0.22	182	0.66
Belgium	1,132	0.25	168	0.63
Germany	3,394	0.28	701	0.73
Denmark	879	0.19	169	0.63
Spain	1,727	0.27	145	0.69
Finland	650	0.21	115	0.67
France	1,498	0.28	381	0.70
U.K.	1,616	0.17	365	0.51
Greece	127	0.25	17	0.84
Italy	2,454	0.35	320	0.80
Japan	798	0.43	376	0.87
Norway	709	0.19	87	0.54
Poland	248	0.33	33	0.76
Portugal	452	0.31	22	0.77

Notes: This table shows for each source country the share of corporate groups that do not exclusively operate in manufacturing, but with some affiliates in the wholesale trade and management services sector. The first and third columns show the number of MNCs in each source country operating in less than five and five or more countries, respectively. The second and fourth columns show the share of manufacturing MNCs with some affiliates operating in the wholesale and management services sectors.

Table D3. Relevance of Corporate Groups

Share of Revenue

Country	local single	local multiple	foreign affiliates		MNCs	
			(< 5)	(>= 5)	(< 5)	(>= 5)
Austria	0.18	0.10	0.03	0.40	0.10	0.19
Belgium	0.08	0.13	0.02	0.57	0.10	0.10
Germany	0.20	0.17	0.02	0.22	0.09	0.30
Denmark	0.08	0.10	0.04	0.25	0.16	0.38
Spain	0.21	0.19	0.02	0.27	0.11	0.20
Finland	0.10	0.17	0.02	0.21	0.09	0.41
France	0.13	0.19	0.02	0.20	0.06	0.40
U.K.	0.12	0.17	0.03	0.34	0.09	0.23
Greece	0.25	0.36	0.02	0.18	0.10	0.10
Italy	0.22	0.27	0.01	0.21	0.11	0.18
Japan	0.08	0.26	-	0.03	0.12	0.51
Norway	0.14	0.22	0.03	0.23	0.11	0.26
Poland	0.21	0.21	0.05	0.35	0.13	0.06
Portugal	0.26	0.20	0.03	0.23	0.19	0.09

Notes: This table presents relevance for each firm type in the manufacturing sector. The first column represents local single firms, and the second column represents local corporations that groups more than one firm. The third column represents the corporate groups whose parent is located overseas; and the fourth column represents the corporations that are part of a multinational where the parent is located in the same country (home-based MNCs). Each entry represents the share of revenue that is accounted for by each type of firm. Foreign affiliates and local MNCs are divided into two groups: those operating in less than five countries and those operating in five or more countries.

Table D4. Gravity Equation of Multinational Production (firm-level pooled regression)

Dep. Variable	Foreign Affiliate Sales					
	(1)	(2)	(3)	(4)	(5)	(6)
ln dist	– 0.030	–0.066***	–0.081***	– 0.026	–0.068***	–0.061***
	(0.020)	(0.021)	(0.022)	(0.020)	(0.021)	(0.022)
ln dist aff		0.105***	0.113***		0.122***	0.119***
		(0.018)	(0.019)		(0.018)	(0.019)
ln tariff			0.263***			–0.708***
			(0.022)			(0.244)
ln parent sales	0.393***	0.383***	0.381***	0.366***	0.355***	0.359***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
$RD_{int} \times dist$	–0.013***	–0.014***	–0.007***	–0.008***	–0.009***	–0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Origin FE	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	No	No	No
Sector FE	Yes	Yes	Yes	No	No	No
Sector-Location	No	No	No	Yes	Yes	Yes
R-squared	0.343	0.344	0.350	0.394	0.395	0.396
N.Obs. (firms)	21,553	21,553	20,498	21,553	21,553	20,498

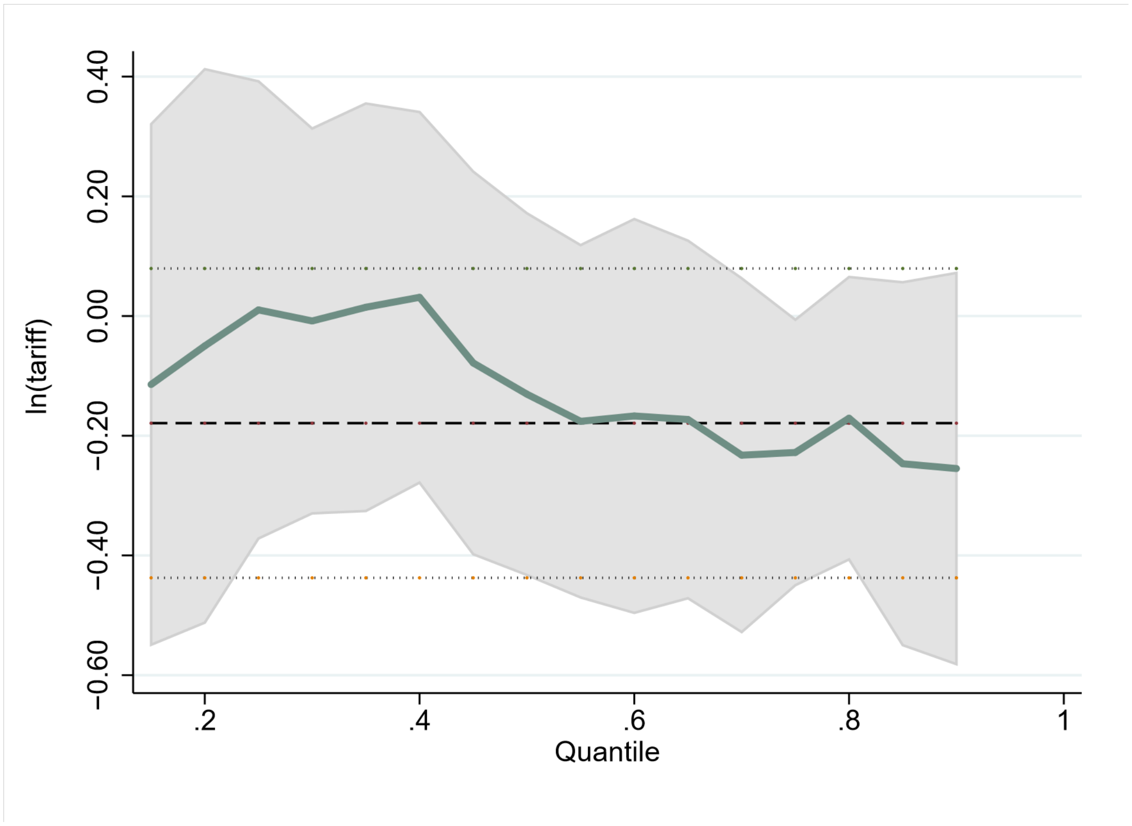
Notes: Dependent variable: natural log of foreign affiliates sales. Independent variables include the natural log of parent's sales, the natural log of the distance between the parent and the host market (ln *dist*); the natural log of distance between the foreign affiliates and other affiliates belonging to the same corporation located in third countries (ln dist aff); the natural log of tariff, a dummy of common border (*border*), common language (*language*) and whether or not the host market and the source country had a colonial relationship (*colony*). Robust standard errors in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Table D5. Gravity of U.S. Foreign Affiliates (Quantile Regression)

Dep. Variable	U.S. Foreign Affiliates Sales					
	OLS	Q(0.10)	Q(0.25)	Q(0.50)	Q(0.75)	Q(0.90)
ln dist	–0.515**	0.502*	– 0.268	–0.680***	– 0.584*	–1.068***
	(.208)	(0.263)	(0.351)	(0.218)	(0.341)	(0.136)
ln dist aff	0.096**	0.129	0.121**	0.067	0.027	0.078
	(0.040)	(0.0.97)	(0.051)	(0.045)	(0.038)	(0.051)
ln tariff	–0.179	–0.068	–0.010	–0.130	–0.228**	–0.255**
	(0.132)	(0.532)	(0.230)	(0.182)	(0.114)	(0.126)
ln parent sales	0.232***	0.167***	0.200***	0.218***	0.265***	0.346***
	(0.013)	(0.032)	(0.019)	(0.014)	(0.016)	(0.022)
$RD_{int} \times dist$	–0.007***	–0.011**	–0.008***	–0.004*	–0.004*	–0.004
	(0.002)	(0.005)	(0.003)	(0.003)	(0.002)	(0.004)
r_{ap}	–0.064	–0.932***	–0.427**	–0.005	0.372***	0.633***
	(0.698)	(0.262)	(0.051)	(0.147)	(0.092)	(0.094)
Other controls		Yes	Yes	Yes	Yes	Yes
Location FE		Yes	Yes	Yes	Yes	Yes
Sector FE		Yes	Yes	Yes	Yes	Yes
R-squared	0.292	0.256	0.280	0.284	0.279	0.258
N.Observations	3,351	3,351	3,351	3,351	3,351	3,351

Notes: Dependent variable: natural log of U.S. foreign affiliates sales. The first column shows the results from ordinary least square regression. The other columns present the results of a quantile regression at different quantiles: 10, 25, 50 and 90 percentile of the firm size distribution. Independent variables include the natural log of parent's sales, the natural log of the distance between the parent and the host market (ln *dist*); the natural log of distance between the foreign affiliates and other affiliates belonging to the same corporation located in third countries (ln dist aff); the natural log of tariff; the interaction between research and development (R&D) intensity and distance. Other controls include a dummy of common border *(border*), common language (*language*) and whether or not the host market and the source country had a colonial relationship (*colony*). Robust standard errors in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Figure D6. Effect of Tariff across U.S. Foreign Affiliate Sales' Quantiles



Notes: This figure illustrates how the effects of tariff between the U.S. foreign affiliate and its parent in the United States in the sector of the affiliate ($tariff_{us,n}$) vary over quantiles, and how the magnitude of the effects at various quantiles differ from the OLS coefficient, even in terms of the confidence intervals around the coefficient. Confidence intervals at the 95% are defined by the gray area.